New V/f–Statics controlled Battery Inverter: Sunny Island® - the key component for AC-Coupled Hybrid Systems and Mini Grids

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1 Introduction

In the past most PV-Hybrid systems in the low kW range were based on mixed DC- and AC-coupled concept, where PV is coupled on the DC-Side with the battery as central component (see Figure 1.a). In these systems AC-loads are supplied by battery inverters which in some cases also act as battery chargers supplied by AC-generators (e.g. Diesel). These systems are usually not extendable and show a complicated (DC-) system design and therefore high system costs. The power that the DC-coupled power generator (e.g. PV) can contribute to the supply of loads is limited by the rated power of the battery inverter.

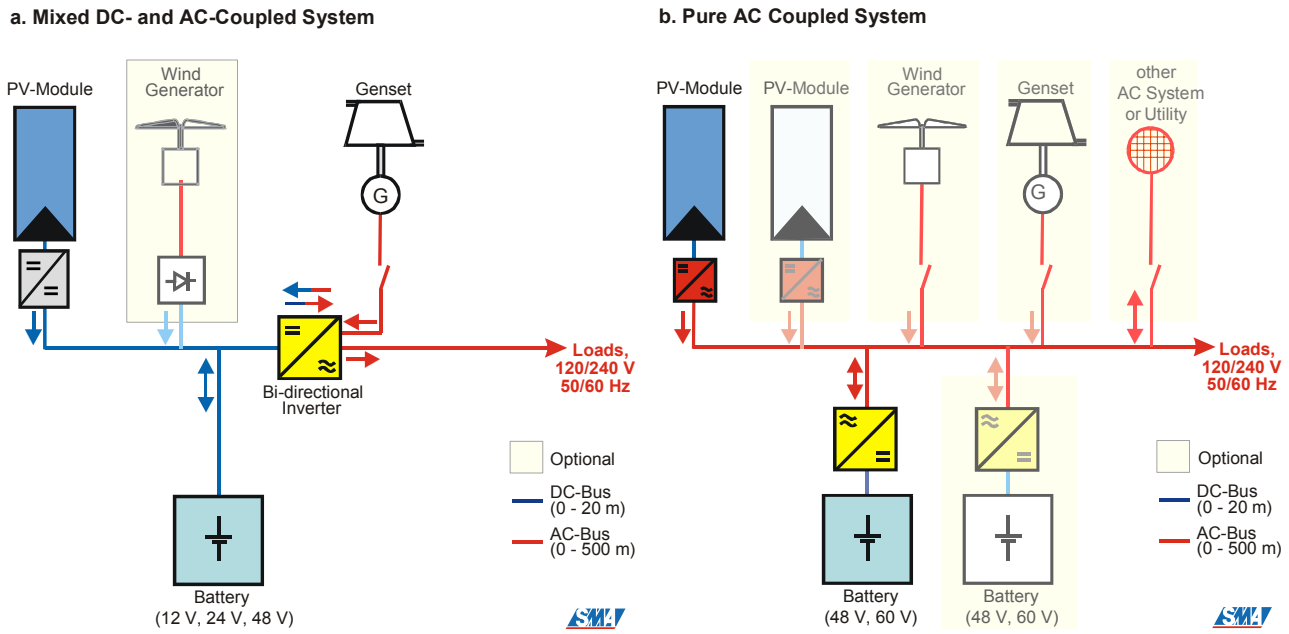

Figure 1: Comparison of mixed DC-and AC-coupled and pure AC-coupled System concepts for PV-Hybrid system design

2 Pure AC-Coupling –"The" concept for PV-Hybrid system design

To overcome the above problems the concept of (pure) AC-coupling has been developed and introduced by ISET e.V., University of Kassel and SMA Regelsysteme GmbH as part of the modular system technology [Kleinkauf 1991] . Pure AC-coupled systems (see Figure 1.b) where all loads and generators are coupled independently on a common AC-bus are currently evolving as a standard due to numerous advantages: [Cramer2002], [Rothert2001], [Rothert2003]

- Standardized coupling of different components (AC-coupling)
- Off-the-shelf grid components can be used
- Simplified design and operation of island grids
- Compatibility with existing grids
- Reduction of system costs
- Increased reliability of supply
- Expandability

3 Droop-Mode-controlled batter inverters: The key component for pure AC-coupling

In order to be able to utilize all the advantages of pure AC-coupling new control algorithms for battery inverters so called V/f-statics- or droop-mode control were developed by ISET e.V. and successfully implemented in SMA's Sunny Island® battery inverter [Engler2001]. Comparable to the control of a pool of conventional power plants (e.g. the European electrical power supply grid UCPTE) the concept of droop-mode-control is based on active power/frequency-statics and reactive power/voltage-statics (see figure 2). This droop-mechanism is inherent in standard AC-generators as e.g. the frequency decreases while the load (active power) increases.

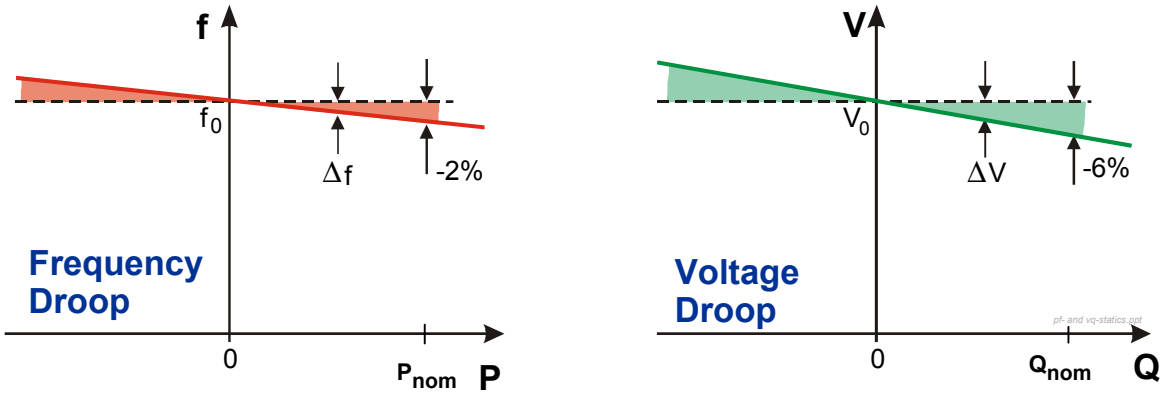

Figure 2: Comparison of mixed DC-and AC-coupled and pure AC-coupled System concepts for PV-Hybrid system design

Due to the following advantages and as demonstrated in many applications [Engler2002] the pure AC-coupled systems with droop-mode controlled Sunny Island® inverters show an outstanding

performance in terms of parallel operation of several battery inverters with (diesel) generators and grid - even in three-phase operation [Engler2003].

- expandable to any number of inverters
- no (high speed) communication necessary
- Increased overload capability of system (real generator support)
- can be combined with synchronous and asynchronous generators
- applicable to systems with distributed generation

The requirements for implementation of droop-mode-control in battery inverters are moderate. Beside a state-of-the-art controller (e.g. Digital Signal Processor) in combination with a fast and accurate measurement of AC-current and AC-voltage only a serial AC-inductor has to be added to the inverter topology.

	Sunny Island 4500	New ***Sunny Island®XX00***	New ***Sunny Island®XX00 Basic***
Generator Manage-ment	• Advanced algorithms for 2 and 3 wire generators • Generator protection	***Generator Manager:*** ***(optional)*** Independend unit with comprehensive algorithms for all possible generators • Standard: Basic algorithms	***Generator Manager:*** ***(optional)*** Independend unit with comprehensive algorithms for all possible generators • Standard: Basic algorithms
Battery Manage-ment	• Advanced algorithms for longest battery life	• Advanced algorithms for longest battery life	• Basic, for long battery life
Load Manage-ment	• Comprehensive, • Several configurable relais	***Load Manager:*** ***(optional)*** Independend unit with comprehensive algorithms for load management • Standard: Basic algorithms	***Load Manager:*** ***(optional)*** Independend unit with comprehensive algorithms for load management • Standard: Basic algorithms
AC-Control	• Droop-Mode-Control (P/f- and Q/V-Control) • Conventional VAC- or Icharge-control Mode (alternatively)	• Droop-Mode-Control (P/f- and Q/V-Control) • Conventional VAC- or Icharge-control Mode (alternatively)	• Conventional VAC- or Icharge-Control Mode
AC-Output	• 230V/50Hz • High overload capability • Parallel operation without fast communication • **3 phase configur. possible**	• 230V/50Hz, 120V/60Hz, 240V/60Hz • High overload capability • Parallel operation without fast communication • Split phase config. possible	• 230V/50Hz, 120V/60Hz, 240V/60Hz • High overload capability • Split phase config. possible
Topology	• Bi-directional DC/DC Conv. with Hf-Trafo • H-Bridge Inverter • AC-coupling inductor	• H-Bridge Inverter • 50Hz/60Hz Trafo • AC-coupling inductor	• H-Bridge Inverter • 50Hz/60Hz Trafo classic-light-siel-1aug03.vsd

Figure 3: Overview and features of *Sunny Island®* battery inverters and independent units for load and generator management

4 Sunny Island® family – Members for a successful family

Encouraged by the great success of the introduction of the *Sunny Island®* inverter SMA Regelsysteme GmbH decided to have a bigger family of off-grid products.

- In order to let customers benefit from SMA's long experience in designing PV-Hybrid systems SMA introduced the product family ***Sunny Island®System Kit*** in spring 2003. The four different system kits represent complete packages of selected power supply systems including Sunny Island® 4500 inverter, batteries, diesel or combined-heat-and-power generator. As an option photovoltaic or wind components can be added to each of the kits.
- In spring 2003 the ***Sunny Island® 4500*** battery inverter has been introduced. The excellent customer benefit of the *Sunny Island® 4500* is among others achieved by an increased output power rating in relation to the Sunny Island® 3300 and an extremely wide input voltage range suitable for 48 V and 60 V batteries. The overview over the feature set of the *Sunny Island® 4500* given in Figure 3. It is by far the most comprehensive feature set of state-of-the-art battery inverters in the kW power range.
- Offering an even better specific price (€/W) in 2004 the new ***Sunny Island® XX00*** battery inverter will be launched. As shown in Figure 3 the low specific price (€/W) is achieved choosing the robust and cost effective inverter topology with line frequency transformer. Another reason for the low specific costs is the "optional functionality concept", where advanced generator management and load management functions are offered optional.
- The optimum in specific price (€/W) will be offered by the new ***Sunny Island® XX00 Basic*** battery inverter which will be launched in December 2003. As shown in Figure 3 the feature set of the NEW *Sunny Island® XX00 Basic* is kept to the very basic functions known from state-of-the-art battery inverters.

5 The new *Sunny Island® XX00* battery inverter

5.1 How off-grid battery inverters can benefit from grid-tied Sunny Boy® inverters?

Figure 4 shows the development strategy for the new *Sunny Island® XX00*. The Sunny Island® XX00 merges the know-how gained with design, manufacturing and marketing of more the 150.000 grid-tied PV-inverters and SMA's off-grid know-how in particular droop-mode control and system resp. battery management.

5.2 Features and technical data of *Sunny Island® XX00* and *Sunny Island® XX00 Basic*

Figure 3 gives an overview over features of the three Sunny Island® inverters. By the time of editorial deadline the *Sunny Island® XX00* and *Sunny Island® XX00 Basic* were still in a test phase and the final technical ratings were still under evaluation. Therefore the technical data sheets will be distributed during the conference or can be obtained at *info@sma.de*.

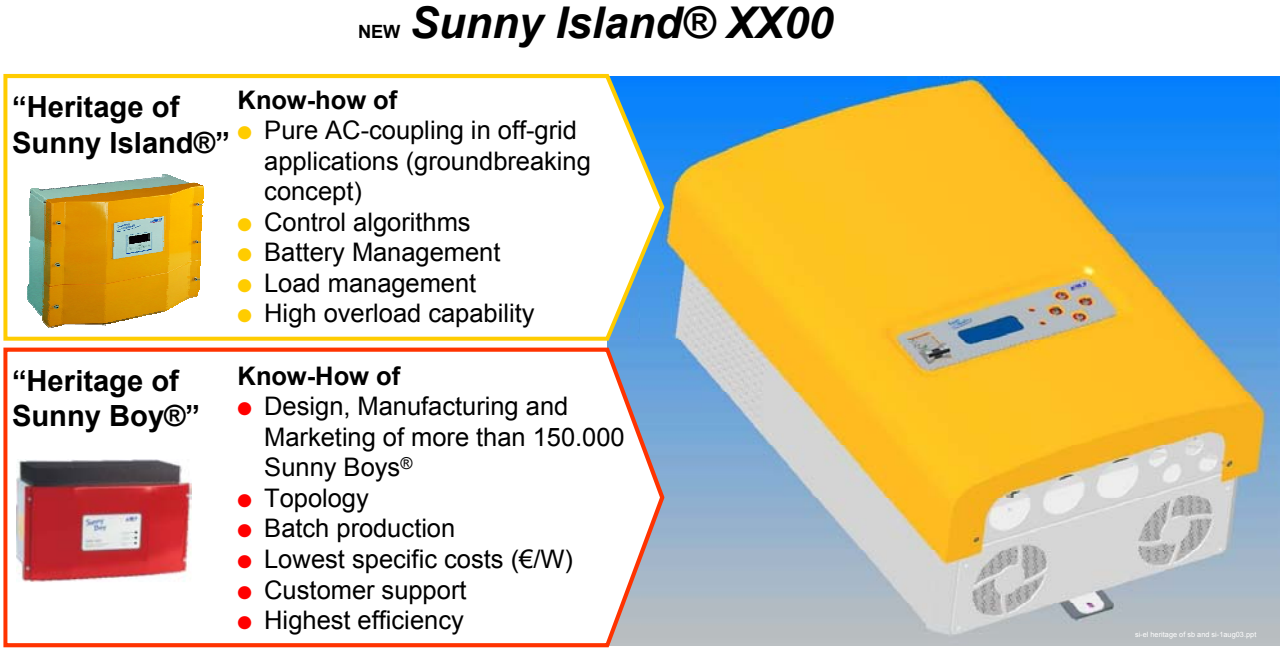

Figure 4: The new "Sunny Island®XX00" – the synergy of know-how of grid-tied Sunny Boy® PV inverters and Sunny Island® 4500 battery inverter

Literature

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Summary

A comparison of mixed AC- and DC-coupled system and pure AC-coupled systems and independently connected on a common AC-bus shows that pure AC-coupled systems have numerous advantages such as. standardized coupling of different components (pure AC-coupling), off-the-shelf grid components can be used, simplified design and operation of island grids, compatibility with existing grids, reduction of system costs, increased reliability of electrical power supply, expandability.

In order to be able to utilize all these advantages new control algorithms for battery inverters (V/f-statics or droop-mode control) were developed by ISET and successfully implemented in SMA's Sunny Island® battery inverter. Comparable to the control of a pool of conventional power plants the concept of droop-mode-control is based on active power/frequency-statics and reactive power/voltage-statics. The implementation of droop-mode-control in battery inverters requires merely a state-of-the-art Digital Signal Processor in combination with a fast and accurate measurement of AC-current and AC-voltage and a serial AC-inductor that needs to be added to the inverter power train.

Furthermore the paper introduces the new battery inverters *Sunny Island® XX00* and *Sunny Island® XX00 Basic*. These new inverters benefit from the know-how gained in different areas. On one hand the cost reduction and manufacturing process know-how developed for batch production of robust and reliable grid-tied PV inverter. On the other hand the off-grid know-how in particular droop-mode control for pure AC-coupling, battery management for longest battery life and system management for efficient and considerate use of (renewable) resources available at off-grid sites. Details on technical data are available at the conference exhibition or at www.sma.de.