# DIP BEHAVIOUR OF GRID CONNECTED INVERTORS

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## ABSTRACT

*The environmental awareness has led to a considerably increasing demand for renewable energy. The majority of renewable energy installations consist of invertor fed systems. In the distribution network, many common power quality phenomena voltage dips, under- and overvoltage, transients, unbalance and harmonic distortion) occur and they affect the quality of the voltage wave form. In this contribution, the effect of voltage dips on the ride through capability of grid coupled invertors is analyzed under the assumption of a rigid grid. Besides these phenomena, also background distortion and transients will affect stability pending on grid configuration, however this is excluded in this analysis.*

## INTRODUCTION

The environmental awareness and European regulation has led to a considerably increasing demand for renewable energy [1]. The energy received from distributed energy generation units, such as photovoltaic panels, is in the first place used to local consumption. Therefore, the distribution network is used as a buffer to absorb temporary energy shortages or excesses. In the distribution network, many common power quality events (such as voltage dips, under- and overvoltage, transients, unbalance and harmonic distortion) occur and they affect the quality of the voltage waveform. A bad power quality of the distribution network can have large consequences on electric devices causing damages and in turn causing economic losses [2], [3]. At distribution level, voltage dips may cause disconnection of generation units from the grid. As a result the energy has to be supplied from the bulk system causing serious changes in the voltage profile. Therefore, it is important to know how a device will react and what will happen in case of bad power quality of the network.

Previous studies [5] show that inverters do not have a simple dip behaviour. The nature of the voltage dip depends on the depth, the duration, the number of involved phases and the time when the dip happens [4]. Also the topology of the inverter can have an influence on how it reacts on a voltage dip. In particular Maximum Power Point Trackers (MPPT) have a critical importance since they are usually the slowest part of the invertor.

Since voltage dips occur frequently [2] it is important to know the ride through capabilities of invertors and their behaviour when a dip occurs. Previous studies [5] have determined the voltage tolerance curves of older invertor types.

The main objective of this study is to determine voltage tolerance curves and dip behaviour of the most recent type of single phase inverters with different topologies. Especially the trip behaviour gives noteworthy conclusions.

## MEASUREMENT SETUP

In this study, compliance and characterization testing of inverters according to the standards for voltage dips (IEC 61000-4-11, VDE 0126) are performed. Starting from these limits a study is made to determine the trip behavior for different types of voltage dips.

The measurement setup is given in Fig. 1. Two energy supplies, one for simulating PV cells and another simulating the grid must guarantee a reproducible analysis. The DC energy supply is a programmable PV generator. The grid is supplied by a free programmable power source of 240 kVA which allows to produce voltage dips with defined magnitude, duration, point on waveform, …. Dips are measured using a transient analyzer for registration of the voltage and current waveforms. A power analyzer is used to monitor constant power generation. The grid impedance is fixed in this study (0,779+j0,51).

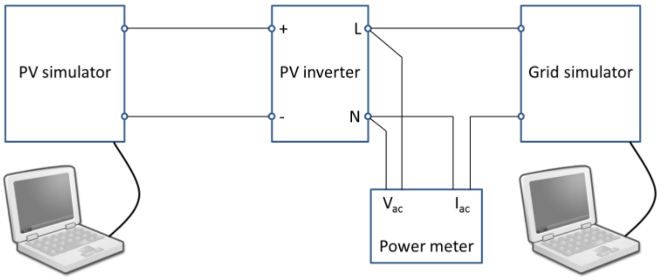

Fig. 1 Measurement setup

Parameters analyzed in order to study the tripping phenomena are: dip depth and duration, point on wave, power generation of the inverter and grid voltage.

## TEST METHOD AND CHOSEN INVERTERS

Based on published material and standards [9] a test method has been developed for the purpose of this research. This method takes into account the specifications of the inverters and items to investigate. These are:

- Effect of the grid voltage
- Effect of the available solar power (output power)
- Effect of the point on wave

For each inverter a first series of test was performed to determine the gross limits of the system. In further tests detailed research was performed to determine the sensitivity of the inverter. For several test also waveforms were recorded.

The chosen inverters are single phase and all have a power of 3 kVA. Some of them are equipped with and without transformers.

## TEST RESULTS AND INVERTER BEHAVIOUR

The study shows that different dip behaviour can be distinguished depending on the topology, injected power of the inverter and the voltage dip parameters such as dip depth, point on wave and duration. In this part the voltage tolerance curve of the different invertors is discussed.

### Transformerless invertor

A voltage tolerance curve is shown in Fig. 2. This curve shows the dip sensitivity at an output voltage of 210V - 100% $P_{nom}$. The measurement results indicate two different trip curves which results in three major zones.

Zone 1: The inverter will not experience degradation of operation

Zone 2: The inverter disconnects from the grid. After the dip, the inverter reconnects automatically to the grid within a period of ten seconds. This trip phenomenon can be perceived by the digital screen and the winking green control light on the inverter. In this zone there is no hard disconnection but a power control by the software so that less or no power is injected.

Zone 3: In this zone, the inverter disconnects from the grid. In this case it is a hard disconnection which means that the relays in the invertor open. This also is perceived digital by the screen and the winking green control light. Automatic reconnecting back to the grid takes several minutes.

An additional zone can be defined , depending on the point of wave (i.e. the starting time) of the dip(zone 4).

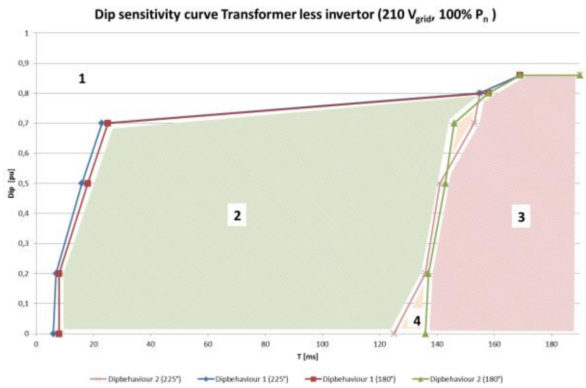

Fig. 2 Example voltage tolerance curve @ 100% $P_{nom}$ (3kVA @ 210$V_{rms}$ )

With a reduced output power (33% and 66% $P_{nom}$) only one curve is determined as shown in Fig. 3. Two areas can be distinguished: operation and disconnection from the grid.

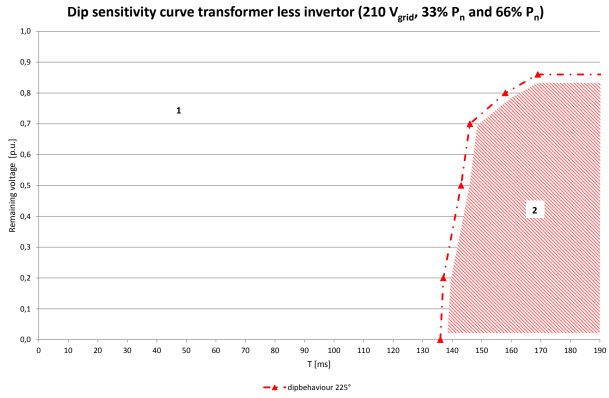

Fig. 3 Example voltage tolerance curve @ 33% and 66% $P_{nom}$ (3kVA @ 210$V_{rms}$ )

The influence of the grid voltage level shows that for a lower output voltage the inverter disconnects earlier than for higher grid voltages due to under voltage protection of the inverter (Fig. 4).

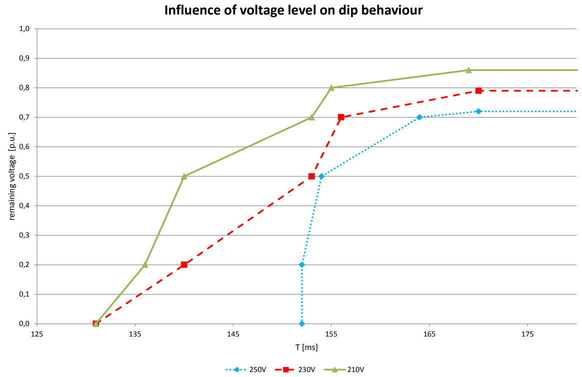

Fig. 4 Example voltage tolerance curve @ 100% $P_{nom}$ (3kVA @ 210, 230 and 250 $V_{rms}$, angle 225°)

## Inverter with transformer

The results of an inverter with transformer give a total different view. In this case only two zones exist independent of the output power. For an inverter with transformer the voltage tolerance curve is independent of the output power level (Fig. 5). The voltage levels show that a higher voltage causes a better ride through (Fig. 6).

The transformer in this circuit acts as an energy storage. The effect of an inductor in a circuit is to oppose changes in current through it by developing a voltage across it proportional to the rate of change of the current.

$$v(t) = -L\frac{di}{dt} \qquad (1)$$

This causes the invertor to give a better dip behaviour.

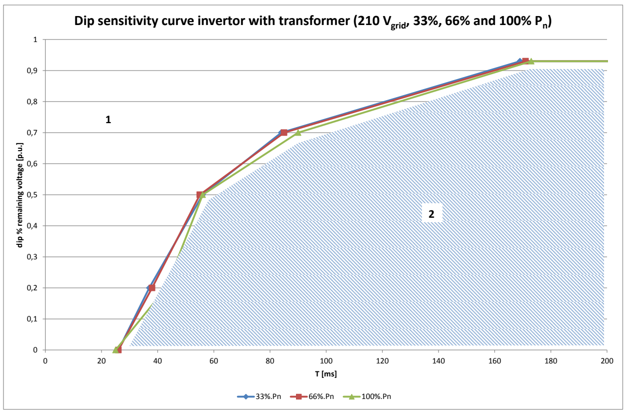

Fig. 5 Example voltage tolerance curve @ 33%, 66% and 100% $P_{nom}$ (3kVA @ 210$V_{rms}$)

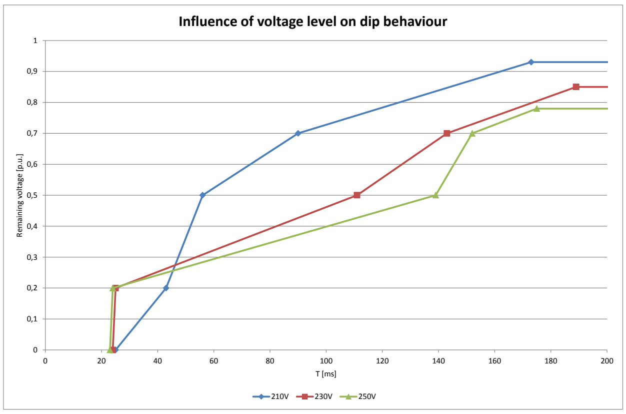

Fig. 6 Example voltage tolerance curve 100% $P_{nom}$ (3kVA @ 210, 230 and 250 $V_{rms}$, angle 225°)

## General sensitivity characteristic

Fig. 7 shows the voltage tolerance curves at 100% $P_{nom}$ with a dip angle of 0° obtained for different invertors and the disconnection limit as stated in the VDE 0126. The VDE 0126-1-1 describes the automatic disconnection device between a grid parallel power-generating system and the public low voltage grid [10] and contains limits for over and under voltage, frequency, DC-current protection, ….

The disconnection limit as stated in VDE 0126-1-1 is indicated on Fig. 7 (full black line). The minimum residual voltage in pu imposed by the VDE 0126 standard for disconnecting of the inverter from the network after a time of 200 ms at normal conditions (230V) is 0.8 pu. This means that every event longer than 200 ms and deeper than 0,8 pu causes disconnection of the inverter. Invertor 2 and 3 on Fig. 7 are the same invertor but with two different behaviours as mentioned in Fig. 2.

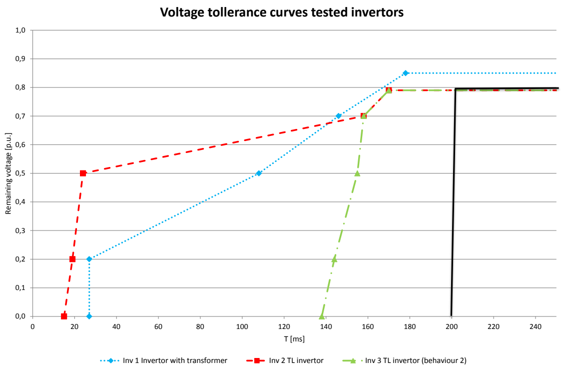

Fig. 7 Voltage tolerance curve for different invertors @ 100% Pn and dip angle of 0°.

Based on Fig. 7 the tested inverters meet the requirements and disconnect earlier than stated in this standard.

## Current waveform behavior

Depending on the type of inverter, the dip depth and duration the current behaviour is different. The transformerless inverter will stop injecting power after one or two periods which insures a fast disconnection (red line in Fig. 8) but will restart injecting what may take up to 1 s. For longer dips the invertor remains disconnected for several minutes.

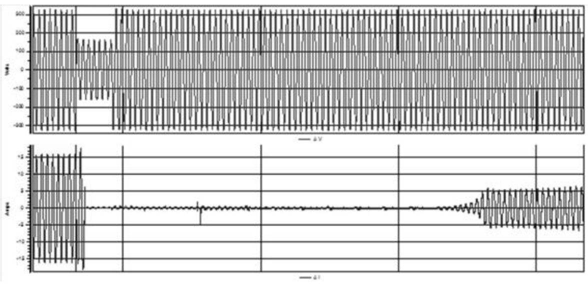

Fig. 8 Voltage and current waveform transformerless inverter.

For the inverter with transformer (Fig. 9) the behavior is different. Due to the presence of a transformer, large variations in current can occur. When the voltage reaches normal operation levels a current transition phenomena occurs after witch current reaches normal operation levels. The time between shutdown and recovery is quite long (480ms) due to the slowness of the MPP tracker but is still faster than the transformerless inverter.

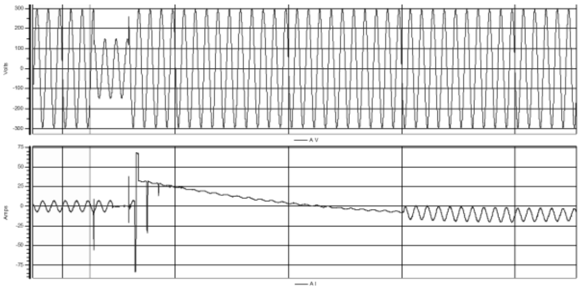

Fig. 9 Voltage and current waveform inverter with transformer.

In other cases the inverter restarts working with a current transition phenomena but shuts down after a number of periods.

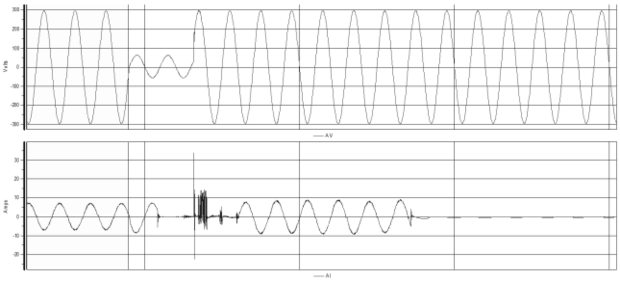

Fig. 10 Voltage and current waveform of a inverter with transformer.

**Disconnection Mechanism**

The safety/protection mechanism used in the tested inverters, will determine the tripping curve. The safety mechanism uses two switching relays, each of which are independently controlled by a control system. One control system monitors the current flow. If the current doesn't fit the threshold in the control mechanism injected power will be reduced or stopped without complete disconnection (Fig. 2, zone 2). In the other case, the decoupling relay is activated. The disconnection from Fig. 2, zone 3 and Fig. 3, zone 2 are caused by the island detection system of the inverter.

It can be concluded that some types of recent inverters have multiple operating safety mechanisms which allow a ride through during short dips.

## CONCLUSIONS

By analyzing different PQ parameters one can determine the dip behavior and voltage tolerance curves of the different topologies of modern PV inverters. They are very sensitive to voltage dips and have different tripping mechanisms as a function of both PQ parameters (only dips are considered) and inverter topology. During short dips the invertor trips but resynchronizes after a short period while during longer dips the invertor will take much more time to reconnect to the grid.

## Further research

Tests on different inverters will continue with the major difference that a variable grid impedance will be available.

## Acknowledgments

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