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AC-COUPLING WITH AN XTENDER INVERTER

A white paper on the use of a grid connected inverter in an islanded system

STUDER Innotec® - April 2010

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 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 hybrid systems and minigrids.

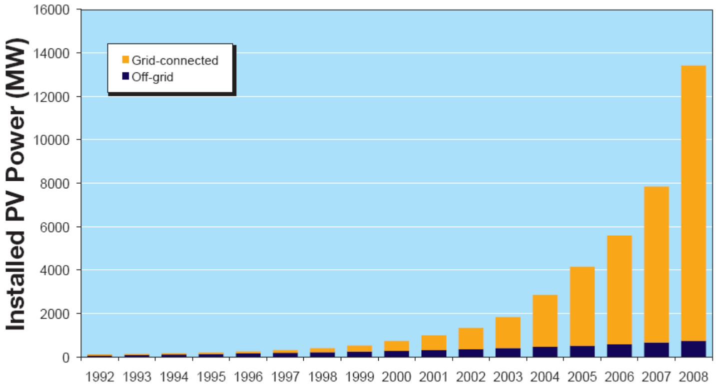


Figure 1: Installed solar power in the world
Source http://www.iea-pvps.org

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 recognizes it like a normal grid, connects to this island grid and starts to perform grid-feeding with solar power.

On the main grid all the available solar power (MPPT) is fed into the main grid to maximize the return on investment. The situation is different in a stand-alone system; 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, stopped or consumed to avoid overcharging of the batteries. This can be done with connection/disconnection of sources with switching circuits, dump loads or other control methods (communication bus ...). The control of the grid connected inverter can also be done very simply without any additional component with the frequency. This system can be realized with all the Studer inverters of the Xtender series.

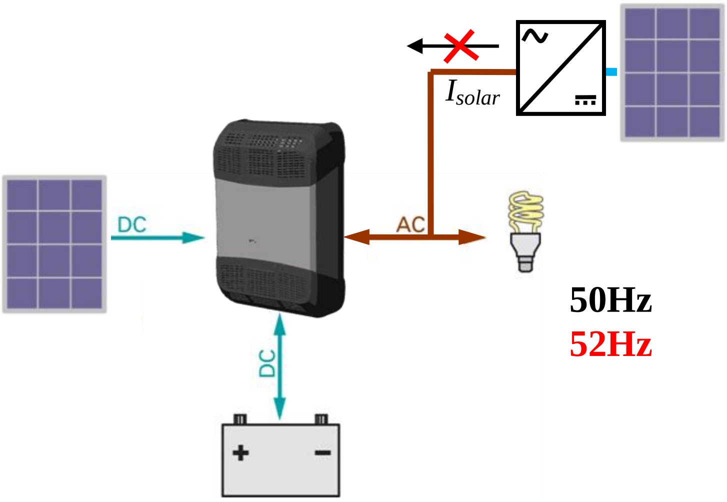


Figure 2 : AC-coupled solar inverter

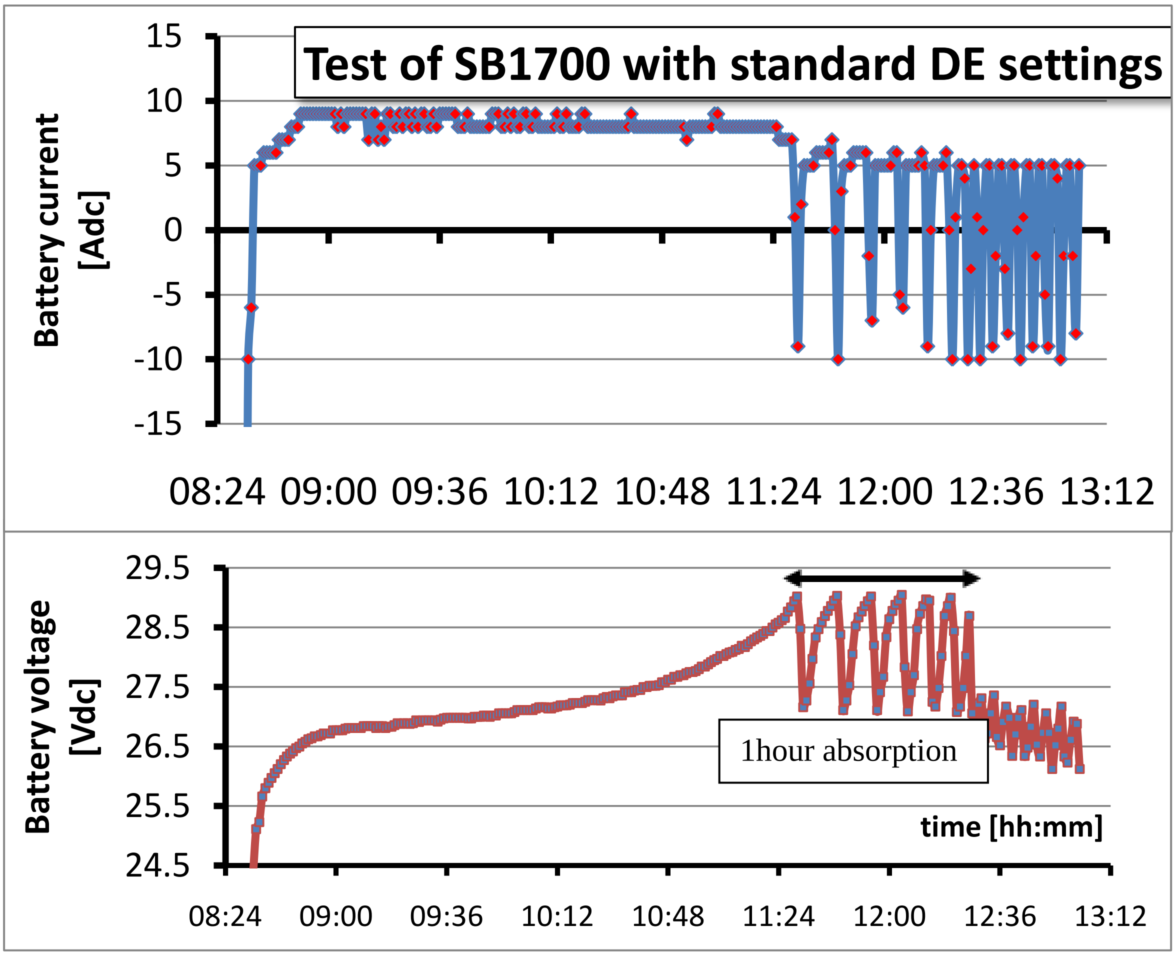
ON/OFF control with frequency

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.

This system works with different scenarios:

1. There is less solar power than user load: → the grid inverter work as MPPT and all the solar power covers a part of the load need.
2. There is more solar power than user load:
    a. The batteries are not full: → the grid inverter work at MPP and the solar power covers the user load and the excess recharges the batteries.
    b. The batteries are full: → the grid inverter is switched ON and OFF with frequency increase to make the top charge. This looks like a slow PWM.

A SunnyBoy1700 with a standard DE configuration is used below with a Studer XTM2400-24. There is a constant user load and a constant 'solar' production simulated with a DC power supply. When the grid inverter is on, the batteries are recharged (positive current on graphic below) and when off, they are discharged. The battery bank is a quite old 250Ah lead acid battery. With a datalogger function in the Xtender XTM inverter, one point is saved every minute over the day and the ON/OFF control behavior of the system can be well seen:



If the max frequency accepted by the grid inverter can be modified (it is generally the case because different countries have different regulations and different max frequencies!) and there is more than one grid inverter, it is interesting to stop one after the other, per example first stops at 50.2Hz the second at 50.5Hz. Then we can modulate the power production with two steps or more.

Frequency shift power control like MEDIUM VOLTAGE DIRECTIVE

The 2009 EEG grid code has set new requirement and one is particularly interesting for our minigrid/AC-coupling application: it is an active power reduction 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.
By changing a little bit its output frequency, the battery inverter is able to control the solar production in the island grid to match production–consumption-storage balance. It will be a more precise control instead of an ON-OFF control.

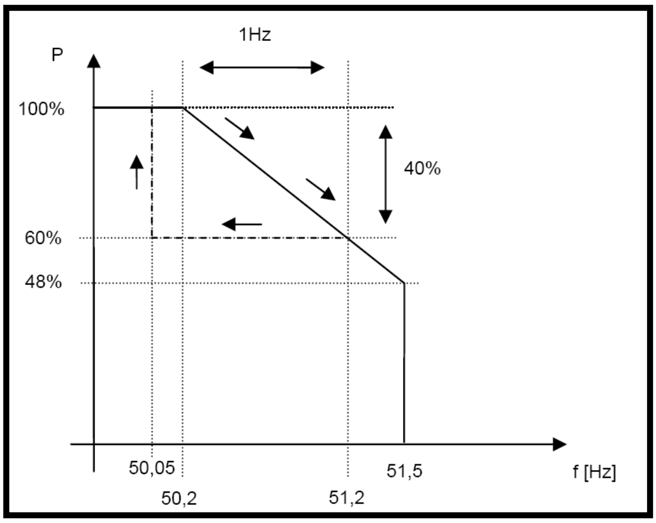


Figure 3 : Frequency dependant power reduction as BDEW in KACO solar inverter

This rule is set for medium voltage and high voltage and is not applied for low voltage yet. Technically this behavior is not very complicated to implement in the low voltage solar inverters, it is a simple modification of the control software. But up to now, the interest from the various manufacturers was low due to the small size of the offgrid market and still smaller size of the minigrid market.

But already in some inverters it is possible to activate this control even for inverters connected to low voltage 230V/50Hz line, per example on the figure left, the behavior of the Kaco Powador inverter with the parameter *'Activate BDEW'* (Medium Voltage Directive) is shown.

The power is reduced down to half from 50.2 to 51.5Hz and stopped over 51.5Hz. It is already a good improvement to control the solar inverter up to 50% with the frequency. Per example if there is 1kW load, a Powador2002 can reduce its power (nominal 1650W) down to 1kW and match exactly the power consumption. At that moment, the batteries are full and the solar produced covers exactly the loads need.

Kaco is the second most sold manufacturer on the market, and is compatible in ON/OFF or BDEW control.

Figure 4: Test bench with Kaco Powador

Full frequency shift power control

More optimal than the ON-OFF control cited above or the partial reduction of power as BDEW, is the complete linear variation of the power injected in dependence of the frequency. It requires that this control is implemented in the grid connected inverter control, which is not the case for devices of all manufacturers at the moment. When this will be widespread implemented, it will be very interesting for the compatibility of elements in offgrid systems. For the moment the only inverter we know to have this behaviour is the SMA Sunny Boy with the Offgrid settings; SB is the most sold grid inverter on the market.

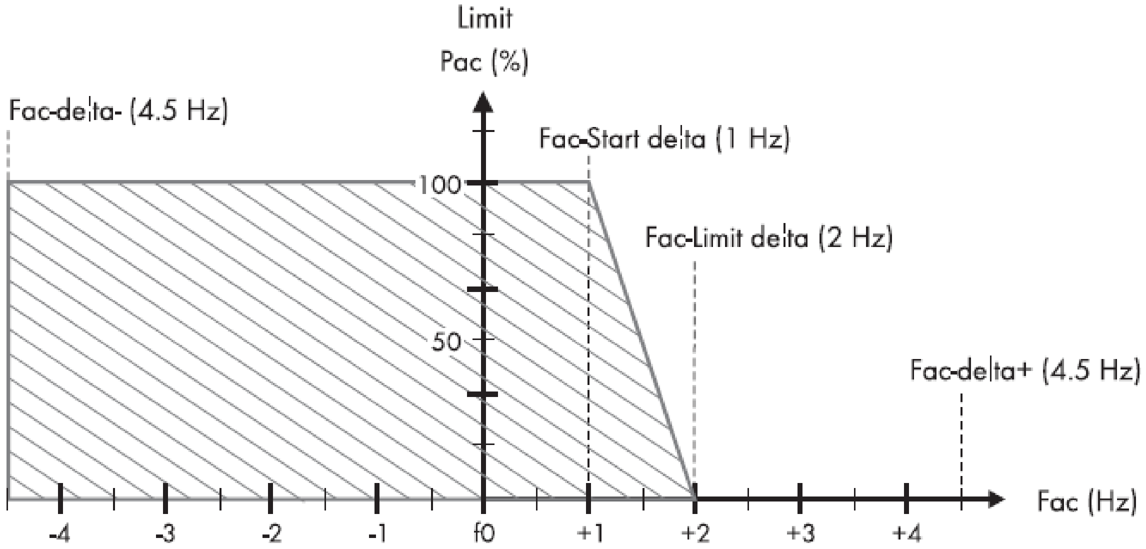


Figure 5: frequency shift power reduction as in SunnyBoy OFFGRID mode

Until the reference user frequency +1Hz the grid-feeding is to the maximum and at user frequency+2Hz the grid-feeding current is zero. Typically in a 50Hz system, the solar production is at the maximum at 51Hz or below, is half at 51.5Hz and is zero at 52Hz and over.

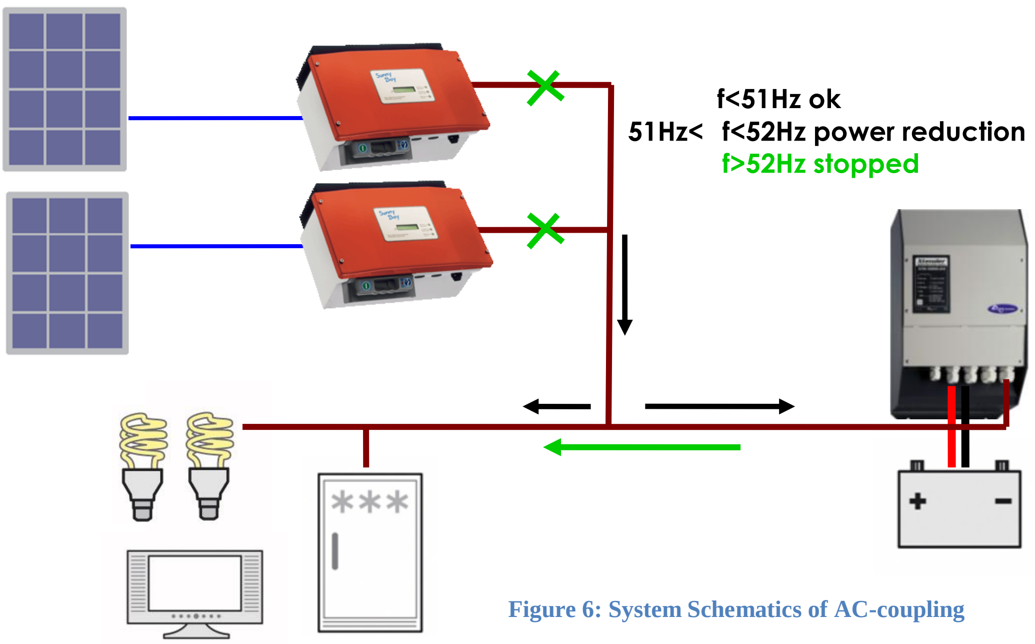
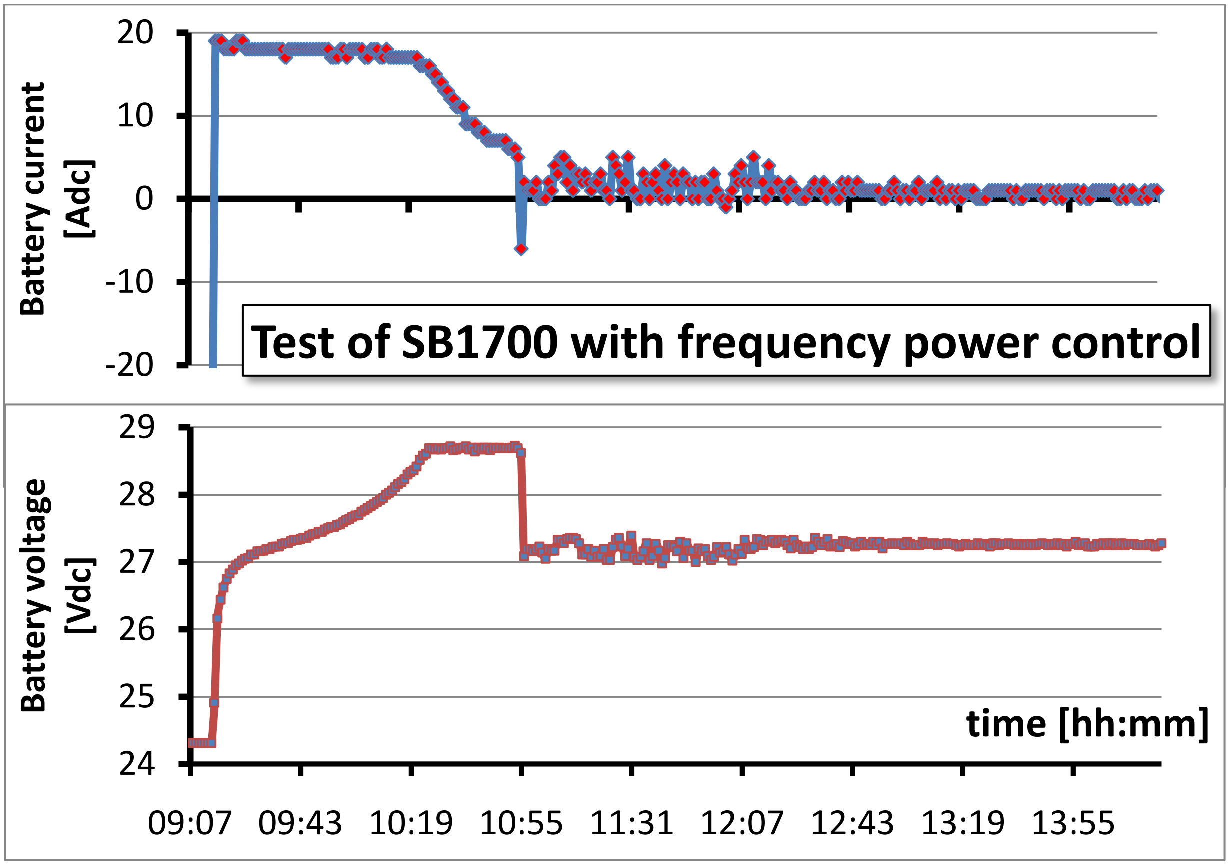


Figure 6: System Schematics of AC-coupling

Example of a charge curve with power reduction in function of the frequency: no PWM-like behavior seen. The charge curve of the battery is clean.



When there are many grid inverter stopped at different frequencies, we approach this kind of behaviour but with steps.

Threephased configuration

The system can be realised as well with threephased grid inverter, successful experiences were done with the StecaGrid9000.

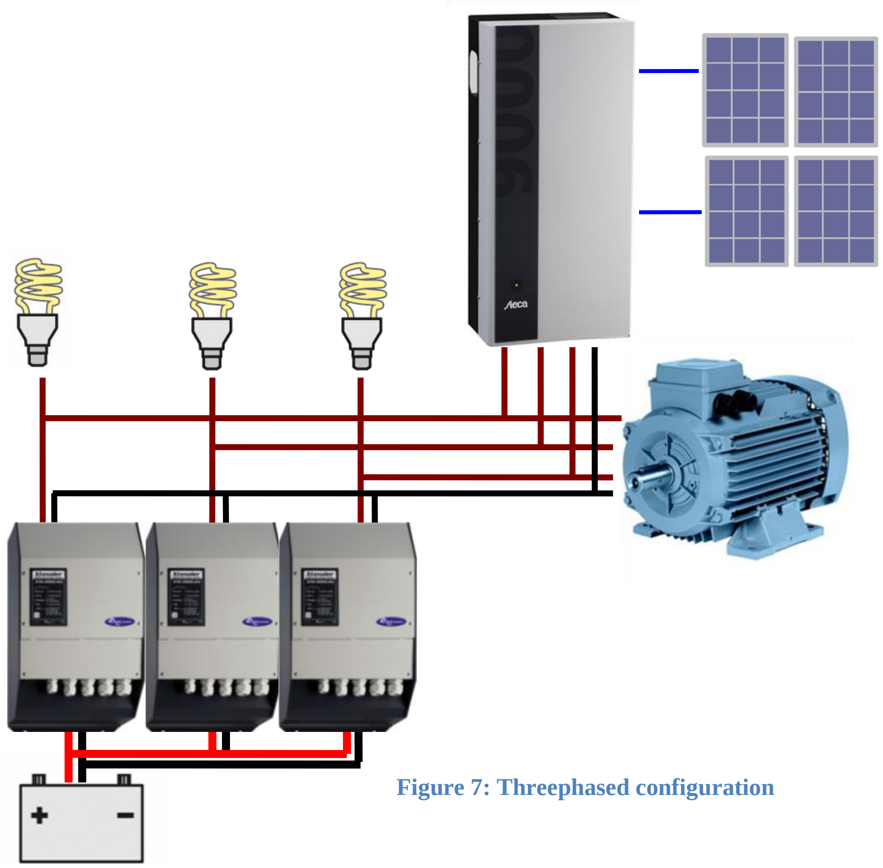


Figure 7: Threephased configuration

Photo: Steca Elektronik, Memmingen

MIXING DC AND AC COUPLING: EFFICIENCY AND ROBUSTNESS

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 that a project integrator optimizes. We will focus on the mix, because there are good reasons to make not only DC neither only AC. That is the '*Partial AC-coupling*' concept.

Considering the efficiency, AC-coupling and DC-coupling are not similar.
The power profile determines the total efficiency again:

- If there is excess solar production during the day and it must be stored into the batteries, DC-coupling has a better efficiency.
- If the solar energy is directly used, there is one conversion less with the AC-coupling.

Following computation is done to compare both cases with assumptions:

Grid inverter efficiency: $\eta_{grid-inv} \cong 0.96$
Battery inverter efficiency: $\eta_{batt-inv} \cong 0.93$
DC solar charger efficiency (with MPPT): $\eta_{batt-charger} \cong 0.95$
Battery storage efficiency: $\eta_{batt-cycle} \cong 0.8$

Energy produced by the grid-connected solar inverter must be stored for the night time. When it is given back to the user, the fraction left of the initial solar energy produced by the solar panel E_{solar} is:

$$E_{back-AC-coupled} = E_{solar} \cdot \eta_{grid-inv} \cdot \eta_{batt-inv} \cdot \eta_{batt-cycle} \cdot \eta_{batt-inv} = E_{solar} \cdot 0.664$$

Energy produced during the day by the grid-connected solar inverter is directly used by user:

$$E_{direct-AC-coupled} = E_{solar} \cdot \eta_{grid-inv} = E_{solar} \cdot 0.96$$

Energy produced during the day by the solar charger connected to DC, stored, and used later by the user:

$$E_{back-DC-coupled} = E_{solar} \cdot \eta_{batt-charger} \cdot \eta_{batt-cycle} \cdot \eta_{batt-inv} = E_{solar} \cdot 0.706$$

Energy produced during the day by the solar charger connected to DC and directly given to user:

$$E_{direct-DC-coupled} = E_{solar} \cdot \eta_{batt-charger} \cdot \eta_{batt-inv} = E_{solar} \cdot 0.883$$

Efficiency on solar energy	**DC-coupled**	**AC-coupled**
Energy stored in battery	70.6%	66.4%
Energy directly used	88.3%	96%

There is not a big difference: 3.5%, between using AC or DC coupling for energy stored in batteries, and a little bit bigger difference on the direct use during the day: 8% at the advantage of AC-coupling that avoids one conversion.

For DC-coupling, this is true only for a modern solar battery charger with MPPT included. The values are very different if the solar regulator is a traditional series or shunt. It is claimed by manufacturers that a MPPT can give up to 30% more energy during a day compared to a direct connection to a battery (if the battery is never full!). In reality experiences and publications shows that the real gain is situated between 5% and 15%.

Then the ideal case for efficiency is direct use of AC-coupled solar energy and storage for night time of the DC-coupled solar.

But practically, install two different types of solar systems, is probably not interesting. The installer will prefer a simpler system with only one connection philosophy even if there are a few little percents of efficiency to gain.

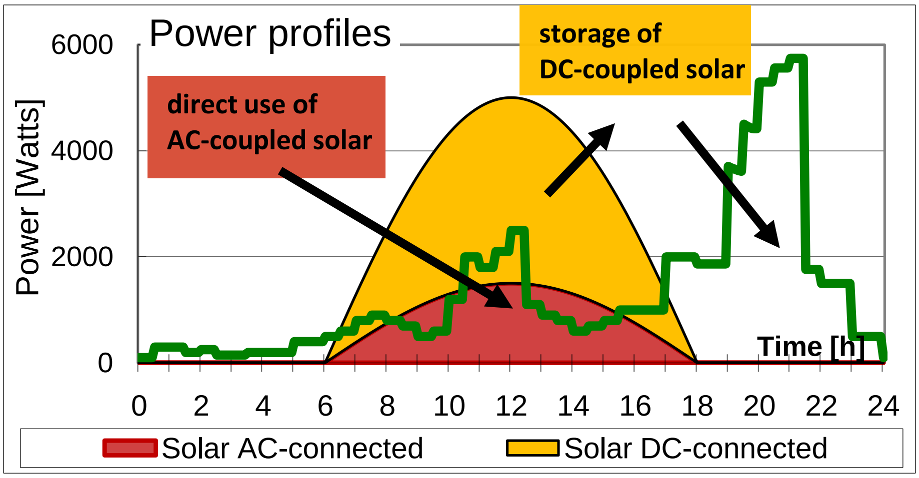


Figure 8: Split solar between AC and DC-coupling

The mix of AC and DC is interesting on another level: for the robustness of the system. If AC is not present for any reasons, the solar grid inverter cannot work. That is a weakness in the system: the solar production depends on the proper operation of the battery inverter that creates the AC; the battery charging depends on two components instead of one. Per example if the batteries are empty after a few rainy days, 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 can be blocked in this situation. If there is solar at the DC, it can recharge the batteries the next sunny day and all the system can restart again. Then we recommend having always a part of solar to DC when using AC-coupling: partial AC-coupling.

Generator

All generators have different frequency behaviors. Generally they have a natural power control with frequency as the frequency is higher at no load. But this cannot be guaranteed in all cases, depending on the type of speed controller of the genset. The effect of a grid inverter pushing power at a generator output cannot be predicted for all genset models.

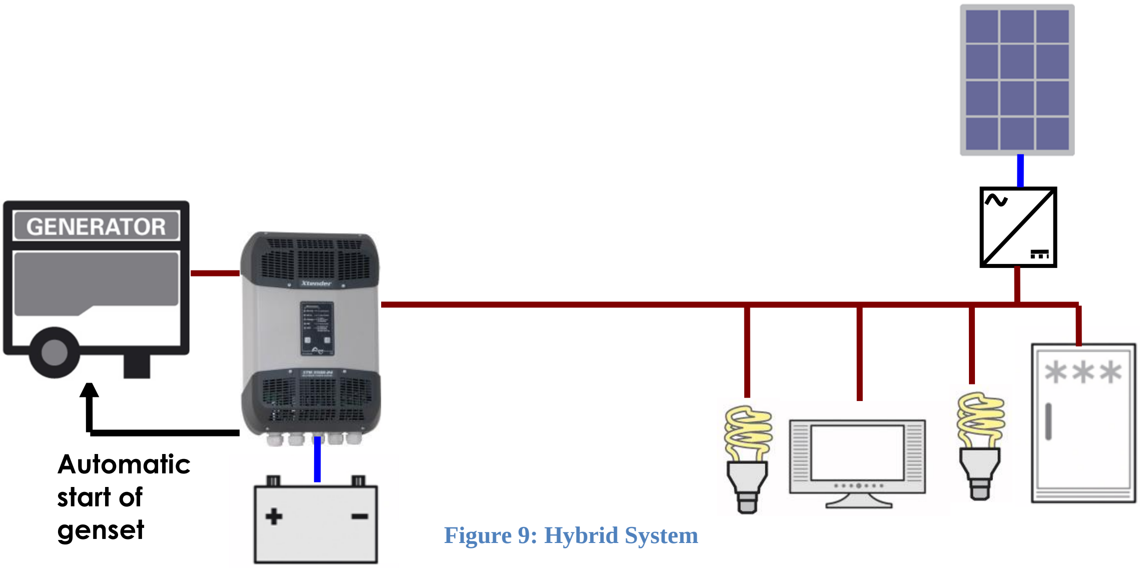


Figure 9: Hybrid System

The problem here is the interaction between genset and grid inverter. When the Xtender is connected to a source at AC-input, the charging of the batteries is always correct.
In case of doubt better install a relay that disconnects the solar inverter when connected to the generator to avoid problems. The auxiliary relay of the Xtender can perform this function with the programming on event: 1236 *Transfer relay ON (AUX1)* or 1344 *Transfer relay ON (AUX2)* connected with the C-NC connections of the relay. When the inverter goes to the generator the relay is activated and goes to C-NO.

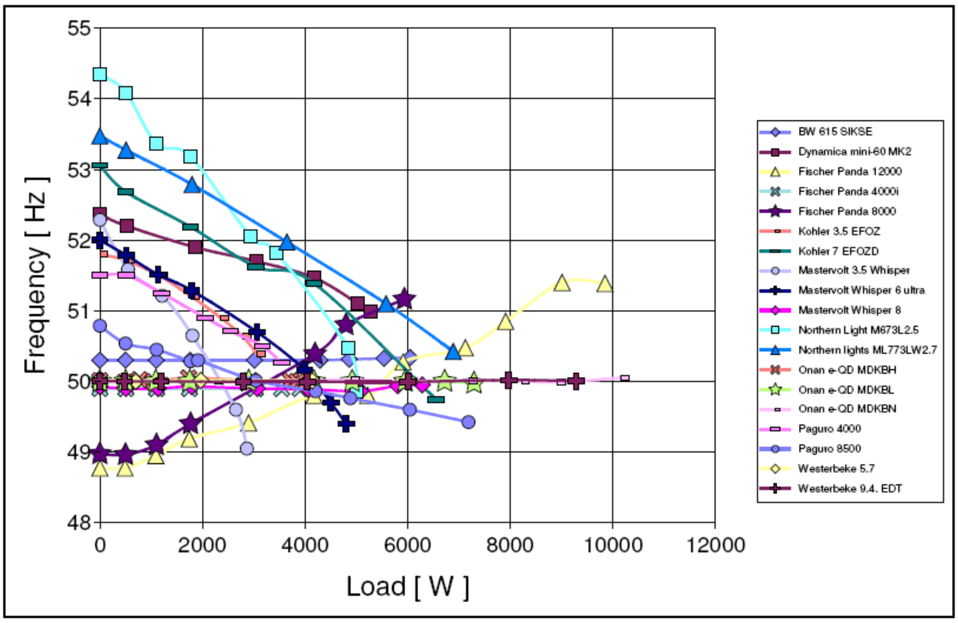


Figure 10: Frequency behavior of generators

Hybrid systems with genset are normally planned to work with some generator running time. It can be done in two ways:

- The genset is used occasionally and only starts up is in function of the battery voltage.
- The system is dimensioned for a daily use of the generator. In that case it is best to plan the start time of the genset and use the automatic start in function of the battery voltage as a security.

The optimum time to start the genset, is to use it at given time schedules, when there is no sun but user loads, ideally during the evening. It is better to make a direct used of the energy provided by the generator than running on batteries and recharging them later with that energy. With a correct time schedule, cycling of energy in the batteries is avoided, giving a gain in efficiency and battery lifetime.

The automatic start of a generator can be done with the auxiliary contacts of the Xtender inverters. Time schedules and conditions on battery status can be combined for activation of the contacts.

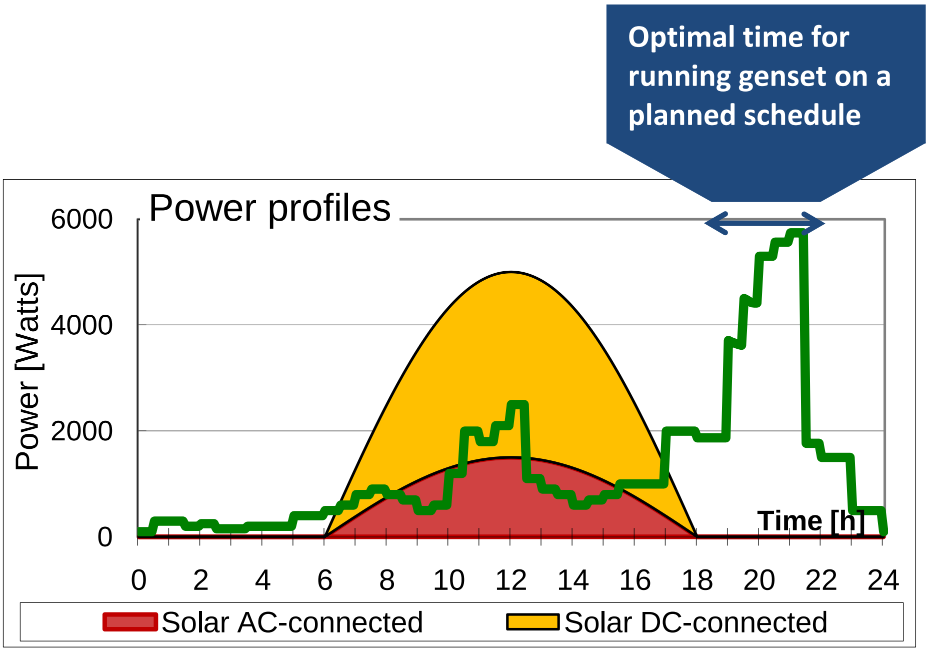


Figure 11: Best time to start a generator: when there is a load a no sun

Tests-Experiences

Practical experiments with different manufacturers of the market are shown in this document. First the stability between a grid connected solar inverter and a Studer battery inverter is tested to assess the robustness of the system. This system has been used for a quite long time in a system called Solsafe, which is a backup for a grid feeding system, see www.studer-innotec.com . Coupling battery inverters and grid connected inverter is not only theoretical but a proven concept. In the past, one problem observed was that there were often disconnections of the grid inverter because of the grid tests performed (ENS). This happens because the battery inverter has higher output impedance than the main grid. It is similar to the 'end of line' effect on the main grid. But now, smarter and more stable tests are performed to detect islanding. The new methods used allow working with standalone battery inverters as voltage source without problems.
Various tests were performed with a Studer Xtender inverter and a Solarmax S3000 together. It worked with the default settings for Germany for the S3000 without any parameter modification. Similar tests were performed with a standard SMA SunnyBoy1700 and a Kaco Powador 2002. The stability tests are: load jumps, impedance added between the units, tests of transients that disturbs the voltage and modify impedance of the line,…

Graphic hereby shows one example of the behavior of a system where a S3000 is used with a XTH5000-24 using 40 meters of 10A rated cable to connect the system together with a high impedance (approx. 1.2 Ohm). A load jump of 1kW is done by turning on a halogen lamp (which has a start current very high when filament is cold at start-up). The voltage (yellow) is distorted due to the high load on the high impedance line, but the solar inverter (current in blue) continues its work almost without noticing it.

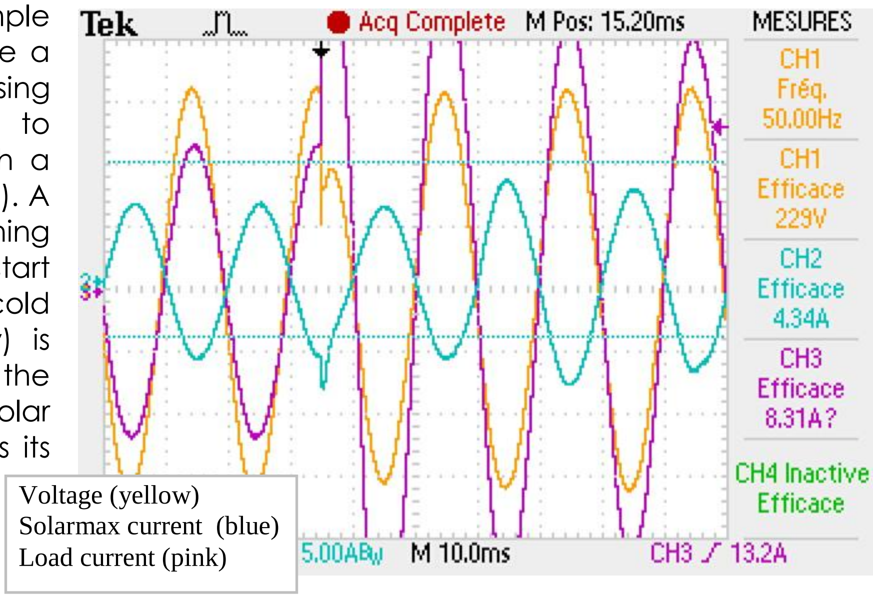
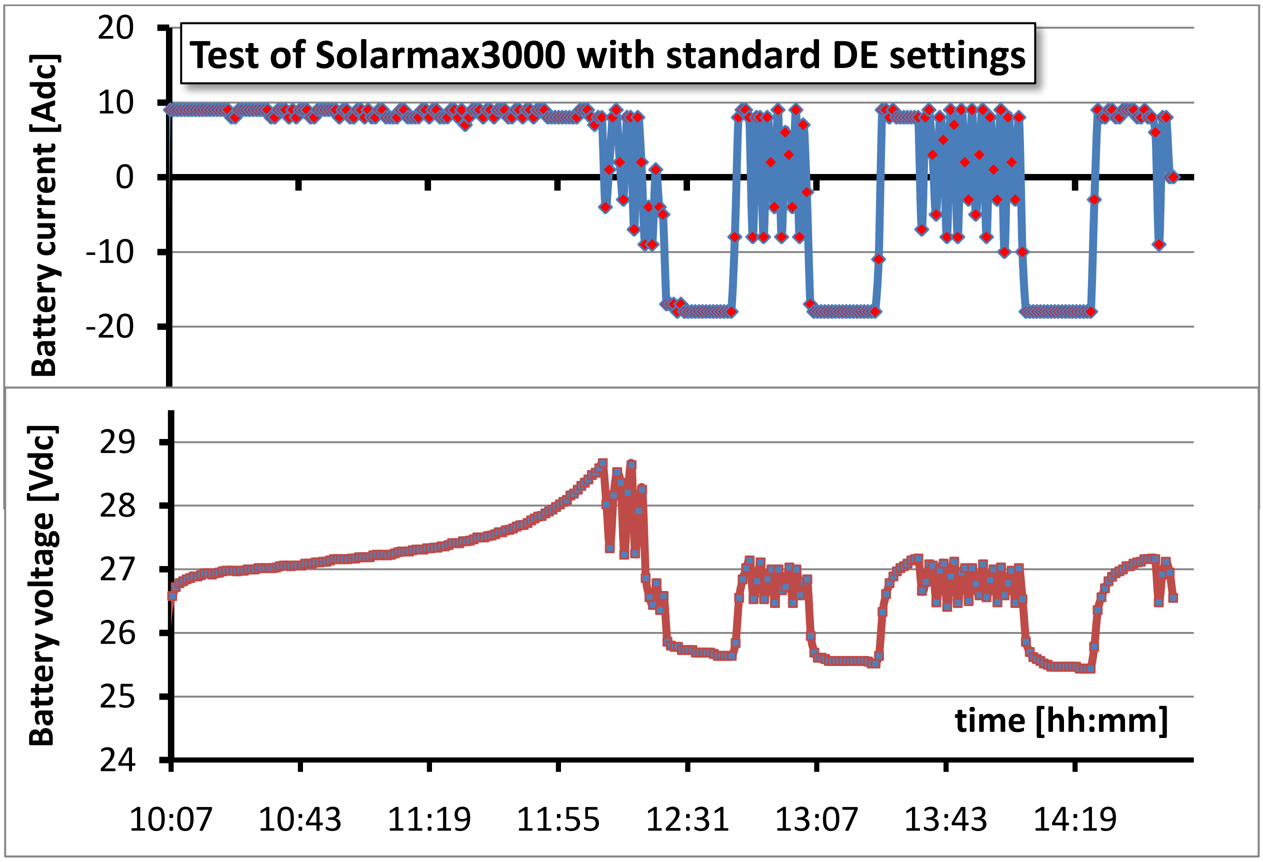


Figure 12: Big load transition on the system

Figure 13: Test bench with Solarmax S3000

All inverters don't have the same behaviour; per example the Solarmax stops 20minutes after a dozen of overfrequency errors when batteries are full:



This behavior gives a less effective use of the AC-coupled solar during the top charge of the battery.

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

- It is feasible to make AC-coupling of Studer battery inverters and grid connected solar inverters. The presented concepts are not only theoretical but were implemented and tested on real products available on the market. Many tests have been done to find out the limits and problems that can occur with the use of grid connected and standalone inverter together. Many combinations were tested and it was found robust enough to be used in the field.
- 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. Studer Xtender inverters can perform a frequency control, Studer Compact inverters must use relays (as in the Solesafe S-Box system).
- The battery inverter rated power must be equal or 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 tests work perfectly without deactivations (Solarmax S-series test, Kaco,…). Inverters with an 'Offgrid' mode are ok (Sunny Boy).
- Optimum design for efficiency is a share of the solar modules between DC-coupling with a solar charger and AC-coupling with a grid inverter according to the load profile.
- Partial AC-coupling is better in term of robustness; it is more reliable to have at least a part of the solar production connected directly to DC, or even only DC coupling.

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 and at different places. DC cable must be short and very thick because the standard battery voltage is low (12-24-48Vdc) and it cannot be used over long distances.

The advantages of the AC-coupling configuration are:

- Price/availability of the grid connected solar modules.
- Longer distance from the solar roof to the batteries is possible.
- Very good efficiency on the direct use of solar energy during the day.

AC-coupling has become very popular recently, but it is just a technical possibility not necessary the best scheme to implement in an offgrid system, as disadvantages we can mention:

- Less efficiency if energy must be stored in the batteries for the night (double conversion).
- Multi-locations of installation.
- Price/KW of a grid inverter is much higher compared to a MPPT charger. Now MPPTs with a larger input range make possible the use of grid connected modules as well.
- Dependence of the proper operation of the battery inverter to maintain the batteries → problem of robustness.

Xtender Programming

To program the frequency control with the Xtender, there are, at Expert level, parameters to control AC output frequency in function of the battery voltage:

{1549} *"Inverter frequency increase in function of battery voltage"* *Yes*

The maximum increase of the frequency is given with:

{1546} *"Max frequency increase"* *4Hz by default*

Those parameters are in the *"Inverter"* menu of the Xtender settings.

The output frequency is changed in function of the battery voltage with the following relationship:

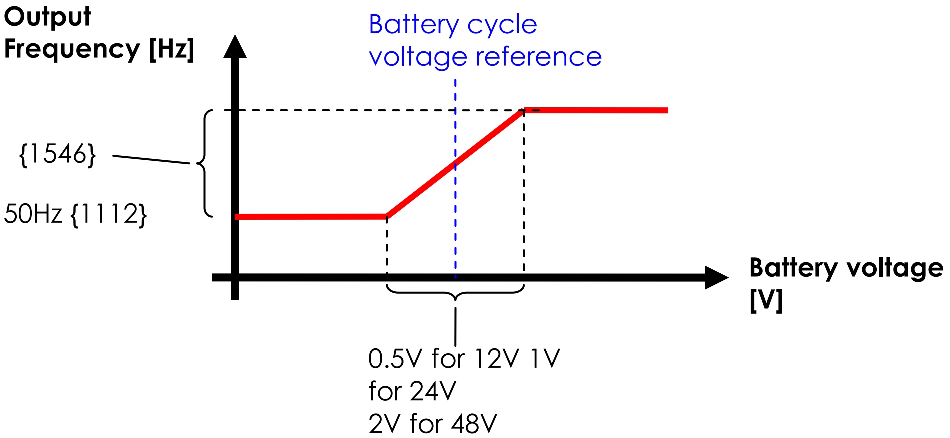


Figure 14: AC-output frequency behavior in function of the battery voltage for Xtender with param 1549

The normal user frequency given by parameter {1112} is used. But when the battery voltage comes close to the desired reference voltage of the current battery cycle state (absorption, equalisation, floating or reduced floating voltage), then the inverter increases its output frequency up to a maximal value ({1112}+{1546}). The range over which the frequency increases linearly is centered on reference voltage and is 0.5V in 12V system, 1V for 24V and 2V for 48V system.

This works the same with 60Hz, setting {1112} to 60Hz. Xtender 120V/60Hz are available.

⚠	It is important to have the two frequencies accorded: if the grid inverter stops at a given frequency, the Xtender parameter must be programmed OVER this value, per example set 50.4Hz if the grid inverter stops at 50.2Hz. For frequency shift control set the 1546 parameter *"Max frequency increase"* at two times the limit of the grid inverter, in order to have the power production completely stopped exactly at the wanted battery voltage. Per example the SunnyBoy stops at 52Hz, then parameter 1546 must be 4Hz.

ON/OFF Control

The ON/OFF control of a grid inverter can be done with a simple frequency step with the parameter:

{1536} *"Inverter frequency increase when battery full"* *Yes*

Instead of a frequency ramp, a step is done which instantly stops the grid inverter when above the targeted battery voltage. When the battery voltage comes under the floating voltage minus a given value (0.5V in 12V system, 1V for 24V and 2V for 48V system) then the frequency goes back to the initial value.

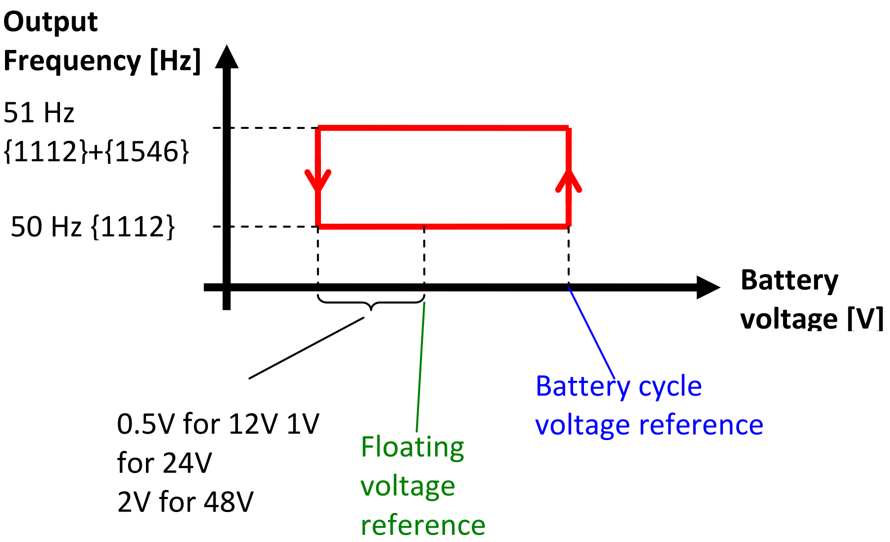
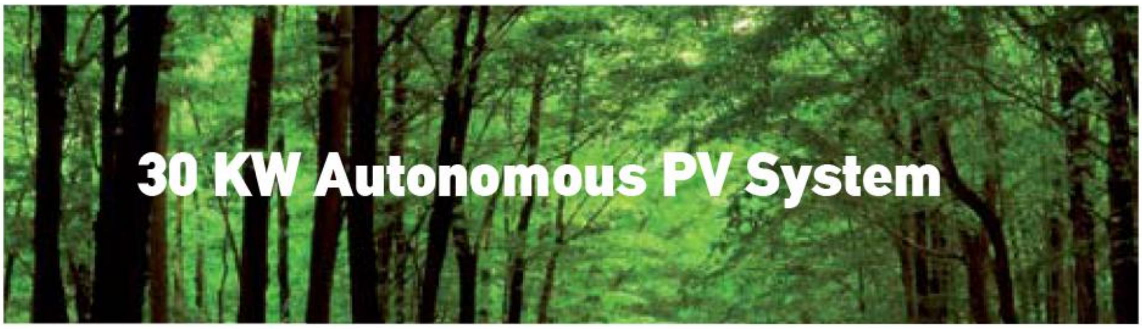


Figure 15: AC-output frequency behavior with a step when the battery is full for Xtender with param 1536

The parameters {1549} and {1536} should not be activated both at the same time, choose the most appropriate for your case.

Examples of systems

Ecosun company has good experience installing this type of standalone systems in Greece. Here are a few examples from their news (www.ecosun.gr):



A new autonomous hybrid system (30kW) was installed in the Timios Prodromos Monastery in Mount Athos.

The person in charge of the monastery had proceeded in the installation of hybrid system from ECO//SUN 10 years ago in order to cover the basic needs of lighting, heating and all remaining low consumptions. After successful use, they selected to make a radical upgrade of the system for the complete cover of all charges. The initial installation included a wind generator BORNEY of nominal force 2KW and 12 photovoltaic collectors of double crystal ASE-300Wp SCHOTT SOLAR.

The new system is three phase and includes:

- 48 photovoltaic collectors of double crystal ASE-300Wp of German company SCHOTT SOLAR
- 3 network inverters SB3300 of SMA Company
- 1 wind generator FORTIS 5KW
- 2 network inverters WB2500 of SMA Company
- 2 network inverters WB1100LV of SMA Company and
- 96 batteries PVS 2280Ah of the German company BAE
- 3 inverter/chargers STUDER XTH8000-48V
- 1 table of automatism
- Lightening Protection

The system is supplemented by a diesel generator PERKINS 50 KVA.

Three Inverter/Charger XTH8000-48V of the famous Swiss company STUDER were used for the creation of the network and the charge of the batteries of German company BAE (Lead Acid, open type, low antimony). The 96 batteries PVS 2280Ah give total stocking of 400kWh. The important and innovative in this installation is that the 3 different sources of energy, that is the STUDER appliances of total capacity 24kW that “sets up” the network, the photovoltaics and the wind generators of total capacity 20kW, as well as the diesel generator of 50kVA, are acting additive in the whole system providing the possibility of catering simultaneously electric charge up to roughly 80kW. Moreover it is worth mentioning the fact of open architecture that allows the increase or addition of new converters, increasing this way the capacity of all system. The whole operation of the system is controlled by a table of automatism which ensures the ceaseless benefit of current in the monastery.

The installation was realised by the technical department of ECO//SUN. In total 7 technicians worked for one week.

The particular system overlaps all needs of the monastery in electric energy, providing thus safety and autonomy in the monks but also in the visitors.

10kW Hybrid installation at a monastery

ECO//SUN completed with success the installation of an autonomous hybrid system for the production of electric energy from Renewable Energy Sources, in a monastery in the prefecture of Viotia (Picture 1 and 2). Due to the continuous increase of the electricity bills the monastery decided to use renewable energy sources in order to decrease its energy expenses. Moreover the frequent voltage flactuations was creating problems to the operation of the monastery. The particular region has high sunlight and wind potential which makes the use of renewables a very attractive solution for energy production.

The renewable energy system has three phases and includes a 5kW wind generator FORTIS MONTANA and a string of twenty seven (27) 175Wp KYOCERA (Japan) photovoltaic panels, giving a total installed power of 4.7 kW. The panels were placed in the roof of the monastery. Special attention was given in the waterproofing of the installation in order to avoid relevant problems in the future.

For the implementation of the system Eco//Sun installed three (3) STUDER inverter/chargers (Picture 3), which create the electric network and also charge the batteries (BAE of Germany, Vented Lead-Acid). In total twenty four (24) 12 PVS 2280 (2280Ah/C-100h, 2V) batteries were installed giving a total storing capactiy of 110 kWh (Picture 4)


Picture 2


Picture 3


Picture 4

The installation that was materialised by ECO//SUN's technical department in a hotel unit in Cephalonia, constitutes a typical solution for the cover of increased energy needs in infrastructures that are located far away from the network of the National Electrical Company (ΔΕΗ). **ECO//SUN**'s hybrid energy systems can be installed in different types of infrastructures for example rural residences or tourist units, offering ceaseless electric current.

The system is three phase and includes:

- 30 photovoltaic panels 275Wp each
- 3 network inverters 3500W each,
- 1 wind generator 10kW,
- 48 batteries 2280Ah.
- 3 inverter/chargers 8000-48V each
- 1 table of automatism
- Lightening Protection
- 5 Trackers
- 1 diesel generator 33 kVA

This hybrid energy system offers to the hotel unit ceaseless and constant electric power.
The profits for the enterprise are multiple with most important being the unhindered benefit of qualitative services to the customers, which is henceforth not influenced by the frequent voltage drops and interruptions of the network of the National Electrical Company.

PRESS RELEASE

PV Off Grid:

Off-grid electrification
thanks to Steca AC-coupling in Africa

Memmingen – Steca Solar has made a considerable contribution to promoting off-grid electrification: a new AC-coupled off-grid system has successfully begun operation in South Africa. It supplies a community centre near Johannesburg with electricity.

Photo: Steca Elektronik, Memmingen