Grid control via power converter

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The aim of this paper is to show a way how renewable energy sources can contribute their part to a stable energy grid. An energy converter was developed that is able to apply instantaneous power. This system was used to investigate the stability of the German energy grid in 2030.

1 Introduction

The supply of electrical energy in Germany will change in the next years to a more environmentally friendly generation. But this change will expose a weakness of the renewable energies as they are right now. Without a substitute for the inertia of conventional generators the stabilization of the grid will cause huge problems [1]. According to a survey two thirds have to be compensated for the year 2030. Possible solutions for this problem are investigated below [1].

2 Generation

In the following images the change in generation of electrical power in Germany is illustrated in figure 1.

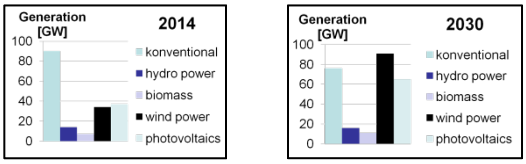

Fig. 1: Installed Power Germany 2014(left) 2030(right)

The amount of installed power of renewable energy sources (particular wind an photovoltaic) will increase significantly over the next 16 years. Most of these renewable energy sources supply their energy with power converters. This means they contribute no instantaneous power which leads to an instable grid control. According to "dena-Studie Systemdienstleistungen 2030" of the "Deutsche Energie-Agentur GmbH (dena)" [1] the amount of instantaneous power missing in the German grid, due to the development of renewable energy sources, is 254 MW and 0,68 MWh for the year 2030.

3 general distribution of instantaneous power

To guaranty a stable power supply the amount of instantaneous power in the German part of the ENTSO-E grid must be 372 MW at any given point [1]. In the future there will be times where nearly all of the electrical power is generated from photovoltaic. On other times the main source of electrical power will be wind. In both cases the instantaneous power must be provided. This paper focuses on the solutions for photovoltaic. A deeper look on wind power is provided in "Grid control via power converter" by Daniel Wagner [2].

4 Wind

Conventional power plants have rotating inertia. The rotational speed of the synchronous generator is proportional to the frequency of the grid. If a problem leads to a drop of the frequency drop the synchronous generator will slow down a bit. The difference in rotational energy is set free as instantaneous power. The power converter disables this functionality in wind power stations. With some changes in the controller the wind power station can use this effect similar to a conventional power plant.

5 Value per kW

The absolute values from [1] needs to be set in relation to the power of a single system. In a worst case consideration the system load is low, in this case 50 GW for the whole German grid [3]. The related values per installed power are calculated as follows:

$$\frac{P_{\mathrm{inst}}}{P_{\mathrm{Solar}}} = \frac{254\ \mathrm{MW}}{50\ \mathrm{GW}} = 5\,\frac{\mathrm{W}}{\mathrm{kW}} \qquad (1)$$

$$\frac{\mathrm{E_{inst}}}{\mathrm{P_{Solar}}} = \frac{0{,}68\ \mathrm{MWh}}{50\ \mathrm{GW}} = 0{,}0136\,\frac{\mathrm{Wh}}{\mathrm{kW}} \approx 50\,\frac{\mathrm{Ws}}{\mathrm{kW}} \tag{2}$$

The values of an additional 5 W und 50 Ws per installed kW system power are very minor and can be provided by a capacitive solution.

6 System Topologies

A capacitor driven system can be build in two different ways. The first topology needs an additional converter and capacitor while the second topology needs an enlarged capacitor and a revised control compared with a standard solar converter. Since the stored energy is proportional to the voltage of the storage capacitor the second topology has a higher intermediate circuit voltage to ensure a proper functionality in case the instantaneous power has been used.

The different topologies are shown in the following images.

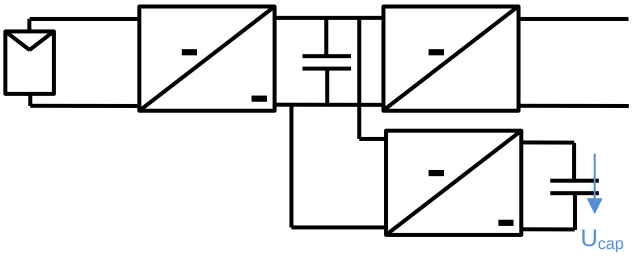

Fig. 2: Power converter topology 1

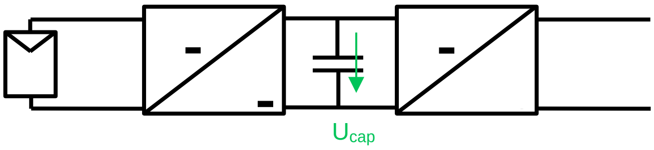

Fig. 3: Power converter topology 2

7 Capacitor configuration

The configuration of the capacitors is dependent on the voltage of the intermediate circuit. For the following simulations the voltage of the first topology was set to a maximum of 400 V. The intermediate circuit voltage for the second topology is allowed to move in the boarders between 600 V and 700 V. With this assumptions the capacitance is calculated as follows:

$$\mathrm{C_{Top.1}} = \frac{2 \cdot \mathrm{E_{inst.}}}{\mathrm{U^2}} = \frac{2 \cdot 48{,}96\,\frac{\mathrm{Ws}}{\mathrm{kW}}}{(400\mathrm{V})^2} = 612\,\frac{\mu\mathrm{F}}{\mathrm{kW}} \tag{3}$$

$$\begin{aligned}\mathrm{C_{Top.2}} &= \frac{2 \cdot \mathrm{E_{inst.}}}{(\mathrm{U} + \Delta\mathrm{U})^2 - \mathrm{U}^2} \\ &= \frac{2 \cdot 50\,\frac{\mathrm{Ws}}{\mathrm{kW}}}{(700\mathrm{V})^2 - (600\mathrm{V})^2} = 770\,\frac{\mu\mathrm{F}}{\mathrm{kW}}\end{aligned} \tag{4}$$

In both cases the capacitance is well under 1 mF per kW installed system power.

8 Simulation in MatLab

To proof that the two topologies can provide instantaneous power for an electrical power grid an MatLab / Simulink simulation model was created. The base of the simulation is a constant solar power which charges the intermediate circuit capacitor. These capacitor feeds the grid over a 3-phase inverter module. For the first Topology the intermediate circuit is supplemented by an additional DC DC converter and one capacitor to store the needed energy.

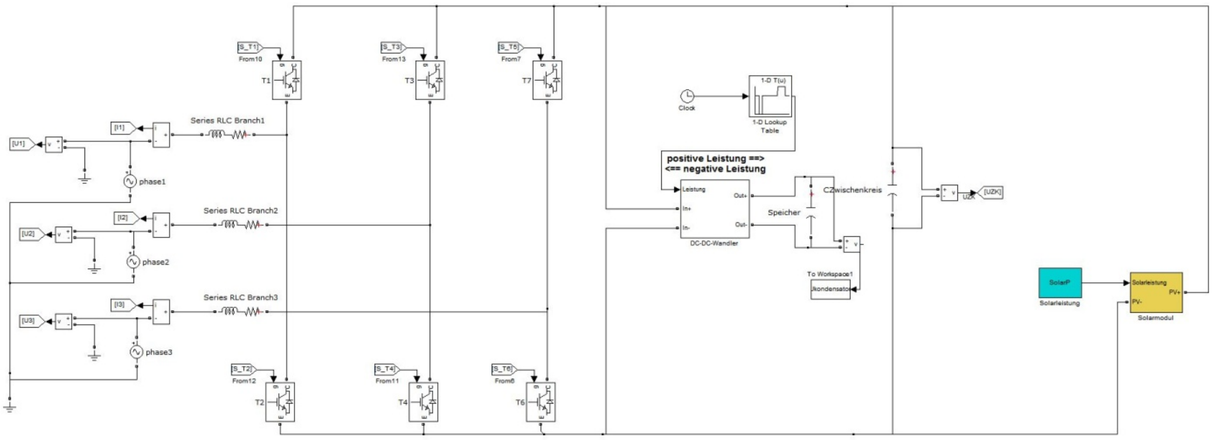

Fig. 4:Simulationmodel for the topology 1

The simulation is for an solar power of 1 kW and a constant grid frequency of 50 Hz. The simulation of the first topology is shown in figure 4. The other model looks very similar to this one, just the added converter and capacitor are missing.

9 Simulation results

A) First simulation

The aim of the first simulation is to successfully contribute instantaneous power for the grid. To achieve this the set value for the instantaneous power starts at 5 s with 5 W. It stays for 5 s constant and after a break of 20 s the recovery phase follows with twice the length but half the power of the emulated inertia. The results for both topologies are shown in the following image.

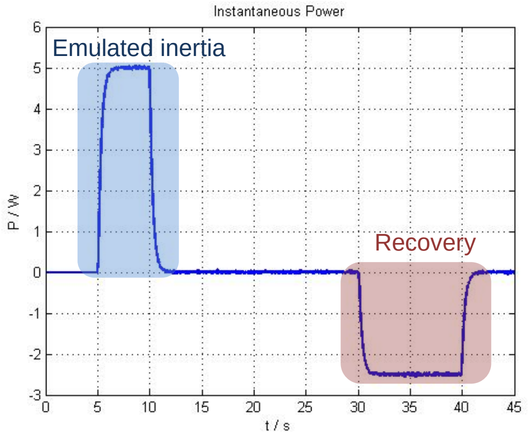

Fig. 5: Instantaneous power

The instantaneous power of both systems follows the set value very well. Just the edges are a bit softer compared to the set value.

The values for the capacitor voltages are shown in figure 6.

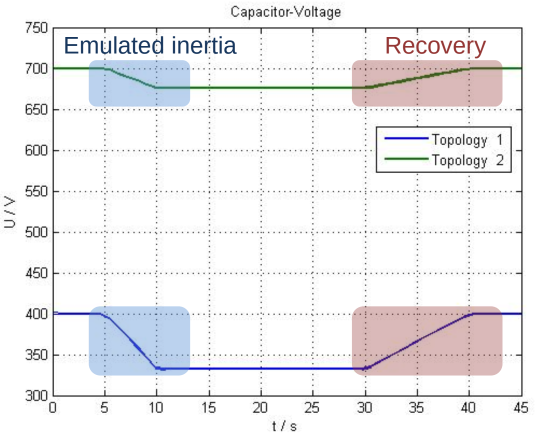

Fig. 6: Capacitor Voltage

The voltage of both capacitors falls in the first phase, where the inertia is provided. While no inertia is provided between 10 and 30 seconds the voltage stays on a constant level. In the recovery phase from 30 to 40 seconds the voltage rises up to the starting level. The recovery phase is important to secure that the system is ready to react to the next event in the same way.

The next step of the analyses is to find out how a grid would react to a failure event if the instantaneous power is provided by one of the capacitor based solutions. To show the development of the frequency the primary control needs to be taken into consideration. The following simulation was created by Daniel Wagner [2]. It is mend to show the German part of the ENTSO-E grid after the worst case failure of a 2 GW power drop happens at 5 s. Assuming the primary control taking over with a linear increase within 25 s up to a maximum of 700 MW [2].

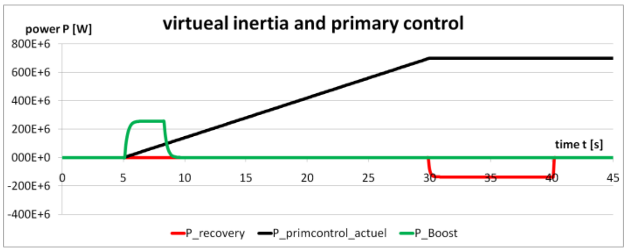

Fig. 7: Inertia and primary control

The first figure shows an overlap of the emulated inertia and recovery phase of the capacitor based systems and the primary control. The inertia from the previous simulation is scaled up to the needed 265 MW [1].

The figure 8 shows the frequency for the case without any control in red and with the emulated inertia and the primary control in green.

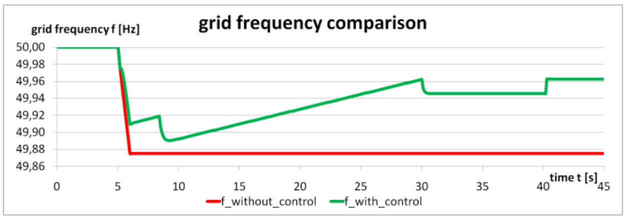

Fig. 8: Grid frequency comparison

B) Second simulation

The point of instantaneous power is to lower the drop of frequency before the primary control takes over. In the previous simulation (*A*) the constant inertia over 5 s provides this effect in a suboptimal way. If the inertia would be provided not in a constant way but with a linear fall over a longer time the effect of the primary control and the emulated inertia should counteract each other. The results for both topologies are shown in the following image:

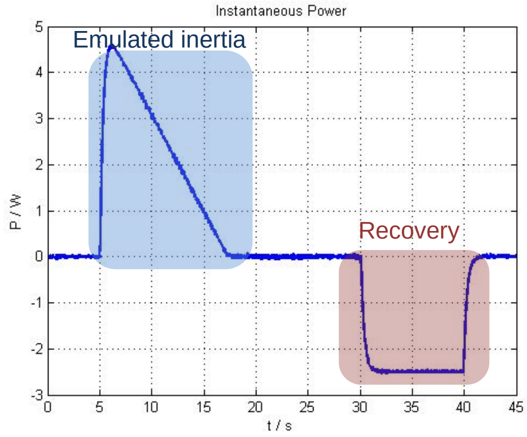

Fig. 9: Instantaneous power 2

The values for the capacitor voltages are shown in figure 10.

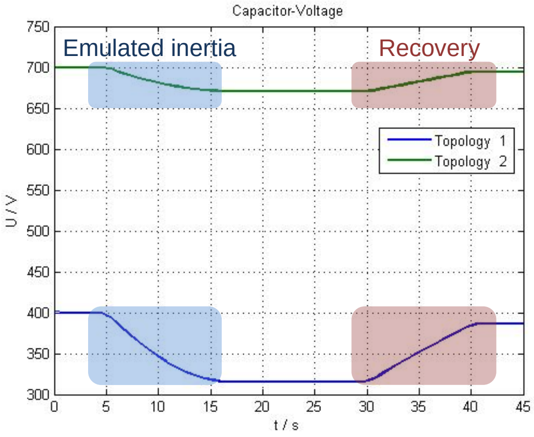

Fig. 10: Capacitor Voltage 2

The voltage of both capacitors falls in the first phase, where the inertia is provided. Different to the first simulation the voltage no longer falls linearly because the instantaneous power is not constant. The break still don´t changes the capacitor voltage. The recovery phase is similar to the recovery phase of the first simulation.

The first figure shows an overlap of the emulated inertia and recovery phase of the capacitor based systems and the primary control.

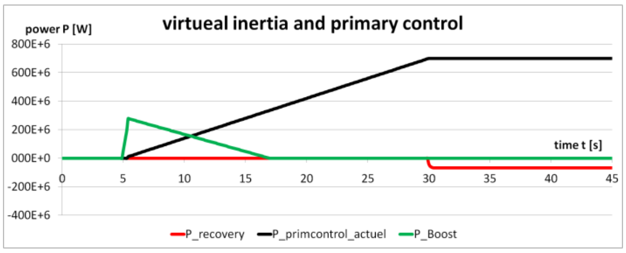

Fig. 11: Inertia and primary control 2

The next figure shows the frequency for the case without any control in red and with the emulated inertia and the primary control in green.

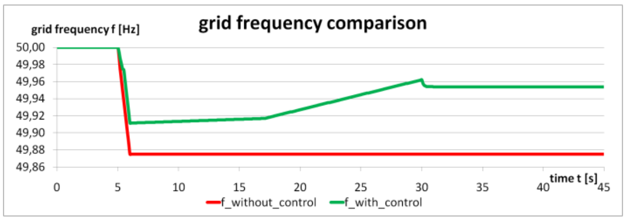

Fig. 12: Grid frequency comparison 2

The frequency with control drops to value of 49.91 Hz and stays at around this value for as long as the system contributes the emulated inertia. The lowest frequency of the first simulation is 49.89 Hz. The smooth frequency response makes the second approach a more suitable solution.

10 Prospects

The instantaneous power in the simulations is based on set values. To build a power converter which reacts to the real grid requirements a control mechanism needs to be implemented. One requirement for an control mechanism is a real-time frequency measurement.

11 Results and Discussion

In the course of these project two different ways to provide instantaneous power based on a power converter have been developed. The reaction of both systems while providing instantaneous power was inspected. And the reaction of a grid that consists of power converters with the developed system was shown. With power converters like this a grid can be build that allows a large amount of renewable energy sources and still operates on a stable level.

References

[1] A.-C. Agricola, H. Seidl, S. Mischinger, C. Rehtanz,, M. Greve, U. Häger, D. Hilbrich, S. Kippelt, A. Kubis, V. Liebenau, T. Noll, S. Rüberg, T. Schlüter, J. Schwippe, C. Spieker, J. Teuwsen, „dena-Studie Systemdienstleistungen 2030 - Sicherheit und Zuverlässigkeit einer Stromversorgung mit hohem Anteil erneuerbarer Energien", Deutsche Energie-Agentur GmbH (dena), Energiesysteme und Energiedienstleistungen, Berlin, Germany, Feb. 2014

[2] Daniel Wagner, " Grid control via power converter" *Cologne Institute for Renewable Energy*, FH Cologne, 2014

[3] Gerald Kaendler, "Netzentwicklungsplan 2012", Amprion GmbH, 2012