New Trends in Hybrid Systems with Battery Inverter

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I. INTRODUCTION

The state of technology for offgrid battery inverters used in hybrid systems and minigrids has gone further in the last years. This is marked by the investigation toward new power electronic topologies, but mainly by more intelligence added with the use of digital control. It allows the use of sophisticated algorithms at every level to build smarter systems. The new control possibilities also give a lot of flexibility and allow building new system topologies where PV, wind, gensets and batteries are mixed. The battery inverter device is integrated in a system where all DC and AC coupling are possible. The general scheme is seen on Fig.1. The inverter is ideally placed to control the power flux, being at the interface between the different AC-source (inverter input/output), AC-loads and between AC and DC.

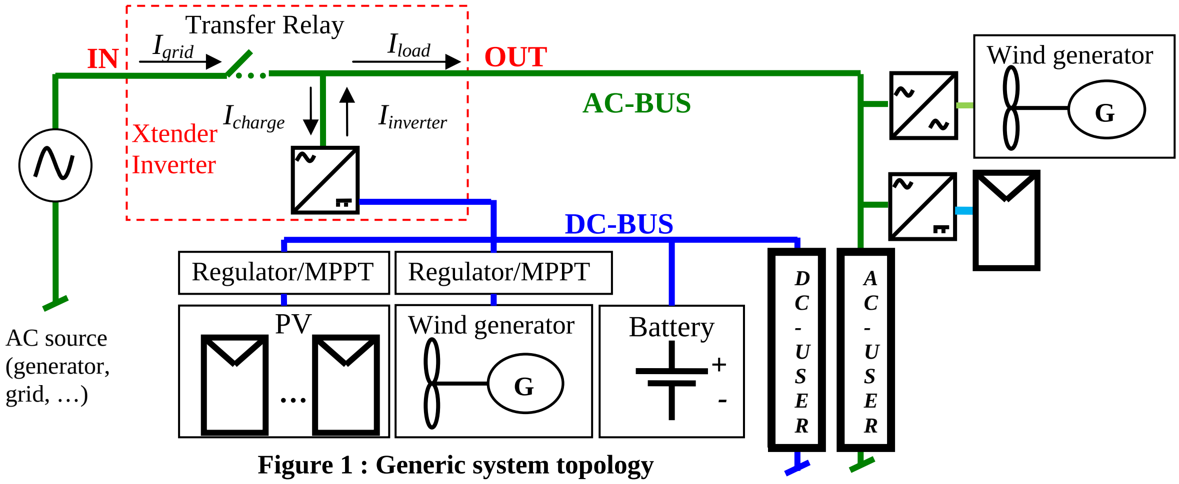

Figure 1 : Generic system topology

As can be read in [1], it is now well accepted that the hybrid systems offer a suitable solution for the rural electrification. Standard configurations are now the use of a DC-bus, or an AC-bus or a mix of DC and AC bus. Every single system tends to be a unique mix of elements that a project integrator optimizes.

A lot of tricks are now possible with the existing products to master the power fluxes and manage energy resources. Aim of this paper is to show a few examples of new functionalities available, which can help a system designer to find his optimal design.

This will be shown with the example of a power assistance function, which can improve the efficiency of a hybrid system with the underdimensioning of the generator size. Second example is the illustration of an advanced algorithm to choose the energy source in function of the different availability in the system from DC or AC.

Last years have seen the emergence of AC-Bus concept; that is typically a technical solution enabled by the addition of more intelligent control for the same hardware, [4], and [5]. Compatibility with this kind of system requires having the same type of V/f control implemented. But without having implemented V/F droop control strategies, it is possible to perform some AC coupling with a few tricks. An example will show this with the use of an offgrid inverter and a grid connected inverter of two different manufacturers together.

II. CURRENT ASSISTANCE

The idea of electric power assistance to a motor is already applied in different domains. Many publications treat this subject and the most relevant use of this concept is probably the successful hybrid cars. Underdimensioning a generator compared to the peak load and operating it at a more constant power allows gain in efficiency. In a hybrid system for rural electrification where generator is combined with a bidirectional battery inverter-charger, the same concept can be used: the energy storage system already exists and the inverter can assume the function of interface between the generator and the load. A specific control method was developed to perform this assistance. The assistance method must be able to handle all types of loads: electronic loads, low consumption light bulbs with high harmonic contents, motors and improperly compensated fluorescent tubes with a high reactive component… The solution proposed to make a proper assist is to recognize the load pattern and help the AC-source with a current similar to the one of the load. The injected current is automatically adapted to the load connected at a very fast regulation speed. This method called Smart-Boost is implemented in Studer inverters. The Smart-Boost control is a current assistance system rather than power assistance. Therefore it can add its own power to the other AC-source appropriately even on special loads. Here one typical example is used to illustrate what can do a new generation inverter in a hybrid system. More examples with the Smart-Boost function are discussed in details in [2].

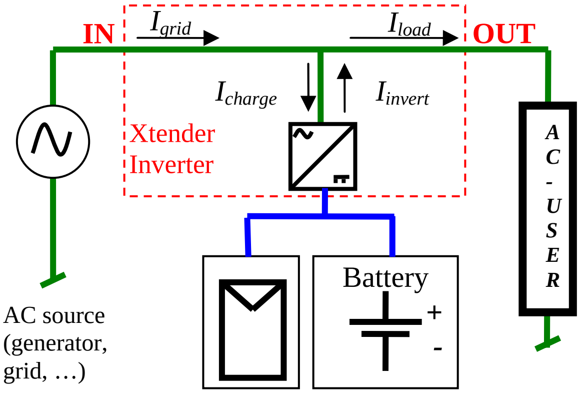

Figure 2 : System topology using Smart-Boost

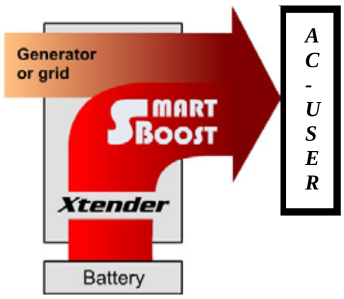

Figure 3: Smart-Boost, current assist control.

Efficiency of the Smart-Boost function and fuel saving with a generator

In a normal hybrid system the generator must be dimensioned for the peak power of the load. With the current assistance function it is possible to subtract the inverter power to the load peak power to dimension the generator. Doing this underdimensioning, there is a gain in initial cost for a smaller generator. Beyond this first gain, the efficiencies in the global system are considered to know if

underdimensioning and Smart-Boost function is a good option when planning an installation. Running costs must be computed carefully.
For one quantum of energy boosted, it was charged before, and the relationship between the charged and the boosted energy is: $E_{grid-charged} = \frac{E_{boosted}}{\eta_{inverter} \cdot \eta_{cycle} \cdot \eta_{inverter}}$

With reasonable mean value for the efficiencies of the inverter $\eta_{inverter} = 0.9$ (higher in reality) and the battery cycle efficiency $\eta_{cycle} = 0.8$ we find the energy charged for a given energy boosted later is 1.48 times higher (67% efficiency). This is a quite high value and to assess the energy efficiency of the system, we have to consider the fuel consumption of a generator. On fig.4. we see that a smaller generator is interesting mainly for the small loads. Precisely load profile in standalone system show a big difference between base load and peak load. The peak power duration is short and only energy of peaks of power must be boosted and re-stored after. This represents a small amount of energy that is cycled with this 67% efficiency. But underdimensioning the generator, all the base-load energy is provided with improved fuel efficiency.

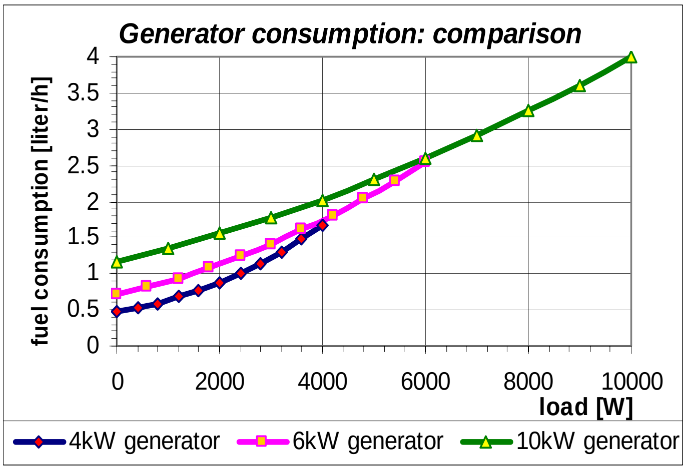

Figure 4: Consumption generators of different sizes

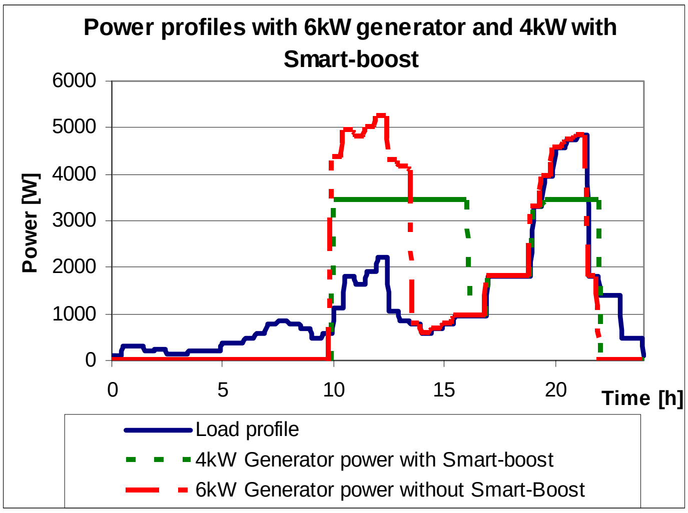

Figure 5 : Simulated profile for fuel efficiency assessment

A simulation of the two systems on the same typical load profile is made, with two different sizes of generators with and without Smart-Boost, seen on fig. 5. For the simulations we consider following hybrid system: the generator runs during the day only, during the night the inverter and batteries are used. In the results, the 6kW generator consumes 15.65 liters and the 4kW consumes 13.38 liters, there is 14% less fuel burned, 828 liters a year. In planning a new system, the smaller dimensioning of the generator saves initial costs. It runs with better fuel efficiency and this saves fuel consumption and running costs. If no underdimensioning is wanted, the Smart-Boost makes the system more powerful when the generator is running, for the same initial price. It can help to manage more loads in the future when demand increases.

Integration and optimization of renewable energies with Smart-Boost

As explained the proposed Smart-Boost function makes a load oriented injection of current and doesn't disturb the rest of the minigrid upstream. It can be a powerful interface between an AC-bus and a DC-bus to make intelligent management of available energy. To optimize the renewable energy connected to DC, an adaptive algorithm was developed which is the DC priority (or solar priority).

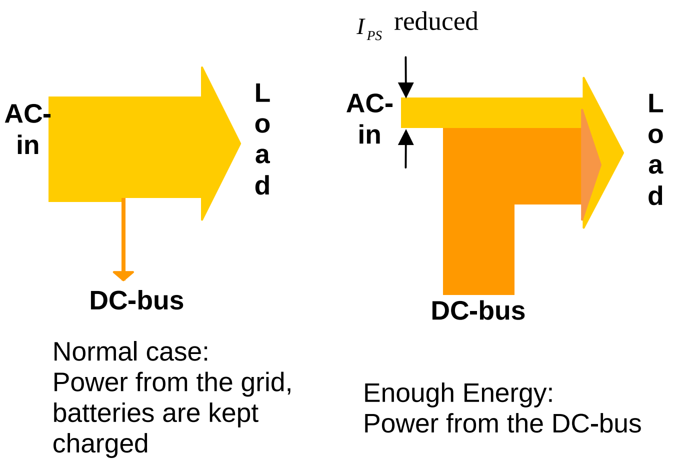

Figure 6 : DC priority algorithm

Principle of the DC priority is an automatic reduction of the input limit (grid current) in function of the DC voltage. If there is a DC power producer, it make the DC-bus voltage rise and this is measured by the inverter which diminished the input limit from the grid. The Smart-Boost is used to limit the input current and therefore it cover more of the load power with power coming from the DC. Under the priority voltage it works at the normal allowing the underdimensioning of the generator as seen above.

III. AC COUPLING WITH FREQUENCY SHIFT POWER CONTROL

The grid connected solar has become a huge market compared to offgrid solar which is the natural market for solar. For the ongrid market much more money was invested and now very good products exist in term of cost and reliability for solar modules and inverters. Those products are not suitable for the small offgrid systems but there is medium size where they can be used, in the range of a few kW, typically in minigrids.

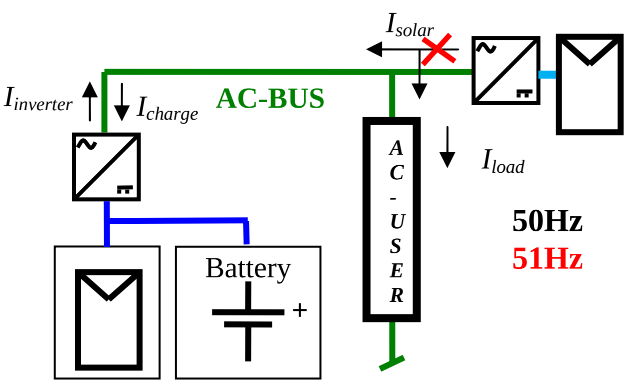

Figure 7 : AC-coupled solar inverter

A grid connected solar inverter can be connected to the AC produced by a bi-directional battery inverter. If the voltage and frequency are within the accepted values, then the grid connected inverter connects to this island grid and start to work. On the main grid all the available solar power is injected (MPPT) to maximize the return on investment. It cannot be the case in a stand-alone system because there is the need to control the power production to match the demand. If there is more production than demand, the excessive solar goes to recharge the battery. If the batteries are full the power production must absolutely be reduced or stopped to avoid overcharging of the batteries. The control of the grid connected inverter can be

done very simply with the frequency. Grid inverter is programmed to accept frequencies only between limits required by grid directives, per example for German Renewable Energy Act EEG between 47.5Hz and 50.2Hz. The battery inverter sets the voltage and frequency of the local grid, then it can increase the frequency and this will stop the grid connected inverter when out of the limit.
The 2009 EEG grid code (see [6] and [7]) has set new requirement and one is particularly interesting for our application, it is an active power derating in function of the frequency. When the frequency increases, the grid connected inverter doesn't simply stops but reduces its power linearly between 50.2Hz and 51.5Hz. This rule is set for medium voltage and high voltage and is not applied for low voltage yet. When this will be implemented generally it will be very interesting for the offgrid systems. By changing a little bit its output frequency, the battery inverter will be able to control the solar production in an island grid to match production-consumption-storage balance. It will be a precise control instead of an ON-OFF control.
The possibility to use standard grid connected solar/wind inverters within offgrid systems to interface the solar panels or wind turbine to an island AC minigrid can facilitate the system design. Per example it is possible to place solar panels far from the batteries. DC cable must be short and very thick (75-90mm2) because the standard battery voltage is low (12-24-48Vdc).

Tests

Tests were performed using different models of Studer-Innotec battery inverters and many brands of grid connected inverters. This system was used since a few years in the Solesafe concept (a backup for grid connected solar installation) and experience was accumulated from it ([3]). Coupling battery inverters and grid connected inverter is not only theoretical but a proven concept. One problem observed is that there are often disconnections of the grid inverter because of the grid tests performed (ENS). So the ENS should have been disconnected sometimes to work properly, which is absolutely legal in a standalone system. This happens because the inverter has higher output impedance than the main grid. But now, smarter tests are performed to detect islanding, not only the ENS grid impedance test is accepted. But different methods are used that allows working with standalone inverters as voltage source without problems. Most recent tests were performed with a Studer Xtender inverter and a Solarmax S3000 together and it worked with the default settings for Germany of the S3000 without any parameter modification, due to the smart and stable grid test it performs.

From experience a summary of the requirements on the elements can be given:

- The battery inverter must be bidirectional to accept power 'backward' at its normal AC-output. It must be able to control the grid connected inverter with the frequency, relays or communication.
- The battery inverter rated power must be bigger than the grid connected inverter: if there are no user loads all the produced power goes to battery inverter.
- The standard grid test of the grid connected must be more 'intelligent' than the old impedance measurement else there is the risk to connect-disconnect a lot of times (end of line effect). The old ENS grid impedance test must be

deactivated. New test works perfectly without deactivations (Solarmax S-series test).

- Optimum design for efficiency and reliability is a share of the solar modules between connected to the DC and connected to AC with the grid inverter as seen on fig. 7. It is necessary mainly for the robustness of the system; if AC is not present for any reasons, the batteries are not maintained. Per example if the batteries are empty, 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 falls in a blocked position. If there is solar at the DC, it can recharge the batteries the next sunny day and all the system can restart.

IV. CONCLUSIONS

In this paper we showed a few examples of new possibilities offered by the new more intelligent battery inverters in standalone systems. The presented concepts are not only theoretical but are implemented and tested on real products. Many tests have been done to find out the limits and problems that can occur with the Smart-Boost in parallel of the main grid or on a wide range of generators, from 1kVA to 60kVA. Similar for the use of grid connected and standalone inverter together, many combinations were tested and can be used in the field. Those practical experiments helped to develop a very robust functions adapted to the field application and implemented in Studer-Innotec Inverters.

V. REFERENCES

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