Instantaneous grid power control with PV inverters using DC-link capacitors

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Abstract: Soon, renewable energy sources may contribute 100% to the power consumption in Germany, at least for some hours per day. Then, instantaneous reaction on load steps must be covered by photovoltaic or wind power converters. This requires additional power of 5 W and energy of about 50 Ws per installed kW power capacity to cover one event.

It is suggested to store the required energy in a capacitor linked to the intermediate DC voltage, either directly or by using an additional converter. A capacitor volume size of about 5 cm³ per installed kW relates to the best case. This corresponds approximately to the size of single phase DC link capacitors. The resulting voltage fluctuations on the capacitor are investigated.

INTRODUCTION

Renewable energy sources put new burdens on the electrical power grid. While fluctuating generation can be compensated by storages [1] [2], the grid control also faces challenges: At certain times, renewable energy sources contribute already up to 80% to the power consumption in Germany (figure provided in the full paper), and soon shares of 100% for longer periods are expected [9]. Most of this power is generated by electronic power converters without rotating inertia. Fortunately, Germany's grid is part of the ENTSO-E, European Network of Transmission System Operators for Electricity, and today the missing inertia can be compensated by the other members, which have less renewable energies [3]. However, in future, this instantaneous reaction on load steps must be covered by the feed-in inverters [4] [5] [6], in the worst case by one of the contributors like photovoltaic (PV). To provide instantaneous reaction control, [3] mentions the following solutions: batteries combined with PV systems, curbing the generation in order to have a margin for positive control power, using the inertia of wind rotors [7] and modifying no longer used rotating generators as control power devices. These solutions are either costly or not sufficient.

Therefore, here a solution for PV inverters is investigated, which provides instantaneous reaction control with minimized effort and no curbing.

POWER AND ENERGY REQUIREMENTS

Here, it is assumed that only the instantaneous reaction is considered, while the following primary control is taken over by dedicated sources in the grid. Then, the photovoltaic system can recover after an event, to always operate at maximum power. To get the power and energy requirements, the methodology and data of reference [3] is used: a worst case event of a lack of 3 GW power in the ENTSO-E grid is assumed. This requires 372 MW in the German grid. Assuming the primary control taking over with a linear increase within 20 s [3], this requires energy of 3720 MWs. Relating this to the peak demand of 80 GW leads to 4.6 W/kW, rounded up to 5 W/kW. In a worst case estimation this is set equal to the installed PV peak power (in fact, to supply 80 GW reliably demands much more installed power). Concluding, additional power of 5 W and energy of 50 Ws per installed kW power capacity is needed to cover one event.

INVESTIGATED TOPOLOGIES

This level of power can easily be processed by the main inverter. The amount of energy relates to the energy content of a somewhat larger DC link capacitor (details see following chapter). Therefore, it is suggested to store the required energy in a capacitor linked to the intermediate DC voltage, either directly or by an additional converter as illustrated in Figure 1. If the capacitor is linked by a converter, its voltage may vary

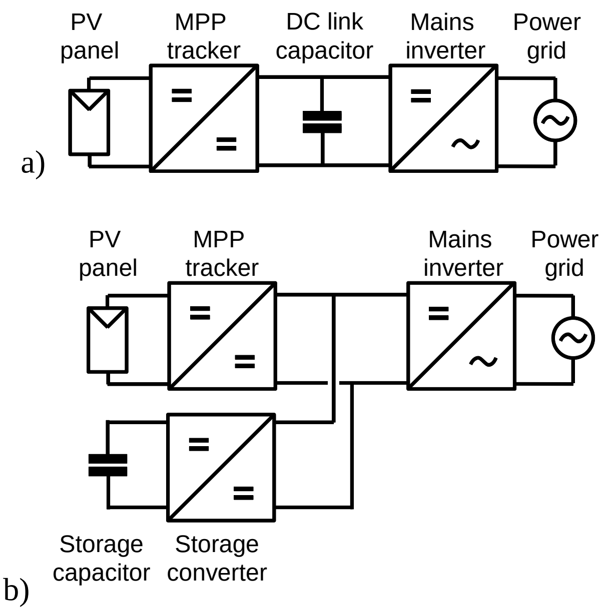

Figure 1: Investigated topologies.
a) Topology A: Storage as direct DC link capacitor.
b) Topology B: Storage connected with a converter.

arbitrarily, independent of the topology of the mains inverter, and more of the rated energy storage capability can be used. The storage converter must be a bi-directional converter. Preferably, the capacitor's voltage is lower than the intermediate voltage. Then the converter can be realized with buck functionality for charging and boost functionality for discharging. The final paper will present the details of the converter topology and the realized circuit. Compared to the main inverter, this storage converter can be much smaller, because it needs to process only a small fraction of 0.5% of the maximum feed in power.

NEEDED CAPACITOR SIZE

Typically, the size of a capacitor relates to its maximum energy content. To determine the interdependence, the capacity, rated voltage, diameter and height of 190 electrolytic capacitors are collected from the website of an electronic components distributor [8]. Rated energy and volume are calculate from this data and shown in Figure 2a. In real circuits, not the maximum rated energy capability E_{max} can be used, because the capacitor is discharged from the maximum voltage U_{max} only by a voltage difference ΔU. Then the usable energy E_{use} is:

$$E_{use} = E_{max} \cdot [1 - (1-\Delta U/U_{max})^2] \qquad (1)$$

This equation is used to illustrate in Figure 2b (orange trace), which E_{max} is necessary, if the required energy of 50 Ws is stored. The blue curve relates to an extrapolation of the volume using the fit function in Figure 2a.

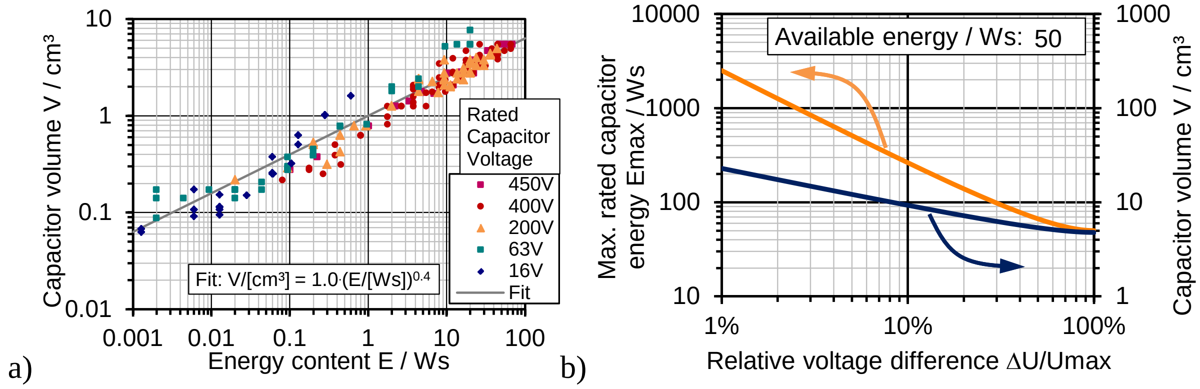

Figure 2: Volume size of electrolytic capacitors.

a) Various electrolytic capacitors, data from [8]. b) Needed capacitor energy and volume size to store 50 Ws.

The maximum voltage has no influence on the capacitor size and can thus be freely selected. Only the relative voltage difference, which can be considered as relative voltage ripple, determines the size. The voltage ripple in the two investigated topologies can significantly be different. A charge converter allows a ripple of about 90%. This relates to using nearly the full rated energy and a capacitor volume size of about 5 cm^3 per installed kW. This corresponds approximately to the size of single phase DC link capacitors. Contrary, if the DC link capacitor is used, the ripple should remain below 10%, requiring least 300 Ws, resulting in at least twice the capacitor volume. This higher volume and cost must be traded off against the charge converter. The considered voltage step is relevant only for the worst case of an extreme power loss event.

VOLTAGE FLUCTUATIONS

During daily operation, frequency fluctuations are much smaller and thus the expected voltage fluctuations on the capacitor are much smaller. Figure 3 shows the measured frequency (orange) for one hour on 8.Feb.2014. Assuming a typical inertia time constant $T_a = 20s$, the required power demand can be calculated from the time derivation of the frequency slope (details see final paper). It is filtered to achieve reasonable results (red). The required power is used to charge and de-charge a capacitor with maximum energy content of 300 Ws, which relates to charging directly the DC-link capacitor (see above). From this the capacitor voltage and its fluctuation (blue) can be calculated. The voltage variation during the investigated time remains between +3.4% and -3.4%. This is a quite small value, which can be handled easily by power electronics.

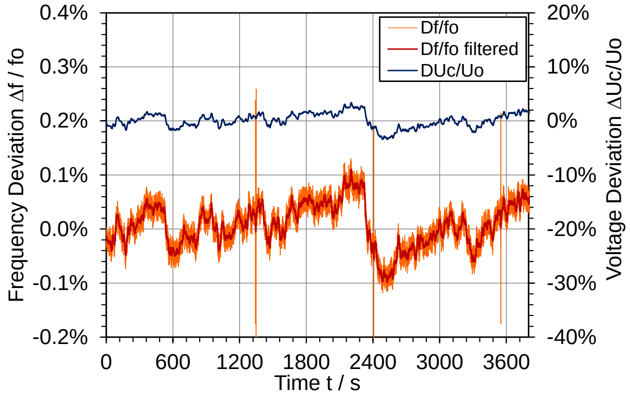

Figure 3: Measured frequency for one hour and related calculated voltage fluctuation on a capacitor with an energy content of 300 Ws.

CONCLUSIONS AND FUTURE WORK

Instantaneous power control of the power grid with electronic converters becomes necessary soon in Germany and Europe. This requires additional power about 5 W with an energy of 50 Ws per event for each installed kWpk. This can easily be implemented in PV converters. The required storage size is in the order of magnitude as DC ripple cancellation capacitors in single phase converters. The use of a small charge and de-charge converter allows using a smaller capacitor size, makes control easier and allows an easy modification of existing circuits.

The final paper will show: Hardware of the circuit and measurements, simulation of the capacitor voltage on a single event and on everyday frequency fluctuations.

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