OPERATIONAL EXPERIENCE AND FIELD TESTS ON ISLANDING EVENTS CAUSED BY LARGE PHOTOVOLTAIC PLANTS

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ABSTRACT

This paper presents the experience on problems of islanding behaviour detected in medium and high voltage networks of Iberdrola, gathered after the breakthrough of large photovoltaic plants in Spain.
Islanding field tests carried out by Iberdrola in PV plants, whose records give the clues to understand the technical reasons for the abovementioned failures, are also described.
The conclusions are focused on the solutions for these problems, including improvements for protection systems, either relays or algorithm included in the inverters, new normative tests to be developed and the use of communication systems.

INTRODUCTION

More that 3,000 MW of PV generation was connected to Spanish networks in 2007 and 2008. Almost 90% of this power corresponds to large plants connected to MV or HV networks, which, along with a significant operation time, constitutes a unique experience.

Several problems have arisen after the commissioning of large PV plants, which can be basically divided as follows:
1) Islanding behaviour during MV network maintenance of faults.
2) Overvoltages in photovoltaic plants, causing damages in photovoltaic plants, as already described in [1] and confirmed latterly with damages in other customers connected to the same MV feeder.

Both failures were reproduced by means of field tests in PV plants connected to the MV network of Iberdrola.

OPERATIONAL EXPERIENCE ON ISLANDING EVENTS

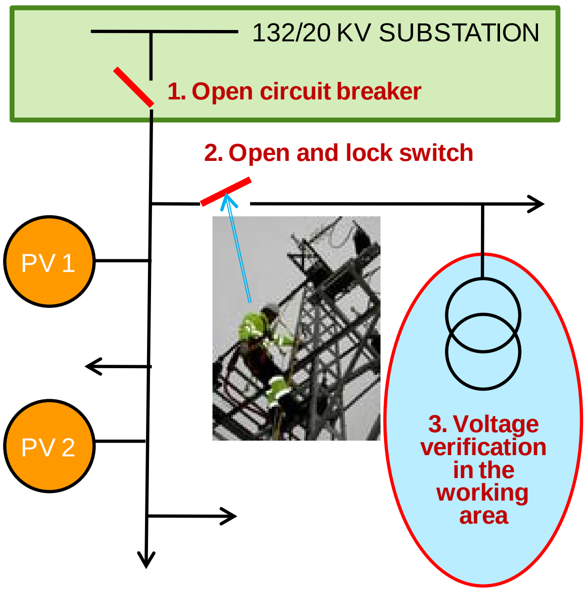
Several cases of islanding behaviour during MV network maintenance or faults have been detected, giving rise to different kinds of negative consequences.
Islanding events during maintenance works, in absence of fault, are the most severe cases and they happen when the anti-islanding systems fail so a quasi-permanent islanding situation takes place.
On the contrary, in case of faults, not only the system ability to detect the islanding, but also the disconnection time is relevant.

Dangerous work conditions

The following event, which took place during the maintenance of a MV/LV substation, describes an example of increased risk due to failure of anti-islanding protections.

According to the first two rules of the safety golden rules, the maintenance staff had to isolate the MV/LV substation from sources of supply and lock the isolation devices. These operations were made by opening, firstly, the MV feeder breaker at the HV/MV substation and, after that, opening the closest disconnector to the MV/LV substation. Since the MV feeder breaker was open, it was expected to open the switch with no load.

Figure 1: Safety procedure for maintenance in MV. First 3 steps



In this case, the workers considered that voltage absence verification in the MV feeder was not necessary. On the one hand, because isolation from voltage sources is a previous step to voltage verification, according to safety legislation in force (see figure 1). On the other hand, because they did not have to work on that place, but on equipment located away from the isolation point.
When the disconnector, which is designed to operate only with no load, was operated electric arc took place, which could damage the disconnector with the subsequent risk for the workers.

Impossibility of network operation or maintenance

The aforesaid event makes clear the need for additional voltage absence verification, going one step beyond on the mandatory safety rules, for any kind of MV switching.

In fact, when maintenance staff included this additional measure in similar cases, they have verified the presence of voltage in different points of the MV network for long times. Cases up to 40 minutes, or repetitive events after opening and closing the MV feeder breaker, have been reported.

The problem in this case is that, as a consequence, maintenance works could not be carried out until the voltage sources (one or several PV plants) were identified. Even after identifying the voltage source, isolating the installations and locking the isolation devices in the open position, as required by safety rules, is a difficult matter. The reason for this additional problem is that network maintenance staff do not have access to the breaker and isolation devices within PV plants. Besides, PV plants can be dispersed kilometres away from the working area.

Failure of network automation

Another problem of sustained islanding behaviour is that voltage in the islanding network looses synchronism with the network.

If breaker control includes synchronism or voltage absence verification for the closing operation, the breaker cannot close until the islanding event disappears, so the normal service cannot be restored and further actions to identify the voltage source and to disconnect it have to be taken.

Damaged inverters

In those cases where the breaker control does not include voltage absence verification, the breaker closes without synchronism. This creates an overcurrent, irrelevant for the network, but that may be harmful for the inverter.

This situation is very likely to happen in case of earth fault followed by a fast reclosing, especially in networks with a limited earth-fault current. The reclosing time ranges from 0.4 to a few seconds, depending on local practices, so if the PV plant protection system is not fast enough, the breaker will close while the PV generators are still connected.

To prevent damages in the inverters IGBTs, an extremely fast overcurrent protection is needed. This protection is implemented by many manufacturers, but some cases of fatal damages, affecting up to 100% of the inverters of a large PV plant, have taken place.

TECHNICAL REASONS

The development of photovoltaic inverters is based in the principle that they are generators of irrelevant power, compared to the network.

Thus, most of the experience previous to the rapid growth of the PV generation in Spain in 2007 and 2008 is related with small installations.

In contrast, in Spain, the same technology was applied to large plants, without any adaptation, reaching in many feeders a generation power similar, higher or even several times higher than load power.

Behaviour of photovoltaic inverters

Inverters integrate control and protection algorithms. They work without coordination between inverters of the same or of different plants. In addition, there is no standardization between brands.

Inverters do not try to keep any particular voltage, but to take out all the energy supplied by the PV panels by generating a voltage slightly higher than the network voltage. Their control loop tries to keep the sinusoidal current that represents the available power with the given voltage, making the necessary corrections in very short times, typically tens or hundreds of microseconds. If the current is lower than the target, the inverter increases the voltage (and the opposite).

On the other hand, national legislations usually include definition of voltage and frequency protection settings. However, anti-islanding protection is not defined either by legislation nor standardize. The method is decided by each manufacturer, and can be a passive method, an active one, or a combination of both.

In any case, the anti-islanding system is tested in lab, in conditions not representative of actual networks, since the test only include a single inverter and simplified load. On the contrary, in real networks, and especially in MV networks, several inverters (of the same or of different types) are working in parallel.

Behaviour of an islanding network

A network working in islanding mode implies a balance between generation and consumption, both in terms of active and reactive power. It is frequently assumed that this kind of balance is hardly reached, given that PV plants do not have power regulation and they do not provide reactive power.

However, field test have proved that, starting from a rough balance at the beginning of the event, the exact balance of active power is reached by means of consumption modification. Consumption depends on the voltage and, in the field tests carried out by Iberdrola, loads behave approximately as constant impedances (a voltage variation implies a quadratic load variation). By changing the voltage, generation and consumption match (even phase by phase) and islanding is possible.

On the contrary, if the generation is clearly lower than consumption, the voltage will decrease and the generation will trip, and if the generation is clearly higher than consumption, voltage increases so the generation trips.

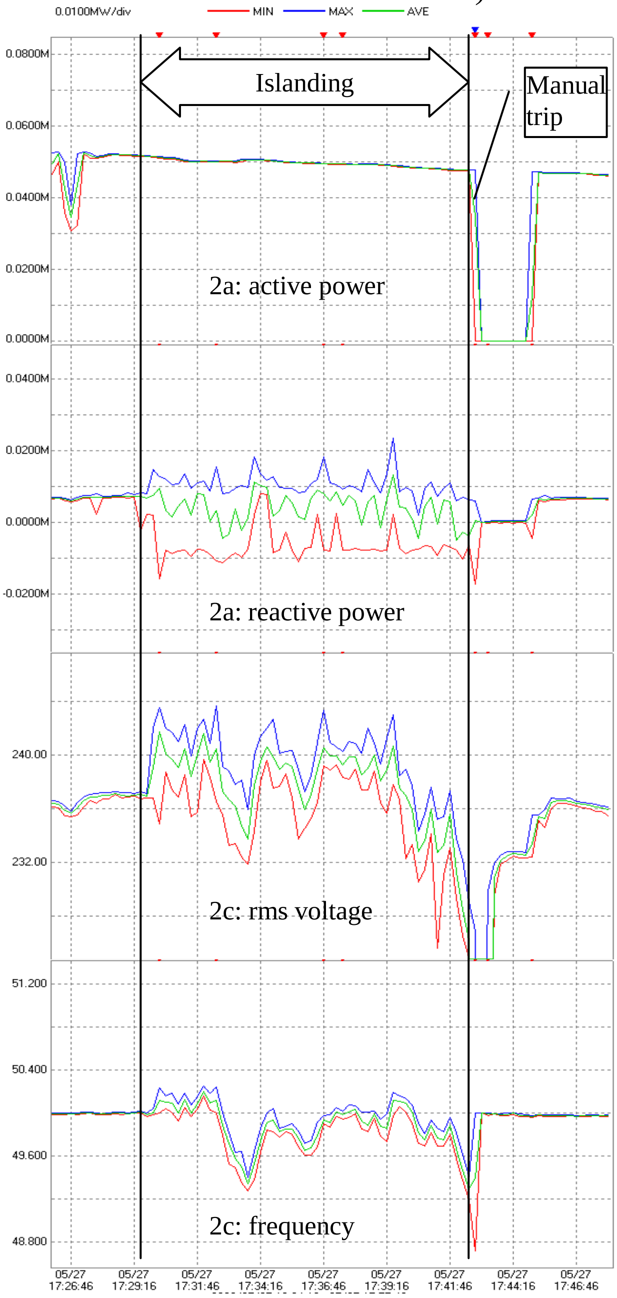
An extreme case of this latter situation takes place when generation is several times higher than load. In this case, voltage increases so much that damages are possible depending on voltage magnitude and duration [1].

Regarding reactive power, in the field tests it could be seen that inverters were not able to keep a stable power factor during islanding behaviour. The addition of all the different reactive power produced by the different inverters and the transient behaviour of loads made the balance possible.

FIELD TESTS

Two field tests in MV systems were carried out in substations where the dangerous conditions where previously reported.

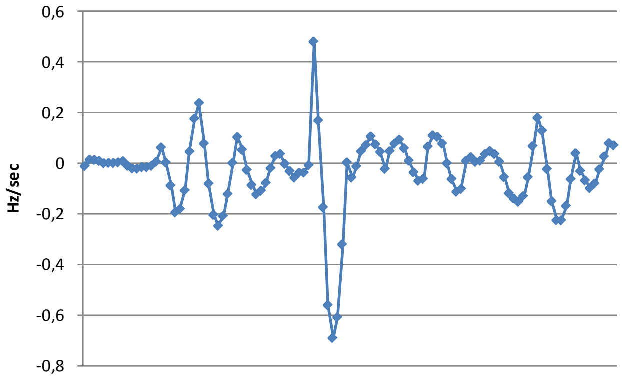
Figure 2: Active power, reactive power, rms voltage and frequency (fluctuation can be seen as difference between max.-blue- and min.-red- values)



The test process started from a situation in which generation was higher than consumption. To balance roughly the power, some inverters were manually disconnected until the current by the substation MV circuit breaker decreased to a few amperes. Then, the feeder circuit breaker was open.
In both cases, the islanding event was reproduced, giving rise to islanding networks of, roughly, 700 kW and 2.5 MW.

Some parameters were more unstable during islanding than connected to network, but rms voltage, distortion and unbalance magnitudes remained within normal limits.
Figure 2a shows the active power of one inverter, which decreased constantly according to the declining irradiance of the evening. At the same time, reactive power of individual inverters suffered a strong fluctuation, as can be seen in the difference between maximum and minimum values of figure 2b. Voltage also fluctuated, but within limits (figure 2c).
Frequency (figure 2d) also fluctuated but not as much as expected, since consumption-generation balance is not done by frequency adjustment, as with traditional synchronous generation, but by means of voltage modification.
Although there were some frequency changes, as can be seen in figure 3, their magnitude was too small or short to be detected with ROCOF settings compatible with system stability constraints.

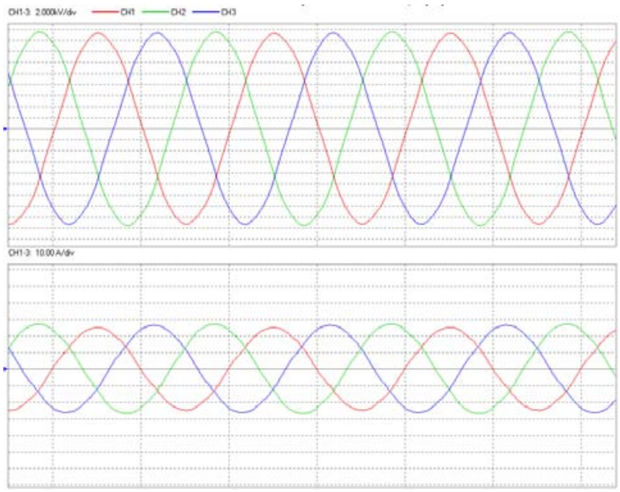
Figure 3: Worst case of rate of change of frequency in consecutive cycles



Network configuration allowed testing different combinations of generators. In one of them, only dozens of inverters with the same impedance measurement method were feeding the islanding system. Those inverters failed to detect the islanding situation, probably affected by the interaction between inverters.
Other active anti-islanding methods, based on frequency shift proved to be able to detect the islanding, but depending on the other generators that they had in parallel. When all or most of the PV inverters were of the same model, they worked satisfactorily. As other inverters, with passive and impedance methods, were connected in parallel, the time needed to detect the islanding condition was progressively longer, until they were not able to detect it at all.

In addition, the almost perfect waveforms shown in figure 4 prove that an islanding identification based on voltage quality cannot be easily found.

Figure 4: Voltage and current at point of coupling to the MV network



CONCLUSIONS

Islanding events have to do with the transient behaviour of the inverters and their interaction with the loads connected to the network. Field tests have proved that:

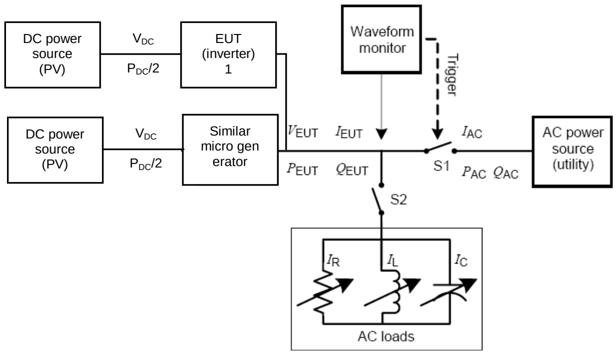
1) Islanding events are possible providing than the difference between generation and consumption is not excessive (~10%)
2) Islanding condition can last long time. The interaction inverter-loads tends to find a stable point, by voltage variations, and not so much by frequency as expected
3) The failure of anti-islanding systems has to do with the interaction between several inverters, either of the same brand or different brands
4) Actual field situation is not represented by laboratory tests. Different inverter brands, from several countries, and different anti-islanding methods have failed.

Voltage characteristics in the island are within normal limits, so it is not possible to detect islanding behaviour with traditional protections settings that allow the normal behaviour of the plant.

In addition, the requirements to improve fault ride through capabilities, necessary to preserve the system stability in case of a voltage dip, as well as frequency insensitivity to events in transmission networks, will do even more difficult to detect the islanding conditions, especially with passive methods.

Active methods require coordination between different brands, so that they are able to work in parallel without inferring each other. A common method would be recommendable. Meanwhile, tests methods using several inverters in parallel, as shown in figure 5, would help to verify inverters capabilities closer to real conditions.

Figure 5: Test with several inverters in parallel



However, the use of some active methods could be a constraint for the penetration of inverter based generation. Thus, frequency shift have proved to be an effective method, but if applied massively, it could lead to loss of stability in case of major events in the transmission network. Therefore, coordination between protections included in the inverters (either active or passive methods), protections of the point of coupling (relays) and communication based protections (inter-tripping or telecontrol) is necessary.

On the other hand, requirements from transmission networks (delayed or insensitive trip to prevent instability) and distribution networks (fast and certain trip, to prevent damages or affecting power quality) are opposite to each other.

A possible solution could be the use of requirements segmentation, as follows:

- Generation plants connected to MV or HV should give priority to transmission needs and have fault ride through capabilities, passive protections (internal or at the point of coupling) and communication based protections.
  These communications systems could be, in general, telecontrol to allow safe operation in case of maintenance, and intertripping, in some network configurations.
- Communication requirements for LV must be necessarily lower, so traditional intertripping or telecontrol should not be applied. Fast active methods should be used when telecontrol is not available, giving priority to safety instead to fault ride through capabilities.
  However, smart meters including an internal switch can be used as a simple and inexpensive telecontrol. Their use can allow reducing the amount of generation without fault ride through capabilities or other characteristics that may affect system stability, allowing this way a higher penetration of disperse generation.

All inverters should be designed to withstand asynchronous reclosing and, in addition, to meet strict limits of temporary overvoltages in case of disconnection from the network.

REFERENCES

[1] F. J. Pazos. 2009, "Power frequency overvoltages generated by solar plants", *CIRED 2009*, Paper 0159.