IMPROVED REQUIREMENTS FOR THE CONNECTION TO THE LOW VOLTAGE GRID

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ABSTRACT

In Germany, about 80% of installed photovoltaic power is connected to the low voltage grid. During the summer of 2011, more than 10 GW actual feed-in is expected on a regular basis, indicating that low voltage power producers have gained significant system relevance. As a consequence they need to contribute to grid stabilisation, whereas former guidelines often demanded an immediate disconnection in case of disturbances. Meanwhile, this has become counter-productive and will be taken care of in new requirements for grid connection.
In this paper the risk of a major disturbance in case of an over frequency event is explained. The solutions which have been found for the high voltage and medium voltage levels are discussed. Differences to the low voltage grid are shown in order to explain the proposed modifications. Results of a simulation with a European Grid model are presented. Finally, measures for the incident and risk management as well as anticipatory precautions are proposed.

1 INTRODUCTION

The German Renewable Energy Act induced a rapid deployment of wind, biomass, and photovoltaic (PV) installations. The latter grew significantly in the last few years, as seen in **figure 1**. In 2010, an estimated 8 GW were added to the existing PV installations.

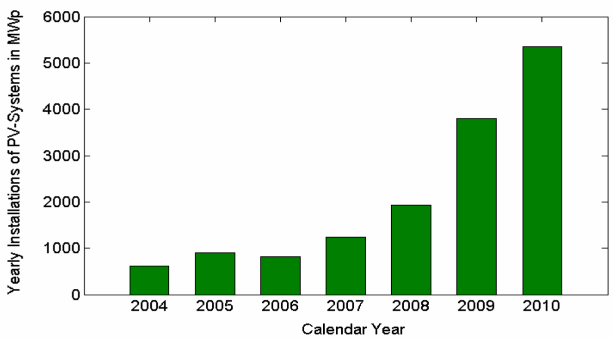

Fig. 1: New PV Installations in Germany, 2010 figures until October [1]

The majority of PV systems are connected to the low voltage grid. Together with other small generators e.g. microCHP, small hydro, and mini wind turbines these LV devices are gaining responsibility for ensuring grid stability. Especially PV may cause high power peaks at noon in the range of 10 GW (**figure 2**). A simultaneous loss of generation is a major threat to the safe operational range of the continental synchronous zone. This could occur as a result of the past technical guidelines for LV devices, which demanded a rather fast disconnection in case of grid disturbances.

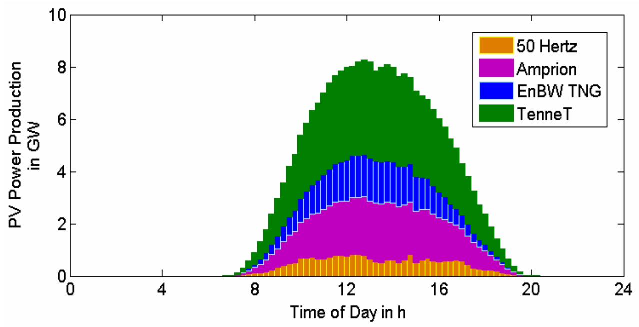

Fig. 2: German PV feed-in on 2010-09-06 [2]

This paper is outlined as follows: First, the theoretical background is described. The reason for inapt frequency dependent behaviour is not the PV system itself, but the chosen settings in several standards. Then, a simulation will clarify the effects on the grid frequency. Finally, possible measures to improve the situation are discussed.

2 RISK OF MAJOR SYSTEM DISTURBANCE

As frequency is a system-wide, global variable, the frequency response of LV generators is important for Transmission System Operators (TSO). In the past, LV generating units had been regarded as "noise generators" and were beyond the focus of TSOs. On the other hand, distribution system operators (DSO) are not responsible for frequency stability and they concentrated on a secure operation, i.e. staff safety with the objective to avoid an unintended islanding.

2.1 Norms & Standards

Some relevant standards for connection to the low voltage grid are the following:

DIN V VDE V 0126-1-1:2006-02
VDE 0126-1-1 demands a disconnection within 0.2 s if a frequency of ≥ 50.2 Hz is detected. A reconnection is allowed after 30s in the valid frequency range 47.5-50.2 Hz. Several other European countries use this standard as well.

DIN EN 50438:2008-08 & DIN CLC/TS 50549:2010-08
EN 50438 is a valid European Standard with an over frequency threshold of 51 Hz. Several national exemption

rules are given in its annex such as VDE 0126 for Germany. TS 50549 is a technical standard, serving as a pre-norm, and covering generators larger than 16 A per phase.

IEEE 1547-2003
IEEE 1547 is used mainly in the United States for Distributed Energy Resources (DER). There is a fixed over frequency related disconnection threshold of 60.5 Hz and even worse an underfrequency trigger level of 59.3 Hz.

ENTSO-E Requirements for Grid Connection (Draft)
ENTSO-E published a working draft [3], which covers the size categories from A to D. A is the smallest class and relevant for LV generators from 400 W to 100 kW. A couple of requirements such as the active power frequency response (over frequency) are mandatory for class A, see **figure 4**.

2.2 System Behaviour of the Grid

The frequency response of the grid shows PID-characteristics. In the scope of this paper only the differential ($\Delta P \sim df/dt$) and proportional ($\Delta P \sim \Delta f$) part are relevant.

D-behaviour results from the rotating masses which provide inertia to the electrical system. P-behaviour comes from primary control as well as the self-regulation effect [4]. As a first approximation, the frequency response after a load step is of PT1-type. The overshooting comes from the fact that primary control needs up to 30s to ramp up in contrast to the self-regulation effect, which is instantaneously available.

2.3 Risk of non-linear Oscillations

In the case of a severe disturbance with several GW of sudden surplus power (loss of load as happened in 2003 or 2006) the frequency may rise considerably. This could lead to a simultaneous disconnection of low voltage generators. The frequency measurement precision is usually in the range of only a couple mHz, so that the threshold of +200 mHz will be detected everywhere more or less at the same time. Considering the time lag of 0,2 s and a rather high ROCOF, it can be assumed within the following model from the simulation section that all low voltage DERs will shut off.

30 s after returning into the allowed frequency range, LV-DER may reconnect and begin to feed-in again. A yo-yo effect could emerge as a general pattern.

The frequency development during a winter day is shown in **figure 3.** During ramp up and down periods, 1-h-block energy trading causes frequency variations of up to 100 mHz on a regular basis and sometimes more [5]. The security margin is largely spent during these few minutes at the full hour. A tripping of a large exporting HVDC line such as the Cross-Channel link at that time could be enough to hit the trigger level of +200 mHz.

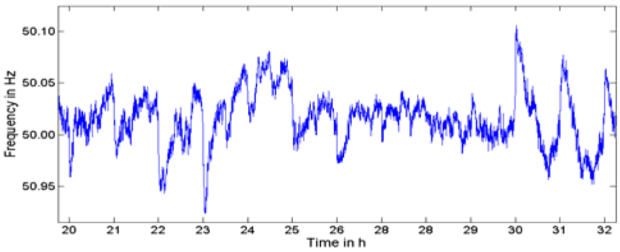

Fig. 3: Frequency Development during a 12 hour measurement period on 2010-12-22

2.4 Preferable Features of Low Voltage Connection Requirements regarding Frequency Response

According to VDN's TransmissionCode 2007 and BDEW's Technical Guideline "Generating Plants Connected to the Medium-Voltage Network" from 2008, an active power reduction is demanded with a gradient of 40% per Hz (droop of 5%). A higher gradient is proposed for the LV grid, as it shifts the influence of control power towards the high voltage grid during a major disturbance [6]. Furthermore, distribution system operators are faced with the situation to operate grid segments with gen-sets during maintenance or emergency supply. In order to avoid feeding back into the gen-set, all DERs are switched off by operating the distribution grid at increased frequency.

Therefore, a droop of s=1.6 % (K_f=125%/Hz) is proposed in this paper. At 51 Hz power production reaches a level of 0% P_{nom}. This may help to avoid hitting another disconnection threshold according to EN 50438, e.g. photovoltaics in Spain. It also leaves a frequency band for operating an islanded distribution grid segment above 51 Hz to ensure that all DERs are powered down.

In order to avoid any reconnection issues, no hysteresis is used when the frequency decreases back to normal after the disturbance. Power is ramped up according to the droop curve. Thus, the frequency is still a clear signal for the load situation of the synchronous zone. As an alterative for switchable units, which are not capable to modulate such as some micro CHP generators, randomised switching thresholds should be used.

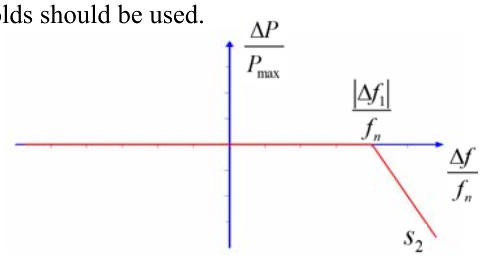

Fig. 4: Active Power Frequency Response (over frequency), R5.9 [3]

Currently, Forum Network Technology / Network Operation (FNN) is moderating the process of enhancing the German requirements for the connections to the low voltage grid. A first draft of this technical rule has been presented and a final version is expected in the first half of 2011.

3 SIMULATION OF FREQUENCY RESPONSE

In this section, the frequency development during a major over frequency event is presented. Two scenarios are shown, one with a sudden surplus power of 5 and another one with 10 GW. Italy's import volume was 7 GW on 2003-09-28.

Three simulations are run simultaneously:

1. PV shows no reaction to frequency excursions.
2. PV disconnects for 30 s if 50.2 Hz is exceeded.
3. Photovoltaic reduces production above 50.2 Hz reaching zero at 51.0 Hz (K_f =125% per Hertz).

3.1 Model Description

To evaluate the effect of PV-systems on the grid frequency stability a Simulink model of the continental part of the grid controlled by the European Network of Transmission System Operators for Electricity (ENTSO-E), called UCTE-grid (**figure 5**) has been devised. The model simplifies the grid as it neglects its spatial extent. For the purposes of this paper it is assumed that the frequency is the same at any point of the grid.

This UCTE frequency model is simplified, yet accurate enough to calculate the effect of power imbalances on the grid frequency. The model takes into account:

- system inertia
- self-regulation effect
- primary control
- load shedding
- pumped storage power plants
- photovoltaic feed-in

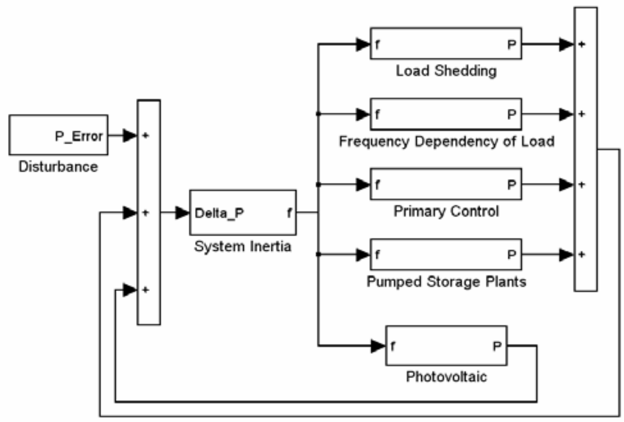

Fig. 5: The UCTE-Frequency Model

Secondary control is neglected, since it has little influence on the system within the first few seconds after a fault occurs. Reactive power is also neglected, since it does not directly influence the grid frequency. The model approximates the actual system behavior, as it is today in Europe. The system modeling is mostly based on [7] and [8]. A more detailed model description can be found in [9].

The model was used to simulate several kinds of system disturbances with different amounts of connected photovoltaic systems. The simulations presented within this paper will however focus on scenarios, where a significant share of the load is lost, leading to a rise of the grid frequency.

3.2 Simulation Results

The frequency development after a sudden loss of load at t=10s in the range of 5 GW is shown in **figure 6**. After ~2 s the 50.2 Hz level is hit and 10 GW of LV sources disconnect from the grid. The frequency decline is stabilised by the self-regulation effect, primary control and pumped storage. 30s later, LV generators begin to resume their feed-in, driving frequency again over the 50.2 Hz threshold.

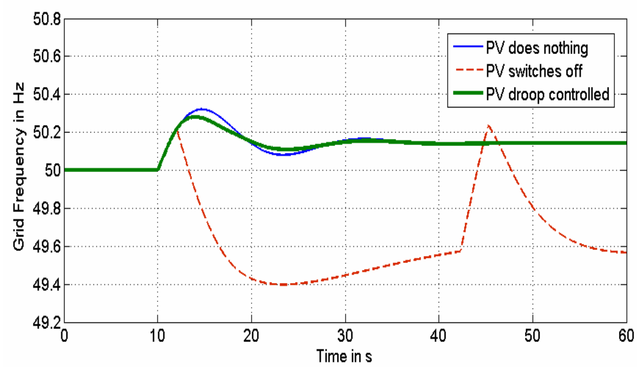

Fig. 6: 10 GW Photovoltaic with a Loss of Load of 5 GW

The scenario with 10 GW surplus power is displayed in **figure 7**. As the loss of load and the disconnecting PV power impulse equal each other, frequency stabilises temporarily around 50 Hz. Nevertheless, a yo-yo effect can be seen here as well.

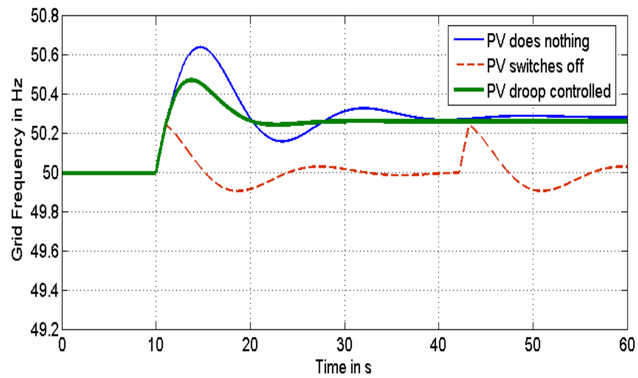

Fig. 7: 10 GW Photovoltaic with a Loss of Load of 10 GW

3.3 Discussion of the Results

Obviously, from a system point of view, the synchronous disconnection of LV generators is worse than no reaction at all. Droop controlled power reduction can be regarded as a method for a smooth stabilising strategy after the first disturbing impact at t=10s.

An important item is the reconnection issue. Even if not all PV inverters begin to resume with active power injection 30 s after frequency falls below 50.2 Hz, most of them do this within 30s-60s. MicroCHPs may need up to a couple of minutes for the restarting procedure. Finally, the automatically activated ramp up of LV power may outweigh the balancing power capacity available to TSOs.

4 DISCUSSION & OUTLOOK

As shown above, old requirements for grid connection of low voltage generators did not anticipate the system relevance of LV feedings. These unfitting connection standards enlarge the risk for major grid disturbances. Suitable countermeasures are discussed in the following section.

4.1 New Guidelines

Amended guidelines should come into effect as soon as possible. As frequency is a global variable within the grid (the effect of inter-area oscillations is neglected here), frequency response should be harmonised on all voltage levels vertically as well as horizontally between participating countries of synchronous zones.

4.2 Incident Management

In case of hitting the 50.2 Hz trigger level, a yo-yo effect as shown in the simulations above may occur. To stabilise this non linear oscillation in the GW range, two options are seen by the authors:
a) Stabilisation of grid frequency within 30s after the first LV shut-off above 50.2 Hz by load shedding until sunset.
b) Keep frequency low by quickly powering down dedicated plants so that the surge after reconnection will not hit the 50.2 Hz threshold again.

4.3 Risk Management

In order to defuse the existing legacy, incentives should be considered to update grid monitoring software in inverters. Modern PV-inverters are ready to update the firmware, but opening a splash proof cabinet to flash new code causes extra maintenance expenses. Monetary incentives could help to make already installed PV systems more grid friendly, please compare with SDLWindV. A simple approach is to randomise the over frequency setting in an evenly distributed interval of 50.2 – 51 Hz.

Synthetic Inertia
Hydro Québec's TransÉnergie already demands a compensation for the decrease of natural system inertia usally provided by synchronous machines. In the UK there are similar thoughts [10]. GE calls this feature of its wind turbines *WindINERTIA*, and Enercon has named it *Inertia Emulation*. Several research projects in industry and research institutions on emulating synchronous machine behaviour with inverters are in progress [11] [12] [13]. ENTSO-E drafted a requirement for power park modules (PPM) larger than 1 MW, see **figure 8**.

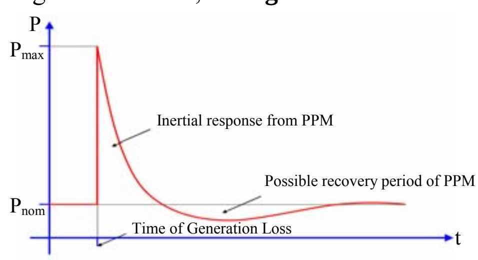

Fig. 8: Active Power Provision by Inertia, R7.10 [3]

Artificially enhanced self-regulation effect
The self-regulation effect is shrinking, as more and more drives are inverter powered and not directly connected to the grid. Frequency dependent power consumption may be introduced to fridges, air conditioning, electric vehicles, etc. They are able to deliver a new kind of ancillary service.

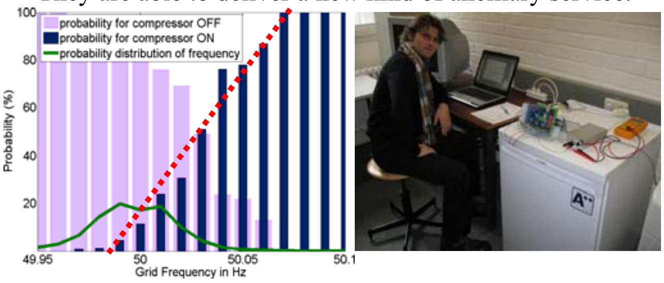

Fig. 9: Student project at TU Clausthal with a Smart Grid Device Controller, results from 32h data recording

Thus, the grid should get "harder" or at least avoid getting "softer", in order to miss the 50.2 Hz threshold. Another option for lowering the likelihood for action from over frequency protection is to popularise intra day trading with ¼-h-blocks which will minimise frequency excursions at the full hour and recover the security margin of 200 mHz intended for unplanned power imbalances.

5 SUMMARY

Existing grid codes for low voltage networks are endangering the system stability with advancing decentralisation of electric power production. Responsible stakeholders need to pay attention towards this issue. Three types of countermeasures have to be addressed: First, amended grid codes shall come into effect as soon as possible. Then, strategies for defusing existing installations have to be agreed on. Additionally, emergency plans in case of an over frequency incident shall be developed according to Policy 5 of ENTSO-E's Operational Handbook.

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