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POWER FREQUENCY OVERVOLTAGES GENERATED BY SOLAR PLANT INVERTERS

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Extended abstract. A new kind of overvoltage, not covered by present standards, has been detected in solar plants when switching the inverters off. This power frequency overvoltage can be transmitted to the MV network, giving rise to damages to some pieces of low voltage electronic equipment. This phenomenon has been investigated in the field, testing several inverters in different solar plants, where the overvoltages, as well as the damages in revenue meters, have been reproduced and recorded.
It has been proved that some inverter configurations are more prone to create severe overvoltages than other. In addition, some solutions have been tested and a laboratory test to reproduce the phenomenon is proposed.

Key words

Solar plant, photovoltaic, overvoltage, islanding, electronic appliance damage, standards

1. Introduction

In the last years, damages in electronic equipment of photovoltaic plants have been reported. It was discovered that damages take place during a switch upstream of the inverter (whether low or high voltage level), in such way that one or several inverters become isolated from the rest of the grid.
At the field tests, the complete phenomenon –switch opening followed by revenue meter damage– was easily reproduced. Measurements proved that the opening of any of the switches upstream of the inverter gives rise to an important overvoltage, as can be seen in figure 1.
However, some aspects have to be taken into consideration. All the inverters comply with present standards, since none of the existing standards deals with this event. Although all the tested inverters produced some overvoltages, not all of them were high enough to damage meters. Clear differences could be observed between different brands.

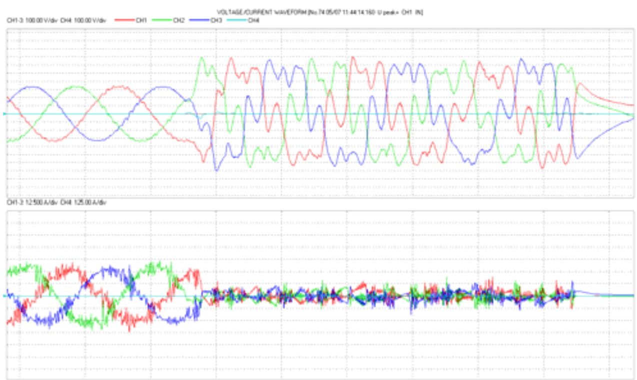

Figure 1: Overvoltage leading to revenue meter damage during LV switching-off (voltages and currents)

2. Analysis

Field tests prove that the inverter trips in around 60 ms but, until then, there is a severe overvoltage up to about twice the nominal voltage. This overvoltage appears when the inverter feeds and over-excites the inverter transformer and the ancillary services transformer. In some cases, the overvoltage is transferred to MV.
Simulations show that the three-phase rectifier behaviour when facing one of the measured overvoltages leads to a huge voltage increase in the dc bus and an excessive inverse voltage applied to the diodes. These values are high enough to provoke many electronic devices to damage.
Besides, these high values give rise to the intervention of surge protection, namely varistors in LV and arresters in MV. Depending on their nominal rate, the exposure of these devices to long overvoltages can lead to their destruction, with the consequent short-circuit in the LV, MV or even HV networks.
In most cases, the most relevant overvoltage is phase-to-phase. However, extremely severe phase-to-neutral overvoltages have been found. Peak values up to 1.17 kV (358% of nominal peak value) have been measured.
In addition, the tested inverters included surge suppressors, connected phase-to-neutral and ranging from

300 to 320 Vrms. Since it is necessary that at least two of them conduct, their residual voltages are added and the phase-to-phase voltage is scarcely reduced. Although the varistors clamp slightly the voltage, the peak values phase-to-phase still exceed 1200 V.

A procedure has been proposed to inverter manufacturers, in order to reproduce the circumstances in which overvoltages have been measured in solar plants, when the solar system becomes isolated

3. Tested solutions

In order to minimize the overvoltages some solutions have been tested.

A. Software protection

The duration of the overvoltage is too long to be treated with surge suppressors, such as varistors, since they could not withstand the energy that they should dissipate.

Therefore, the first measure to be taken is to include a.c. voltage supervision, in order to limit the overvoltage duration. This supervision should stop the inverter switching in the very moment when the beginning of the overvoltage is detected.

Although the behaviour in this case is much better that in the previous ones, it can be seen that there are still overvoltages. In this event, the phase-to-phase voltage, the d.c. voltage or the inverse voltage at a diode would reach a peak of approximately 1100 V.

Faster protection reduces the overvoltage to lower values. But even with detections of 1 millisecond, they have been measured peak voltages phase-to-phase of 162% of the nominal voltage while the most affected phase-to-neutral voltage reaches a 188% of the nominal voltage.

B. Surge suppression

The persisting overvoltages, despite the fast switching stop, could be controlled by means of surge suppressors.

Nevertheless, they have been proved inefficient when connected phase-to-neutral. Given that the inverter behaviour is three-wire and does not requires the neutral, surge suppressors would be more efficient if they were connected phase-to-phase since this would allow lower residual voltages. However, in order to use these suppressors safely, it is necessary to dimension them according to the energy delivered by each inverter. Therefore, the manufacturers should specify them taking into account the total power of the inverter and the tripping time of their overvoltage protection.

In addition, the overvoltage software protection settings should be lower than the surge suppressor residual voltage, in order to guarantee the switching tripping while the suppressors are working.

Besides, the inverter operation should be dependent on the good state of the surge suppression system. To this aim, both suppressors and their circuit breaker should have auxiliary contacts to stop the inverter in case of failure.

C. Inverters with DC/DC Chopper

The inverter behaviour depends on its configuration. The aforementioned measurements correspond to inverters whose dc busbar do not have a fix voltage, since it varies depending on the insolation.

Nevertheless, some inverters include a dc/dc chopper to control and limit its dc voltage. The resulting overvoltage is the lowest of the tested inverters, with a peak value of 134%.

4. Conclusions

Severe overvoltages have been detected in solar plants when switching the inverters off. These overvoltages damaged some pieces of low voltage equipment, in particular revenue meters and electronic devices associated with the inverters. The overvoltages take place during a switch upstream of the inverter, in such way that one or several inverters left isolated from the rest of the grid.

In large solar plants (several MW) fed by Medium Voltage busbars with no other load, it has been verified that overvoltages in the MV side reach dangerous values. Such overvoltages affect not only the LV equipment, but the MV or HV grid.

This problem is not covered by present standards, since usual limits are not oriented towards transients but towards relatively long overvoltages during normal operation. The phenomenon is related to the interaction among the inverters until the anti-islanding protection trips. It must be pointed out that these islanding conditions are not considered either in the standards.

In any event, the problem is not the islanding detection, whose procedures are usually focused on a reliable detection when generation and consumption are balanced. The circumstances in which the overvoltage appears are the opposite, with a generation much higher than the load.

Since standards are not applicable, it has been necessary to investigate this phenomenon in the field, testing several inverters, from different manufacturers, in different solar plants. The overvoltages, as well as the damages in meters, have been reproduced and recorded.

In addition, a simplified test method has been proposed. The affected manufacturers have successfully used this method, or a simplification of it, to reproduce the problem in laboratory.

It has been proved that some inverter configurations are more prone to create severe overvoltages than other.

Thus, the use of dc/dc choppers is a possible solution to limit the overvoltage.

For those inverter configurations that generate overvoltages, other solutions have been tested:

- Overvoltage supervision, focused on the a.c. side, to rapidly stop the inverter switching in case of overvoltage.
- Particularly rated surge suppressors to reduce the voltage to peak values within the admissible limits for all the equipment connected to the grid.

Although these solutions do not provide an optimum overvoltage value, they can reduce significantly the damage risk, being applicable to existing equipment.

Therefore, further work seems essential, especially to develop appropriate standards and tests to be applied to distributed generation.