NETWORK OF BATTERY INVERTERS WITH DIFFERENT CONTROL MODE

Other elements than the solar grid inverter can be used in this system with a centralized VS. On the AC-bus, standard battery inverter/chargers can be connected, if they are in current-control mode (CS). It is possible to distribute battery inverters in the minigrid and make them work together without V/f droops as long as there is only one voltage source in the system. We obtain a system with a central VS and distributed CS. The reliability of this minigrid is high, because each battery inverter with a transfer relay can work on his own as a UPS, if there is a problem elsewhere in the minigrid.

More than that, each CS-inverter can have its own solar charger (or other sources) connected to its DC side and is able to share this energy with the rest of the mini-grid because it is bidirectional. The global energy management can be done with the frequency of the minigrid.

MIXING DC AND AC COUPLING: EFFICIENCY AND ROBUSTNESS

Considering the efficiency, AC-coupling and DC-coupling are not similar.

The power profile determines the total efficiency again:

- If there is excess solar production during the day and it must be stored into the batteries, DC-coupling has a better efficiency.
- If the solar energy is directly used, there is one conversion less with the AC-coupling.

Following computation is done to compare both cases with assumptions:

Grid inverter efficiency: $\eta_{grid-inv} \cong 0.96$

Battery inverter efficiency: $\eta_{batt-inv} \cong 0.93$

DC solar charger efficiency (with MPPT): $\eta_{batt-charger} \cong 0.95$

Battery storage efficiency: $\eta_{batt-cycle} \cong 0.8$

Energy produced by the grid-connected solar inverter must be stored for the night time:

$$E_{back-AC-coupled} = E_{solar} \cdot \eta_{grid-inv} \cdot \eta_{batt-inv} \cdot \eta_{batt-cycle} \cdot \eta_{batt-inv} = E_{solar} \cdot 0.664$$

Energy produced during the day by the grid-connected solar inverter is directly used by user:

$$E_{direct-AC-coupled} = E_{solar} \cdot \eta_{grid-inv} = E_{solar} \cdot 0.96$$

Energy produced during the day by the solar charger connected to DC:

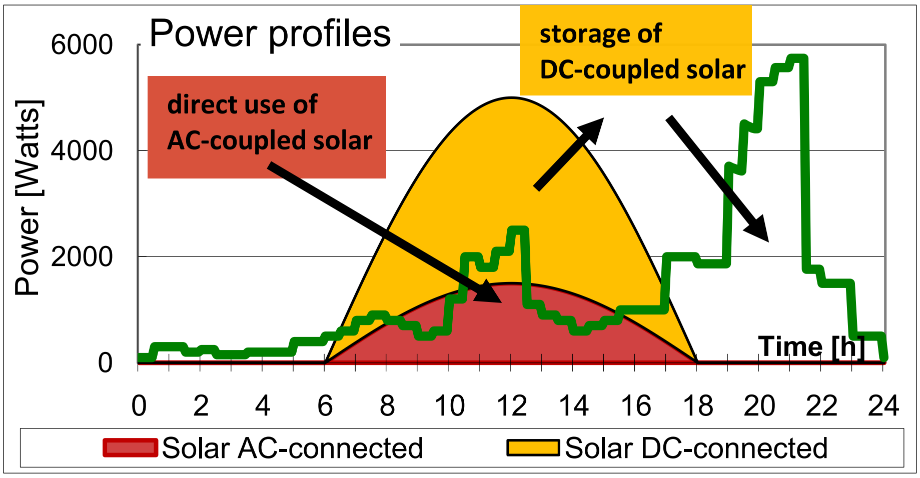
$$E_{back-DC-coupled} = E_{solar} \cdot \eta_{batt-charger} \cdot \eta_{batt-cycle} \cdot \eta_{batt-inv} = E_{solar} \cdot 0.706$$

Energy produced during the day by the solar charger connected to DC and directly given to user: $E_{direct-DC-coupled} = E_{solar} \cdot \eta_{batt-charger} \cdot \eta_{batt-inv} = E_{solar} \cdot 0.883$

Efficiency on solar energy	**DC-coupled**	**AC-coupled**
Energy stored in battery	70.6%	66.4%
Energy directly used	88.3%	96%

There is not a big difference: 3.5%, between using AC or DC coupling for energy stored in batteries, and a little bit bigger difference on the direct use during the day: 8% at the advantage of AC-coupling that avoids one conversion.

This is true only for a modern solar battery charger with MPPT included. The values are very different if the solar regulator is a traditional series or shunt. It is quite well accepted that a MPPT can give up to 30% more energy during a day compared to a direct connection to a battery (if the battery is never full!). The ideal case for efficiency is direct use of AC-coupled solar energy and storage for night time of the DC-coupled solar. But practically, install two different types of solar systems, is probably not interesting. The installer will prefer a simpler system with only one connection philosophy even if there are a few little percents of efficiency to gain. The mix of AC and DC is interesting on another level: for the robustness of the system. If AC is not present for any reasons, the solar grid inverter cannot work. That is a weakness in the system: the solar production depends on the proper operation of the battery inverter that creates the AC; the



battery charging depends on two components instead of one. Per example if the batteries are empty after a few rainy days, the battery inverter stops in order to protect them. And when the sun comes back the grid connected inverters don't start if there is no AC. With AC-coupling only the system can be blocked in this situation. If there is solar at the DC, it can recharge the batteries the next sunny day and all the system can restart again. Then we propose to always have a part of solar to DC when using AC-coupling: partial AC-coupling.

CONCLUSIONS

Partial AC-coupling:

- It is feasible to make AC-coupling of some compatible elements without V/f droops. Standard elements available on the market were tested.
- Optimum design for efficiency is a share of the solar modules between DC-coupling with a solar charger and AC-coupling with a grid inverter according to the load profile.
- Partial AC-coupling is better in term of robustness; it is more reliable to have at least a part of the solar production connected directly to DC, or even only DC coupling.

The presented concepts are not only theoretical but were implemented and tested on real products available on the market. Many tests have been done to find out the limits and problems that can occur with the use of grid connected and standalone inverter together. Many combinations were tested and it was found robust enough to be used in the field with the precautions mentioned about microcycling.

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