Design and Control of DC Microgrid for Integrating PV in Built Areas

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Massively integrating PV in built areas raises both challenges for power quality and opportunities to solve them by local energy management. With photovoltaic generation, storage systems, and an increasing number of loads natively operating in direct current (DC), interconnection of this equipment in DC with a single interface to the AC grid opens new ways to locally manage power quality. Our approach, which is based on decentralized control, is particularly suitable for use in commercial or industrial buildings.

High penetration of photovoltaics in the power system raises several issues for the quality of supply due to fundamental differences between PV and conventional generation. The combination of weather-dependent fluctuations with the decentralized nature of PV creates issues for local power quality. Indeed, large up or down ramps of power can create rapid voltage variations in the distribution grid.

For PV to be systematically deployed on buildings, these power quality issues need to be dealt with. An opportunity is provided by the combination with local loads. In particular, more and more electric loads in buildings are either natively powered in DC (LED lighting, computing equipment, televisions, etc.) or have a DC stage in their power supply (variable-speed drives as used in energy-efficient appliances such as inverter heat pumps). Since both PV and battery storage are native DC components, DC interconnection within a building can reduce the number and complexity of power converters, and increase energy efficiency. Gains of 2% to 8% have been demonstrated [1, 2].

The novelty of our approach consists in using this interconnection not only to increase energy efficiency but also to manage power quality. The proposed structure is shown on Figure 1. In this structure, the DC microgrid has a single interface to the larger AC grid: a bidirectional inverter. Whereas most microgrid approaches rely on a communication layer, here all the information on the status of the system is represented by the voltage on the DC bus. All PV generators are set to operate at their maximum power point and loads operate freely so any control can only be effected on the storage converter or on the bidirectional inverter.

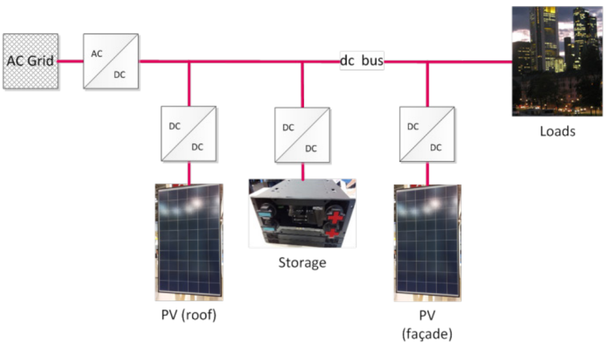

Figure 1: General architecture of a building DC microgrid without communication layer.

The coordination between the two controls is defined at the design stage; in operation, they operate independently based on the local voltage. The main questions were whether voltage levels could be simultaneously managed on the DC and AC sides, and how much storage would be necessary.

Both the storage converter and the inverter use a proportional-integral (PI) controller based on the measured DC bus voltage and, for the storage controller, the state of charge. Parameters of the storage controller were set first for maximum responsivity to voltage fluctuations on the DC bus. Then three sets of parameters were defined for the inverter control, each leading to a different dynamics but all at least one order of magnitude slower than the storage controller.

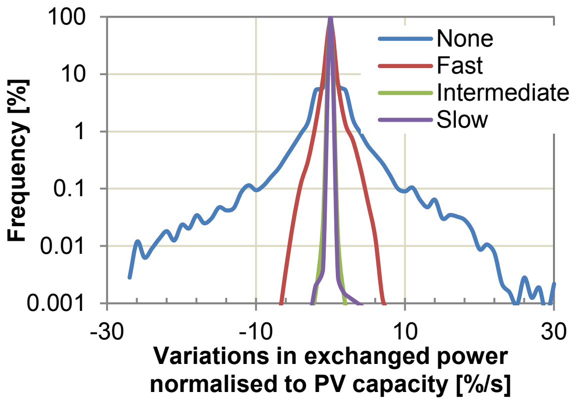

Figure 2: Power ramp rates at the interconnection with the AC grid as a function of the control applied on the bidirectional inverter.

With the “intermediate” control on the inverter, modeling with realistic grid parameters and measured load and solar irradiance shows that both DC and AC voltage levels can be maintained within ±10% of their nominal values. As shown on Figure 2, with this control the maximum ramp rates are divided by 15 as compared to direct power exchange without control. To achieve this outcome, a storage capacity equivalent to 40 min of PV production at nominal power is necessary. Dynamic battery technologies such as lithium-based ones are therefore best indicated for this purpose.

The modeling results have been obtained with data for a tertiary building with a 100 kW_p PV system. Indeed the potential impact of such systems on the grid, the local availability of loads, and the structured maintenance of their electricity infrastructure make them prime targets for using this approach of DC microgrids.

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[1] D. Fregosi, *et al.*, “A comparative study of DC and AC microgrids in commercial buildings across different climates and operating profiles,” in 2015 IEEE First Int. Conf. DC Microgrids ICDCM, pp. 159–164 (2015)

[2] U. Boeke, M. Wendt, “DC power grids for buildings,” in 2015 IEEE First Int. Conf. DC Microgrids ICDCM, pp. 210–214 (2015)