



# Hybridinfo

The semi-annual newsletter on photovoltaic hybrid systems in Canada

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## Xantrex-Natural Resources Canada Partnership

by Sophie Roussin, CETC-Varennnes

NRCan is pleased to announce an important technological partnership with Xantrex, within the framework of a Technology Early Action Measures (TEAM) project. TEAM is a Canadian Government initiative supporting environmentally promising technological projects that can reduce GHGs.

The project involves the development and demonstration of a multi-energy (hybrid) platform. This new technology will combine and integrate several types of renewable energy (PV/wind/fuel cell) into a single system with a generator. The use of multiple energy sources offers a great deal of flexibility and enables optimized use according to application type. This technology offers an interesting solution for off-grid applications: residential, commercial and institutional.

The platform offers financial and environmental advantages. It is innovative because it simplifies the installation and design of hybrid systems, thereby reducing related costs. Currently, system components originate from different sources, and are often wired together in complex designs that do not always perform optimally. The platform's modular,

software-controlled design overcomes this hurdle, and will contribute to the growth of the Canadian photovoltaic market. As well as being energy-efficient, the platform offers an effective alternative solution that decreases GHG emissions by reducing fossil fuel use.

The project involves a number of components, including product development, and demonstration of target applications at monitored sites—recreational lodges, telecommunications sites and residential sites—where data will be analysed and validated in order to optimize the product.

NRCan will work with Xantrex on the product development. In particular, NRCan will contribute *PV Toolbox*, a *SIMULINK<sup>TM</sup>*-based work tool, and will share its expertise in operating monitored demonstration sites.

Xantrex is a North American leader in the field of advanced, renewable-energy power electronic systems. The company has facilities in Canada, the US and Spain. Most of its 500 employees are located at its head office in Vancouver. □

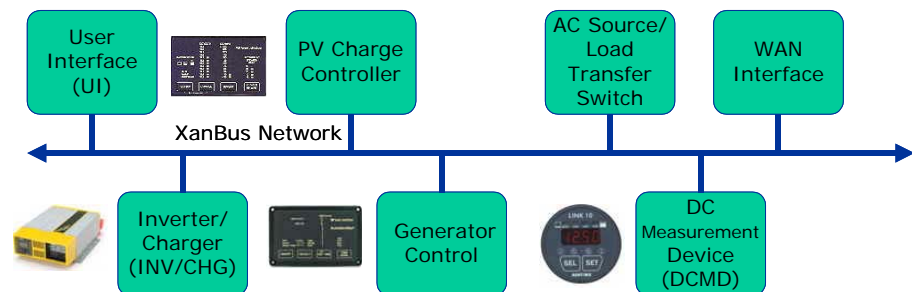


Figure 1: Xantrex multi-energy platform architecture



## Bus Configurations in Hybrid Systems Part I - What they are

By Michael Ross, Renewable Energy Research and Dave Turcotte, CETC-Varenes

" In North America, PV-Genset hybrid systems typically utilize an AC/DC bus configuration..."

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In North America, PV-genset hybrid systems typically utilize an AC/DC bus configuration: the connection between the photovoltaic array and the battery is entirely DC, and the AC output of the genset is used to satisfy any AC loads present when the genset is running. Recently, two competing bus configurations have appeared (see Figures 2, 3, and 4). In Europe, an AC bus configuration, in which the output of the photovoltaic array is converted to AC through module or string inverters, has been introduced. At the same time, a DC bus configuration, built around a variable-speed DC genset, has been proposed in North America.

Compared to the AC bus configuration, the AC/DC bus intuitively makes more sense. In the AC bus system, a portion of the array output will be converted from DC to AC and then back to DC in order to charge the battery bank or power a

DC load. Yet a simulation study by H. Gabler and E. Weimken at the Fraunhofer Institute for Solar Energy Systems in Freiburg, Germany, asserts that "in spite of the additional transforming processes, the AC-coupled system is not far away in performance, solar fraction, and auxiliary energy input from the [AC/DC] system".<sup>1</sup>

Variable speed DC gensets, on the other hand, promise reduced fuel consumption when the genset is operating at part load. In a conventional AC genset, the rotational speed of the genset is a fixed multiple of the desired AC frequency, regardless of the power demand. In a DC genset, this constraint is eliminated, permitting the genset speed to decline when power demand falls (as in a car engine revving up or down depending on whether the car is accelerating or decelerating). □

<sup>1</sup> GABLER, H. and WIEMKEN, E. (Vienna, Austria, 6-10 July, 1998) *Modelling of Stand-Alone PV-Hybrid Systems and Comparison of System Concepts*, Proceeding of 2<sup>nd</sup> World Conference on Photovoltaic Solar Energy Conversion.

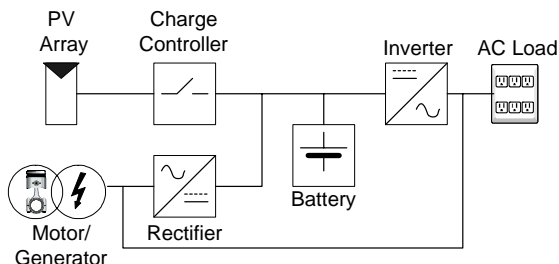


Figure 2: AC/DC Bus Configuration

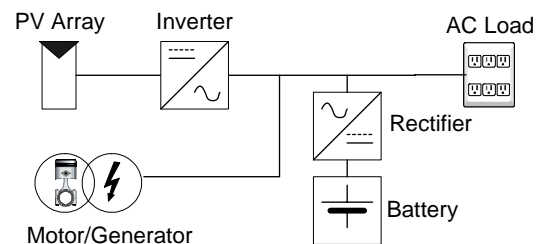


Figure 3: AC Bus Configuration

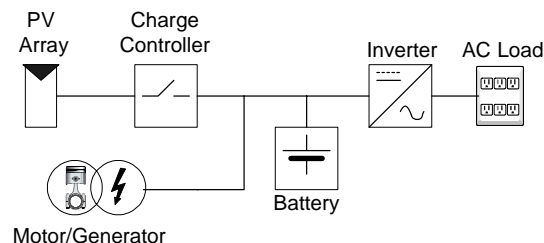


Figure 4: DC Bus Configuration

## Bus Configurations in Hybrid Systems Part II - A Comparison using PV Toolbox

By Michael Ross, Renewable Energy Research

In order to investigate the claims for the AC and DC bus configurations, a series of simulations were run using *PV Toolbox*, a flexible simulation tool developed at CETC-Varenes<sup>2,3</sup>.

First, the simulation was configured in an effort to recreate the Fraunhofer results. Encouragingly, *PV Toolbox* was able to do this very closely.

Then, two modifications were made to the system studied by Fraunhofer. In that study, a very inefficient rectifier and very efficient inverter were assumed, and only the AC bus system has maximum power point tracking—the battery fixes the voltage of the array in the AC/DC bus system. In reality, there is no reason that the efficiency of the rectifier and the inverter should be so different, so the rectifier efficiency curve was changed to match that of the inverter. Furthermore, for a fair comparison, maximum power point tracking must be included in both systems.

Following these changes, the performance of the AC bus system declined in relative terms. In particular, it required 10 to 18% more electricity from the genset than the AC/DC bus system. This conclusion was largely insensitive to changes in the size of the array and the pattern of load variation on a daily and seasonal basis.

Finally, the DC bus configuration was included in the comparison. A commercially available 6 kW variable speed DC genset was assumed. Compared to the AC/DC bus system, 0 to 3% more electricity was required from the genset and the genset therefore ran 0 to 2% longer, but 7 to 10% less fuel was consumed.

The DC bus fuel savings occurred during monthly equalisation charges, when the genset would operate for hours under partial loading. Indeed, when equalisation was not done, the DC bus system used 3% more fuel than the AC/DC bus system. Fuel consumption of the AC/DC bus system falls by 30% when equalisation is turned off. This suggests that variable speed genset operation may be less effective at reducing fuel costs than either intelligent genset dispatch strategies that minimize the time that the genset is operating at part load, or the use of batteries that can be cycled between partial states-of-charge without long-term damage.

Thus, the conventional AC/DC bus system offers some compelling advantages compared with either AC or DC bus systems. It can satisfy AC loads directly, unlike a DC bus system, and its fuel consumption suffers only during part load operation. □

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**" The conventional AC/DC bus system offers some compelling advantages compared with either AC or DC bus systems. "**

<sup>2</sup> ROSS, M. M.D. (2004) *Comparison of AC, DC, and AC/DC Bus Configurations for PV Hybrid Systems*, CANMET Energy Technology Centre - Varennes.

<sup>3</sup> SHERIFF, F., TURCOTTE, D. and ROSS, M. (Kingston, Ontario, 18-20 August, 2003) *PV Toolbox: A Comprehensive Set of PV System Components for the Matlab/Simulink Environment*, Proceedings of the 2003 Conference of the Solar Energy Society of Canada Inc.

## Bus Configurations in Hybrid Systems Part III – Practical Issues

By Dave Turcotte, CETC-Varenes

Apart from raw performance and energy efficiency, practical issues related to the different bus options are also at stake. This article will review the different buses and compare them with respect to cost, reliability, scalability and adequacy to the load type.

### **Range of applications**

While analysing the advantages and disadvantages of a bus structure, one must bear in mind that the final destination of the system will modulate significantly the results. Table 1 expands the characteristics of four different ranges of applications and highlights the most important criterion to look at. ▷

## Bus Configurations in Hybrid Systems

### Part III – Practical Issues

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Table 1: Application - Specific Requirements

Categories	Remote Equipment	Remote Residence	Island	Village
Applications	Telecom site, weather station	Remote house, cottage or resort	Community living on an island	Remote community
Load increase rate	Low	Medium	High	High
Requirement for peak energy supply	High	High	Low	Low
Probability of interconnection with another system or grid	Low	Low	Medium	Medium to High
Probability of having a maintenance crew on site	Low	Medium	High	High
Geographical distribution of sources	No	No	Possible	Possible
Dominant criterion	Reliability	Cost	Adequacy	Scalability

#### *Pure DC bus practical issues*

One of the main advantages of a DC bus structure is that it can benefit from the use of DC sources such as PV and variable speed genset directly with little losses and hardware, leading to a simple, low part count configuration.

On small system with fairly constant load, this is the perfect option. Everything can be sized to meet closely the requirements and top performances can be achieved. However, where high peaks of energy supply are required, the inverter will need to be oversized to supply them (poor efficiency at low load) or a second inverter will be required (increase of capital cost).

Scalability of the system on the DC side is practical where the generation is centralized in one point. Adding batteries and inverters is fairly easy to do assuming the inverters can be paralleled. Otherwise the inverter(s) will need to be replaced by a larger one. Large infrastructures built on the DC bus though are rather prohibitive. In fact, switchgear and protective devices for DC are more expensive and more difficult to find with the required standard approvals.

Finally, the DC only bus relies solely on inverters to provide the AC voltage so if only one unit is installed; there is no backup available.

#### *Pure AC bus practical issues*

AC has definite advantages:

- ♦ Ability to rise and decrease voltage with a simple passive device (transformer)

- ♦ Cheap and widely available switchgear equipment
- ♦ Three-phase provides rotating magnetic field for compact and efficient motors
- ♦ Frequency can be used as a control mean (frequency droop)

And since everything around us runs from an AC outlet, it is rather easy to think that running all system components on an AC bus is the perfect solution. Theoretically, this is true. However, there are many practical caveats to this option. First, having to convert all DC sources to AC and back to DC to charge batteries is not only inefficient, but involves more hardware and thus a higher capital cost and an increased rate of failure.

Additionally, all AC sources must be synchronized together. There are different means to achieve that:

- ♦ A communication bus: This allows all inverters to communicate together, however it is done at the expense (and inconvenience) of additional wires which will increase the risk of failure and prohibit geographical distribution.
- ♦ A grid-forming source: An inverter or a generator can be used to generate the AC power signal to which all the other sources will synchronize.

The second approach is very convenient but the issue in this case is to balance sources and loads in a stochastic environment where the resources can go from not-enough to more than 10 times ▷

" While analysing the advantages and disadvantages of a bus structure, one must bear in mind that the final destination of the system will modulate significantly the results "

## Bus Configurations in Hybrid Systems Part III – Practical Issues

(Cont'd from page 4)

the load. Frequency droop techniques can be used to accomplish this but will be prohibitively expensive on small units (<10kVA). Also, units relying on frequency droop cannot use anti-islanding techniques to disconnect which may rise a safety issue on distributed hybrid generation systems or systems connecting to the grid.

### AC/DC bus practical issues

As shown in Figure 2, an AC/DC bus configuration is simply a DC configuration where the AC sources are allowed to supply the AC loads directly. In this regard, this is both more efficient and less stressful on the inverter. It also offers the ability to power heavy loads from a large AC source. For example, a 150W telecom system with a genset planned to charge a 50kWh battery bank in 6 hours can also supply an arc welder for repairing the transmission tower.

### Summary

On the practical point of view, there is no single perfect approach. Remote equipments and residences will most probably be best served with an AC/DC or DC bus architecture as proposed by the classical SW series from Xantrex technologies. Small islands and villages that can be powered by a single station and eventually be connected to a large grid will also be well suited by an AC/DC or DC bus system. Island/village systems that will have multiple generation points with no connection to the grid will probably be best served by the AC approach with a grid-forming inverter. This concept has been tested by SMA with their Sunny Island at different sites. However, for the transition from one isolated system to two coupled system to a system connected to the grid to the safe islanding of a area in the grid, there is still investigation to be accomplished to develop a concept that will allow this scalability with minimum wiring and operation hassle. □

**" There is still investigation to be accomplished to develop a concept that will allow this scalability with minimum wiring and operation hassle. "**

<sup>4</sup> ENGLER, A. and al. (Kassel, Germany, September 25-26, 2003) *Next generation AC coupled Hybrid systems: 3 phase parallel operation of grid forming battery inverters*, 2<sup>nd</sup> European PV-Hybrid and Mini-Grid Conference.

## Hybrid Systems coverage at the IEEE-PES General Meeting 2004

by Dave Turcotte, CETC-Varenes

The IEEE-Power Engineering Society holds annual general meetings, featuring multiple sessions pertaining to the fields of production, transmission, distribution and transformation of electrical energy. This year, in Denver, the meeting featured more than 575 papers in about a hundred sessions over 5 days. More than 1000 persons registered for the meeting.

While stability of transmission and distribution systems grab the focus, distributed generation and remote power sources also get their share of attention. Also, considering that the intended islanding of a portion of the grid is equivalent to operating an autonomous power system, there is a place for hybrid systems in this area. This short article highlights some of the papers pertaining to hybrid systems.

A group from Politecnico di Milano presented some cost analysis for hybrid system in their paper *Hybrid Photovoltaic System and Sustainability: economic aspects* [2]. There is nothing really new in this paper, but it is of interest for comparison purposes. Also, a paper entitled *Economic Analysis and Environmental Impacts of a PV with Diesel-Battery System for Remote Villages* [5] presents some interesting economic and environmental figures based on experience with PV/Diesel hybrid systems in Alaska.

More on the technical side, researchers at Howard University reported on a neural network and genetic algorithm approach to optimize the dispatch strategy in PV systems. Their paper, *Optimal Power Dispatch of Photovoltaic System* ▷

## Hybrid Systems coverage at the IEEE-PES General Meeting 2004

(Cont'd from page 5)

with Random Load [4], could be useful for optimization work on hybrid systems.

Since hybrid systems are often remote, maintenance and reliability are an important issue. A paper entitled *Failure Rate Modeling Using Equipment Inspection Data* [1] addressing preventive maintenance of distribution equipment was presented. While not directly addressing hybrid systems, the techniques and references highlighted may be useful to systems developers and operators.

Finally, for those interested in the autonomous operation of an islanded micro-grid, the paper *Micro-Grid Autonomous Operation During and Subsequent to Islanding Process* [3] investigates the islanding behavior under different fault types on a feeder. Many other papers were covering distributed generation.

For more information on the IEEE-Power Engineering Society, do not hesitate to visit their website at:

[http://www.ieee.org/portal/index.jsp?pageID=pes\\_home](http://www.ieee.org/portal/index.jsp?pageID=pes_home). The program of the General Meeting is available online as well as some of the presentations.

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- [1] BROWN, R.E., "Failure Rate Modeling Using Equipment Inspection Data", *IEEE Power Engineering Society General Meeting*, June 6-10 2004.
- [2] IANNONE, F.; ZANINELLI, D., "Hybrid Photovoltaic System and Sustainability: economic aspects", *IEEE Power Engineering Society General Meeting Proceedings*, June 6-10 2004.
- [3] KATIRAEI, F.; IRAVANI, R.; LEHN, P.W., "Micro-Grid Autonomous Operation During and Subsequent to Islanding Process", *IEEE Transactions on Power Delivery*, 2003.
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- [5] WIES, R.V.; JOHNSON, R.A.; GRAWAL, A.N.; CHUBB, T.J., "Economic Analysis and Environmental Impacts of a PV with Diesel-Battery System for Remote Villages", *IEEE Power Engineering Society General Meeting Proceedings*, June 6-10 2004. □

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The CANMET Energy Technology Centre - Varennes (CETC-Varennes) is under the management of the department of Natural Resources Canada. This Canadian government Centre provides its customers with a solid foundation of R&D expertise. It is committed to developing technologies that use energy wisely and help Canadians stay competitive in the market place.

The Centre has two areas of technology specialization and expertise: Energy Efficiency R&D and Renewable Energy & Hybrid Systems. The latter includes the Photovoltaic (PV) and Hybrid Systems Program that is focused on the development and implementation of photovoltaic technologies for new applications, and their adaptation for use in cold climate conditions. It is concerned with the development of photovoltaic technologies that meets immediate and future market needs, domestic and international.

Two strategic approaches have been adopted in the PV Program: the accelerated advancement of PV in the Canadian marketplace and the exploitation of international market opportunities. Efforts are geared toward removing the technical and economic barriers to deployment of PV, as well as raising the profile of solar energy among potential users.

If you need further information on the Centre's PV Program or if you want to submit an article for the next issue of *Hybridinfo*, you can write an email to [hybridinfo@nrcc.gc.ca](mailto:hybridinfo@nrcc.gc.ca). □