DC Bus based microgrid for buildings applications

Rodolfo HORTA
HES-SO Valais-Wallis – Switzerland
rodolfo.horta@hevs.ch

Dominique ROGGO
HES-SO Valais-Wallis – Switzerland
dominique.roggo@hevs.ch

Christoph ELLERT
HES-SO Valais-Wallis – Switzerland
christoph.ellert@hevs.ch

ABSTRACT

The project DC-bus for microgrid at HES-SO Valais-Wallis is a full scale demonstrator where the main electrical components in a modern building, i.e. photovoltaic power sources, various consumers and distributed storage systems are directly connected to a common DC distribution system. This paper describes the specifically designed DC/DC converters with MPPT for individual PV panels and the bidirectional AC/DC interface to the LV AC distribution grid. A model of the controller in the frequency domain of the AC/DC inverter has been used to optimise the control coefficients, with focus on both DC bus stability and reduction of the current harmonics on the AC grid side. Realisation, a simulation model and tests results are presented.

INTRODUCTION

Microgrids can bring numerous advantages to the local electrical energy distribution systems. A single interface to the grid for a whole building or district can result in a much better control of power quality and harmonics. , The power exchanges between the microgrid and the grid can be predicted or smoothened with the help of an energy storage system. This significantly simplifies the integration of high percentages of strongly varying renewable power sources into the distribution grid. In case of regional supply loss some microgrids can be islanded and run independently until the situation is cleared.

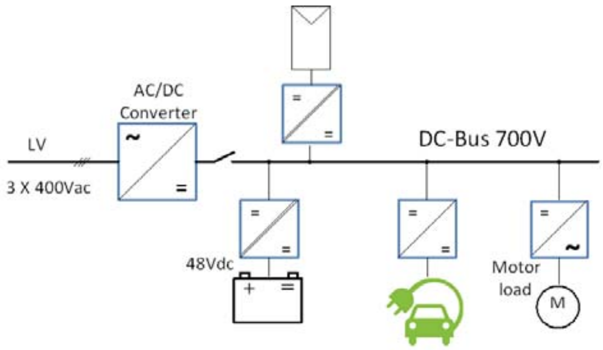

Figure 1: Fully integrated microgrid based on the DC power link with connection to the AC-distribution grid

Today's low voltage general electrical distribution systems rely on AC technology. But more and more industrial applications use a low voltage DC bus based distribution system, with voltages between 300 V and 750V. This is the case in datacenters or in large automation applications where several drives are fed by a common DC-BUS interfaced to the grid with a single active front end unit. Better efficiency and cost reduction can be achieved in a DC system through the suppression of AC/DC conversion stages between DC sources (typically PV panels) and DC loads (typically variable speed drives for electrical motors, pumps, compressors) or batteries. Low voltage distribution systems based on DC technology are still not widely spread in building applications due to technical challenges inherent to safety for persons and equipment.

The objective of the project *DC-bus for microgrid* at HES-SO Valais-Wallis is to realize a full scale demonstrator where PV energy sources, consumers and distributed storage system, i.e. the main electrical components for a modern building, are integrated into a common DC distribution system (Fig.1). The demonstrator is a "learning by doing" platform, where critical issues linked to that technology can be identified and its feasibility shown to the distribution grid stakeholders. The key components of a distribution system based on a DC-bus are the specific converters between power sources and sinks: individual or serial PV converters, the bidirectional DC/DC converter between the bus and the storage system or the four-quadrant converter between the DC bus and the AC distribution system. We focussed on designing highly efficient and reliable converters as well as fast and robust algorithms dedicated to their control. The converters do not only take over energy transfers but contribute to the stability of the bus voltage by controlling energy flows.

Energy monitoring and communicating devices are implemented at each conversion stage of the system. Control algorithms for the high level energy management in the application can now be programmed and evaluated.

DC/DC CONVERTERS WITH MPPT FOR INDIVIDUAL SOLAR PANELS

Figure 2: View of the DC/DC converters for individual PV-modules on the roof of HES-SO Valais-Wallis

Each of the 45 available PV panels is interfaced to the DC–Bus with its own DC/DC converter with integrated maximum power point tracker (MPPT). Individual converters were realised for commonly used crystalline silicon PV-modules up to 300W with U_{mpp} = 32V and thin film silicon tandem modules with U_{mpp} = 120V (Fig.2).

A galvanic isolation at each converter improves the safety of the complete system. The conversion efficiency of the individual converters reaches 97% to 98%. A wireless Zig–Bee communicating interface transmits the current, voltage, temperature and identification of each solar panel to a central supervision system at time intervals of down to 10 seconds. Thus a permanent online supervision of each panel is guaranteed. The system design allows connecting and disconnecting any DC/DC converter at any time while the entire DC-bus system continues to function. Both last features strongly simplify maintenance, system extensions and upgrades.

LV-AC GRID INTERFACE

A 10kW AC/DC converter interfaces the DC bus with the AC distribution grid. This converter will mainly control the +/-350V DC bus voltage, with energy transfers in both directions. The main purpose of the developed inverter is to ensure a unique connection between the 700V DC bus and the AC distribution grid. This way the number of connected devices to the network is reduced and thus the potential disturbance contributors.

The 10kW AC/DC converter is a 2-level 6 branches topology with coupled inductors. In order to create an LCL input filter, an inductor and a capacitor are added between the inverter and the grid (Fig.3).

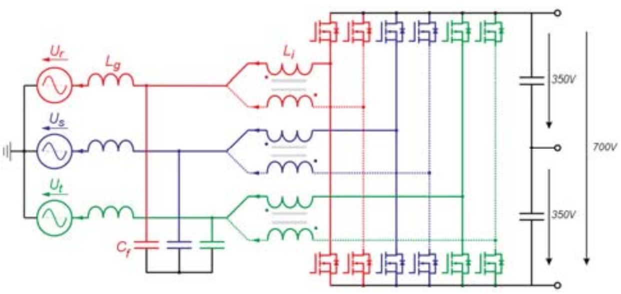

Figure 3: Grid-Connected 2-level DC/AC inverter with coupled inductor and LC filter.

The 6 branches can be represented as two 3 branches inverters connected in parallel. Due to extra conduction paths, the parallelization of three phased converters can lead to “crosscurrent” between modules. Several solutions are proposed in [1], the chosen one here is the coupled inductor. In order to reduce the current ripple injected into the grid the switching patterns of both modules are 180° phase shifted. In our case, the grid current has a 40 kHz ripple for a 20 kHz switching frequency. This leads to the size reduction of filtering elements in the LCL input filter. Since the overall current is split by the number of total paralleled modules, semiconductor devices with lower rated current could be selected. Other advantages such as modularity, higher power density and reliability are achieved through the paralleling of multiple voltage source converters (VSCs) [2]. Efficiency is one of the main objectives in energy conversion and transfer. 1200V Carbide Silicium (SiC) Mosfets were chosen as switching components for this inverter. With a low R_{dsOn} and reduced switching losses this rising technology is a relevant choice for high efficiency power electronics designs. The AC/DC converter, its controller, the EMI filter, the security elements and relays are shown in Fig.4

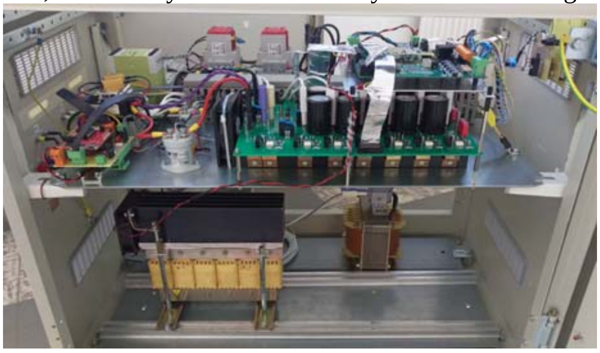

Figure 4 HES/SO Wallis AC/DC 10kW converter for 700V DC Bus control

AC/DC CONVERTER SIMULATION MODEL

The input LCL filter used for current harmonic reduction can in combination with a weak network become a critical issue in converter stability [3]. These types of filters require more complex current regulation in order to maintain the system stability. The three phased current control is often realised with a synchronous frame proportional integral (SRFPI) controller gained by a transformation of the three-phase values into DC. A simple proportional- integral control is then enough for controlling the current without steady-state error.

This section describes the modelling of the converter in closed-loop. This model results in an equivalent Norton circuit (current source) [4]. Figure 5 shows an inverter with an LCL input filter and its current control. The superposed voltage control is not represented for this analysis and is assumed to be much slower than current control. The regulation is composed of a current regulator G_{ci} and a point of connection voltage feedforward G_U.

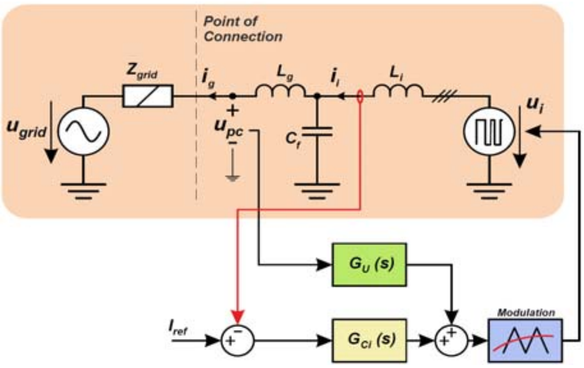

Figure 5 Current control loop of a Three-Phase AC/DC converter with LCL EMI filter

The grid current I_g can be described with the following equation:

$$
\begin{aligned}
I_g(s) &= \underbrace{\overbrace{a_1 \cdot [a_2 + G_{ci}(s)]^{-1} \cdot G_{ci}(s)}^{G_{Norton}} \cdot i_{ref}(s)}_{I_{conv}} \\
&\quad - \underbrace{\left[C_f \cdot s \cdot a_1 - a_1 \cdot [a_2 + G_{ci}(s)]^{-1} \cdot [G_u(s) - a_1]\right]}_{Y_{conv}} \cdot u_{pc}(s)
\end{aligned}
$$

Where :

$$a_1 = \frac{1}{C_f\ L_g\ s^2 + 1} \cdot I^{3\times 3} \quad a_2 = \frac{s \cdot (L_g + L_i + C_f\ L_g\ L_i \cdot s^2)}{C_f\ L_g\ s^2 + 1} \cdot I^{3\times 3}$$

The current control G_{ci} is obtained by converting the SRFPI into an equivalent stationary a-b-c frame [5].
The Norton equivalent circuit can directly be derived from the I_g equation (Fig.6).

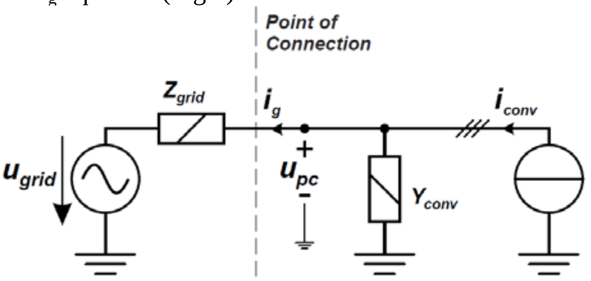

Figure 6 AC/DC converter Norton equivalent circuit

This representation is composed of an admittance Y_{conv} and a current source I_{conv}. Each of those component include the influence of the control and the passive elements of the filter. Such a modelling approach can be applied to any kind of controlled AC/DC converter. It can be used for control strategy optimization and analysis of control stability with the scope to reduce inverter-grid or inverter-inverter interferences resulting in resonances and harmonics.

ENERGY STORAGE AND BATTERY CONVERTER

A Pb-gel battery storage system is directly connected to the DC-Bus via a bidirectional DC/DC converter of the company Studer-Innotec SA, Sion. The used system is a modified version of a commercially available product, which links the 700V bus to the 48V nominal voltage of the Pb-battery. Presently the capacity is 200 Ah, which allows a total of 5 kWh while keeping the State-of-Charge above 50%. An upgrade of storage capacity is ongoing, linking a Pb-gel of 900Ah/48V and Li-$FePO_4$ with about 18 kWh. This storage allows smoothing and limiting the power exchange between the DC bus based microgrid and the AC Grid. The major advantage of a semi-autonomous microgrid can be fully exploited, since the distribution grid operator doesn't need to cope with strongly varying renewable power sources.

TESTS RESULTS

The DC Bus based microgrid has been running for several months with most of the produced solar energy fed into the local AC grid. Different DC loads and the battery have been lately connected with success to the system.

PV system

The measurements of the PV production of several individual converters in Figure 7 show that the MPPT function allows optimizing each panel working conditions according to the local solar irradiance on the roof: during the morning hours the individual optimization of power is successfully coping with the unfavourable partial shadowing on the roof caused by nearby trees. (For better visibility only 7 modules of 45 are shown in the figure.) The individual MPPT function allows integration of larger sections of partial shadowed roofs reducing further partial shadowing losses in comparison with today's standard string connected PV-modules solution.

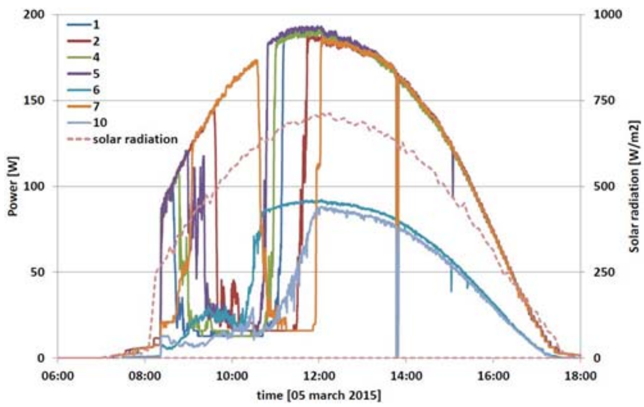

Figure 7 Power profiles of 5 c-Si and 2 tandem PV-modules equipped with individual DC/DC converters.

Harmonics reduction for the microgrid

A small total harmonics distortion ratio (THD) is required in the LV AC distribution grid. With the increasing proportion of distributed renewable energy production this aspect becomes a key element in power quality assessment of new installations. Thus, the AC/DC converter developed for this project needs to generate as little current THD as possible. This goal has been reached using an optimized current control, obtained according the simulation model described in Figure 5.
The current THD at the AC-side of the inverter stays under 10% THD for the major part of a sunny day (Fig.8).
The reduction of current distortion in comparison with a market solar PV inverter is shown on Figure 9.

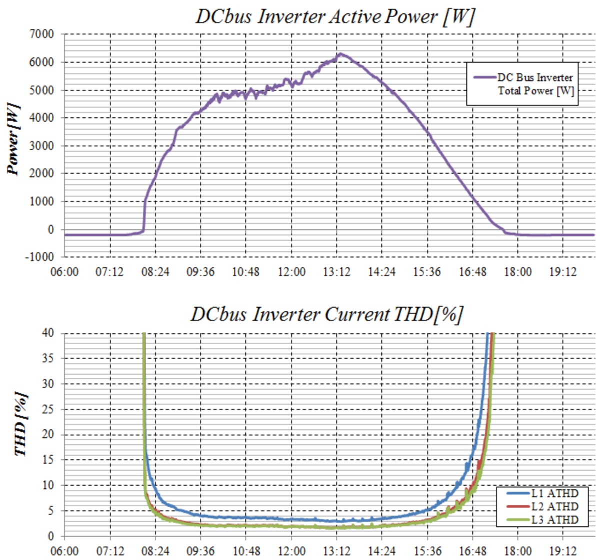

Figure 8 Current harmonics generated by the AC/DC converter interfacing the DC-Bus during one full day

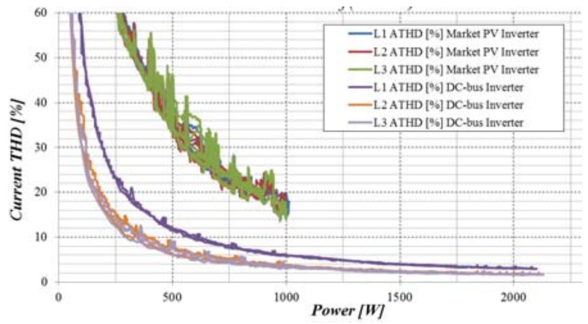

Figure 9 Current THD with DC Bus inverter and market PV inverter in function of the power generated

CONCLUSION

The project saw the realization of a simple LVDC electrical distribution system, integrating a 10kWp PV energy production, an interface to the local AC distribution grid and battery system capable to store a portion of the daily PV energy produced. Further equipment like HVAC systems for a small building can next be connected to this +/-350V DC backbone. Developments of a safety concept and device protection have been an important challenge and are not fully satisfying at this stage of the project. Together with the lack of accepted standards this represents some limitations in the deployment of this technology at an industrial level.

Each component of the system has very high energy efficiency. The impact of the final protection solution on efficiency needs to be evaluated. The global efficiency of the whole system will then be measured and compared with an AC distribution system working in similar application and conditions.

The design of the AC/DC interface brought us to the development of a new converter model in the frequency domain. The resulting demonstrator shows good stability and robustness in the control. The reduced current harmonic distortion produced during one day for a complete building is presented as one example of the numerous advantages of such a microgrid for the Distribution System Operation. Control algorithms helping to predict and flatten the global power consumed or produced by a building will be developed in a large scale project follow-up.

ACKNOWLEDGEMENTS

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