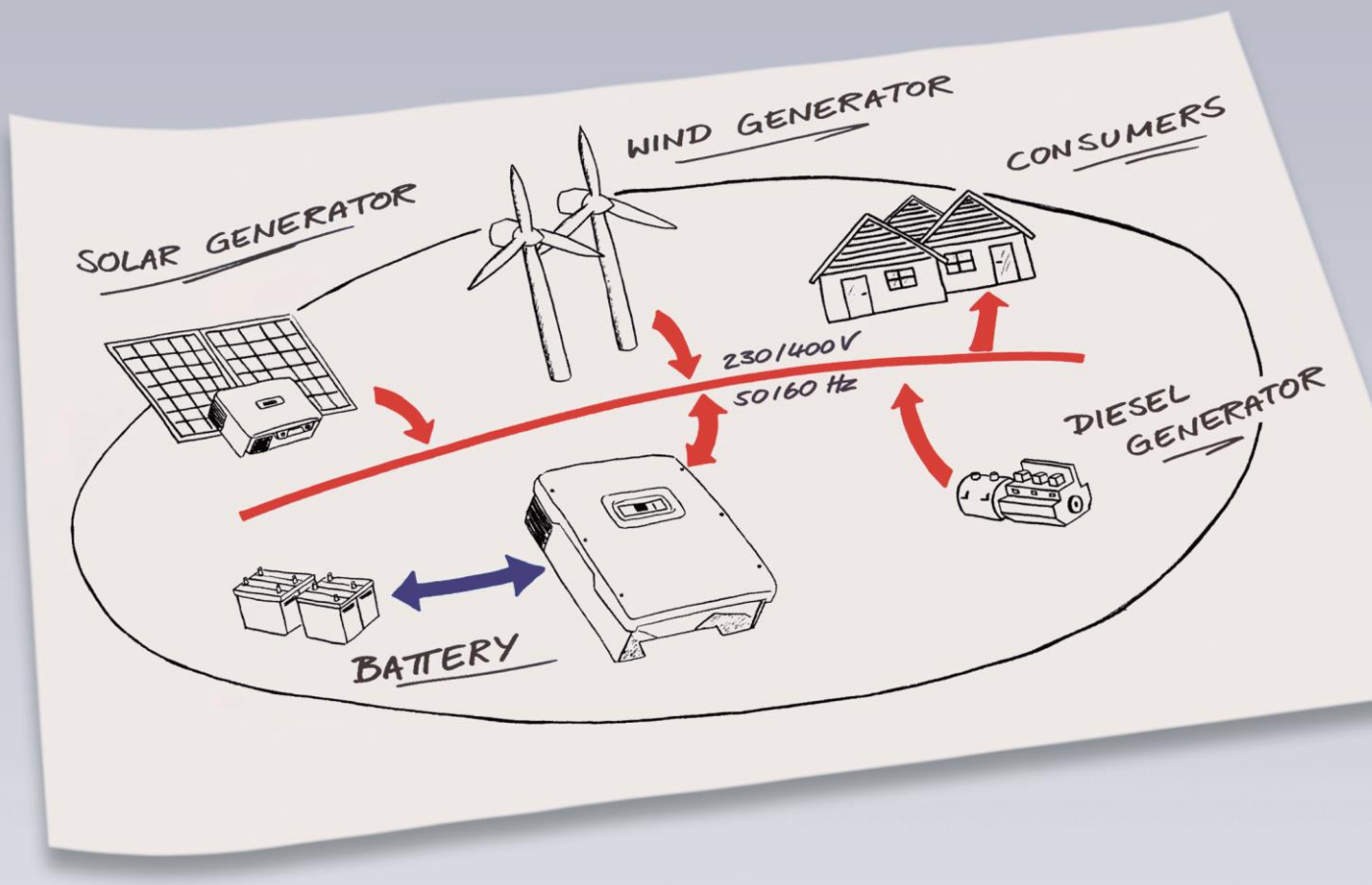
Sunny Island
Generator - White Paper



Revision History

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-11:FD0412	1.0	A	First edition	C. Allert
-11:FD1212	1.1	A	Minor corrections – format, etc.	Lisitschew/Allert
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[1]) A: Revision due to inaccurate documentation or improvement of the documentation

B: Revision assuring complete or forward compatibility

C: Revision limiting or excluding compatibility

	Name	**Date**	**Signature**
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Explanation of Symbols Used

To ensure the optimal use of this manual and the safe use of the assembly during commissioning, operation and maintenance, observe the following explanations of the symbols used in this document.

This symbol indicates a fact that is important for the optimal operation of your product. Please take note of the information in these sections.

This symbol indicates a fact which, if ignored, could result in damage to components or personal hazard. Please read these sections very carefully.

This symbol indicates an example.

Table of Contents

1 Introduction

This document describes the general conditions that must be observed to successfully select, install and smoothly operate generators in conjunction with a Sunny Island.

This document includes information on the following Sunny Island battery inverters:

- **Sunny Island 6.0H**
- **Sunny Island 8.0H**
- **Sunny Island SI5048**
- **Sunny Backup SBU5000.**

Within the context of this document, generators refer to synchronous generators generally powered by internal combustion engines, which can establish an electricity grid and therefore operate as a voltage source.

The information for installing, configuring and operating generators together with a Sunny Island can be found in the technical description for the Sunny Island.

This document lists the basic requirements in Section 3 and provides references to other sections for each requirement. Section 7 describes the basic operation of a Sunny Island in conjunction with a generator.

Sections 4 through 8 describe the aspects that must be taken into consideration when selecting a generator. Section 9 provides information on the parallel operation of generators on the Sunny Island system. Section 10 provides information that must be taken into consideration when connecting the generator. Section 11 describes special operating modes and section 12 provides help on what must be done if the system does not operate immediately.

The technical description for the Sunny Island contains more in-depth details on the individual points, in particular when and under which conditions the generator is started or stopped.

If a reference is made to a Sunny Island or the Sunny Island in this document, it naturally also refers to systems consisting of several Sunny Islands (a "cluster"), which operate in parallel on a single phase or several phases and multicluster systems.

2 Terms

Sunny Island - stands for Sunny Island and Sunny Backup here

Statics – describes a characteristic curve for operation (e.g. frequency as a function of active power or voltage as a function of reactive power)

Self-sync – describes how characteristic curves are applied to the parallel operation of Sunny Island inverters as well as with other voltage sources

Droop – also describes statics This term is generally used in connection with the generator regulation.

AVR – Automatic Voltage Regulator (on the generator)

Governor – speed control on the generator

3 Requirements for the Generator

The generator is used as an energy reserve or backup in the off-grid system. If, for example, the generated AC power (e.g., by PV inverters) is not sufficient to supply loads, the Sunny Island can tie in the additional energy from the generator into the off-grid system via the intelligent generator management.

The technical general conditions should be examined as part of the project planning for a plant with a generator. It must be determined whether the generator in question has the required characteristics and satisfies the conditions specified in this document for smooth operation in conjunction with a Sunny Island.

The following requirements must be met to successfully use a generator in a system with Sunny Island:

- The generator must establish an electricity grid during operation (→ Section 4)
  Additional points must be observed for inverter generators that establish an electricity grid during operation (→ Section 4.2))
  Generators that do not establish an electricity grid during operation – i.e., those for parallel grid operation – are only marginally described in this document (→ Section 4.3).
- The generator must have a reasonable size (→ Section 5)
- The generator is to have a contact with autostart capability (→ Section 6)
- Statics (droop) must be used for the generator regulation (→ Section 8)
  - The generator should have "soft" characteristics that are as continuous as possible (→ Section 8.4)
  - The generator regulation is to be adjustable (→ Section 8.4)

Before the project is implemented, the technical documents (documentation, characteristics, etc.) concerning the generator and the generator regulation as well as the required tools (e.g. the configuration tool for configuring the generator regulation) should be acquired to make any necessary on-site settings. This includes the idle speed and, in particular, the frequency and voltage control settings. Having knowledge of exactly how the generator's frequency and voltage control are set up has proven very helpful for commissioning a generator. Explicit access to the generator regulation parameters (P, I, D gain) is the best option to adjust the generator to the Sunny Island system if necessary.

It is wise to have contact between the generator manufacturer and SMA when designing the plant in order to prevent unpleasant surprises during commissioning.

Since generator or generator control manufacturers do not generally make the technical control data available to the public, the project/plant planner may need to request this information or encourage the generator manufacturer to contact SMA (→ Section 12.1).

4 Generator Types

With regard to its frequency and voltage, the generator used should generally behave according to the characteristics of a synchronous generator.

4.1 Synchronous Generator

The behavior of a synchronous generator refers to a load-dependent speed and a frequency that drops when a load increases. The synchronous generator increases the voltage in response to an increasing leading load. This is illustrated in Figure 4.1 and Figure 4.2.

The control requirements are described in Section 8.

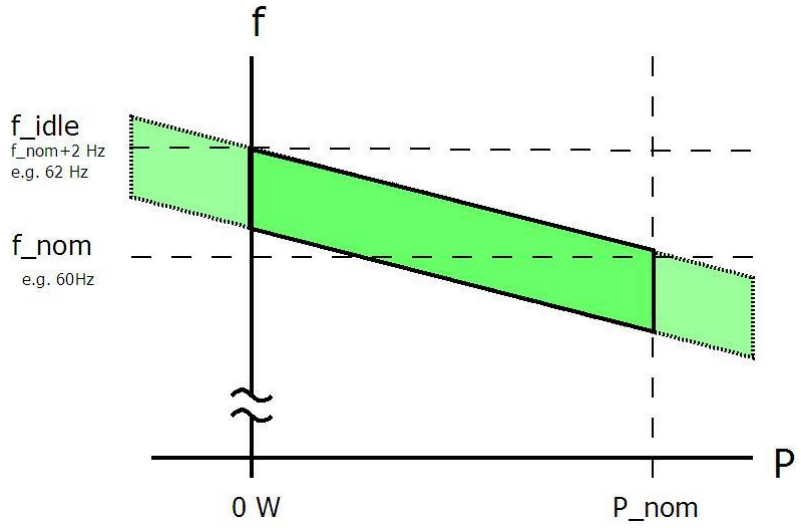

Figure 4.1: Generator behavior: frequency

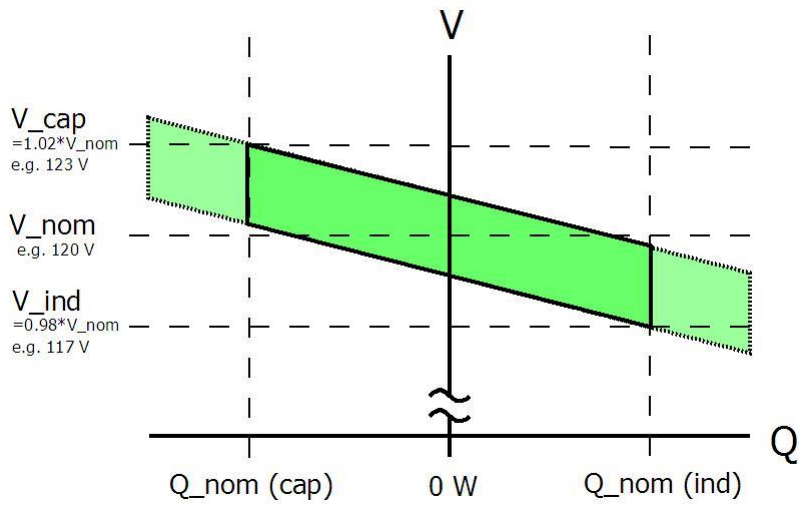

Figure 4.2: Generator behavior: voltage

4.2 Generator with Electric Energy Converter

Some manufacturers offer "inverter generators" or "generators with variable speeds" for particularly quiet and efficient operation during partial loads. The motor speed for these generators is configured so that it is perfectly matched to the electrical power drawn. Consequently, the generator powered in this manner provides a frequency and voltage that cannot be used directly to supply common loads. It must therefore be brought to the required frequency or voltage using an electric energy converter.

This electric energy converter is generally not suitable for parallel connection with other electric energy converters or inverters. However, the Sunny Island is sufficiently tolerant towards other electric energy converters that it enables satisfactory operation with inverter generators if some points are observed:

- With system configurations in which a Sunny Island can be operated in a current-controlled mode, this is the preferred setting when using inverter generators.
- From the perspective of the Sunny Island, inverter generators that are capable of absorbing the largest possible load fluctuations (including inrush currents) that can occur in the system behave as a public, rigid electricity grid. They can be operated without any problems or restrictions.
- According to the aforementioned point, you can assume that inverter generators that are very large dimensioned compared to the loads to be expected will operate smoothly.
- Smaller inverter generators can also be used, provided they have a "soft" control behavior (see Section 8.4).

In addition, it must be ensured that these generators are tolerant towards overvoltages and overcurrents, i.e. they either protect themselves by disconnecting from the system before any damage occurs or are designed so that they cannot be damaged by reverse power.

4.3 Generator for Parallel Grid Operation

Generators which do not establish an electricity grid during operation (generally asynchronous generators or generators with downstream inverters) and are used for pure parallel grid operation can operate normally on a stand-alone grid established by a Sunny Island as though they were connected to an electricity grid. There may be some restrictions with regard to the power balance in the system.

It logically follows that it should be possible to control these types of generators at the Sunny Island using the frequency, see “FSPC – Frequency Shift Power Control” in the technical description for the Sunny Island.

5 Dimensioning the Generator

A plant design with generator power corresponding to the power of the installed Sunny Island (approx. 80.. 120%) has proven meaningful (in particular, in terms of energy). (This is naturally subject to additional general conditions that must be observed for the plant to be installed and that are outside the scope of this document).

A design with more generator power than a Sunny Island offers may result in more stable operation.

Generator power that is at least twice that of the Sunny Island has proven wise for operating generators with inverters (see also 4.2).

The reactive power usually delivered by generators which establish an electricity grid during operation (cos phi of 0.8 leading to lagging) is completely sufficient for conventional systems, in particular, when you consider that a Sunny Island can supply reactive power (see also 8.3).

6 Generator Start

A Sunny Island starts and stops a connected generator automatically depending on the configuration. The common conditions for this include:

- Battery state of charge (SOC) with two possible time frames
- Generated Sunny Island power
- Full or equalization charge of the battery
- Time control for regular operation
- Manual start

The generator will also be stopped if the Sunny Island goes into error mode or a manual stop is triggered at the Sunny Island.

There are several options for remotely starting generators. A Sunny Island supports the most widely used option: dry contact as a start/stop signal. The closed contact indicates the start and operation of the generator and the open contact indicates the stop.

This means that the generator must have autostart capability that can be started and stopped using a single contact. In comparison, the generators without an autostart function are started with a crank or a cable pull.

7 Operating a Sunny Island together with a Generator

A Sunny Island operates as a voltage source just as a generator. If a generator and a Sunny Island are to be operated together, both voltage sources must be synchronized to avoid equalizing currents when they are connected. To do this, the Sunny Island measures the generator voltage. The Sunny Island synchronizes the frequency, voltage and phasing in the stand-alone grid provided by the Sunny Island with the generator. If both sources (generator and Sunny Island) are synchronized, the connection is established.

Now, the power of both sources must be distributed to the loads. Sunny Island assumes this task. The Sunny Island measures the current generated by the generator and loads or decreases the load of the generator according to the settings (generator current limitation). Since the Sunny Island operates in two directions, the battery can be used to place a load on the generator in order to charge the battery or decrease its load by reducing the charge rate. In the same context, the Sunny Island can also support the generator by discharging the battery. Of course, this can only be carried out within the limits preset by the installer, such as max. battery charging current, nominal inverter current.

During transient processes (switching operations), the Sunny Island uses the integrated, self-synch mechanism. In this case, the power is distributed between several sources (several Sunny Island devices and also parallel to a generator) by using statics (see Section 8.3). These statics are based on the common behavior of synchronous generators, for example, that brake in response to loads, which is indicated by the lower speed in a lower frequency. If the voltage sources that are connected in parallel exhibit this behavior, a joint operating point is created that ensures the power is suitably distributed.

This also applies to how the voltage behaves during a load with reactive power (voltage increase with leading load).

7.1 Sunny Island Operating Procedure for operating with Generator

The following phases are important when operating the generator. The Sunny Island is equipped with an internal generator control for this, which is represented as a finite state machine.

- Start – the generator is started by the generator control of the Sunny Island. It is signaled by the dedicated multi-function relay at the Sunny Island. The generator starts and supplies voltage at its output.
- Stop – the Sunny Island triggers the multi-function relay so that it deactivates and thus signals the generator to stop. The generator stops.

- Warm – this phase serves to warm up the generator. The Sunny Island warms up the generator for a configurable time before the generator is synchronized with and connected to the stand-alone grid.
- Lock – after the generator has been signaled to stop, the repeated generator request via the multi-function relay and the automatic connection to an externally started generator are suppressed for a configurable time. This helps operate generators that are equipped with an integrated shut-off delay function.
- Cool – this is the phase when the Sunny Island reduces the generator load via the control and then generally disconnects all generator loads and lets the generator continue to run for a configurable time.

The behavior of generators equipped with an advanced generator management system must be observed. Here, the times for the individual functions must be appropriately adjusted.

Generators with integrated contactor frequently output line voltage at their output only after their warm-up time has expired. A Sunny Island expects the generator to output voltage at the latest 2 minutes after it starts. To ensure smooth operation, the generator's internal warm-up time should be switched off or reduced as much as possible and the warm-up time of the Sunny Island's generator control should be used.

7.2 Sunny Island Protective Functions for operating with Generator

Generator Overload

A Sunny Island has a function for limiting the set nominal generator current as well as other optional protective functions to prevent a generator from overloading. This is achieved by observing the set nominal generator frequency (with nominal power). If the frequency falls below this value, the Sunny Island reduces the generator's load (reduction of the battery charge through to discharge operation and up to the max. nominal power of the Sunny Island).

Reverse Power in the Generator

A Sunny Island also features an integrated function that protects the generator from reverse power coming from the stand-alone grid. This reverse power is used to power the generator and the motor, just as the motor of a vehicle that is rolling down a hill.

Over the short term, this state is not critical for the motor of the diesel generator. We recommend checking the generator documentation for the maximum permissible times and outputs and if necessary, adjusting the parameters in the Sunny Island accordingly.

Reverse power usually occurs in the generator when there is another energy source other than the generator in the system. This can include, for example, a PV plant that supplies the stand-alone grid. In case a load is disconnected, there is suddenly excess energy available in the system. This generally flows to the battery. If the battery is fully charged at this time, it can only absorb some of the energy or none at all. The excess energy then ensures that the generator's load is reduced until the energy flow switches direction.

This state can be prevented by using the FSPC function – Frequency Shift Power Control. Here, cleverly configuring the corresponding settings in combination with setting the generator's idle frequency and the nominal frequency of the stand-alone grid is helpful. This ensures that the generator's idle frequency regulates the PV feed-in to 0, for example.

Alternatively, the PV power can be partially or completely switched off, for example, to prevent this state.

A Sunny Island has an adjustable reverse power monitoring system that disconnects the generator if reverse power is detected.

The set power and time for when the value is exceeded must be in line with the generator documentation.

8 Generator Regulation

For the generator connection displayed here, the respective generator must operate as a voltage source and be capable of establishing an electricity grid and supplying loads.

With regard to its frequency and voltage, the generator used is to generally behave according to the characteristics of a synchronous machine (see also 4.1). The corresponding characteristic curves are displayed in Figure 4.1 for the frequency and in Figure 4.2 for the voltage.

The generator is internally and separately controlled according to the voltage and frequency. You can find additional information for regulating the voltage in Section 8.1 and the frequency in Section 8.2.

The generator regulation is to ensure that the generator frequency and generator voltage each remain in a corridor, as displayed in Figure 4.1 and Figure 4.2. The graphics display the areas in which the generator frequency and voltage are to be located with the various loads - during rated operation (dark green) and beyond (light green). Ideally, the behavior is to be linear. As long as the characteristics are not discontinuous, the requirement for stable operation is still satisfied. Figure 8.1 and Figure 8.2 illustrate suitable behavior and Figure 8.3 and Figure 8.4 illustrate unsuitable behavior for the frequency. The same applies to the voltage.

A setting option (in particular, on-site during commissioning) has proven very helpful. The documentation for the regulation and tools (e.g. software) should therefore be available for any required adjustments during commissioning.

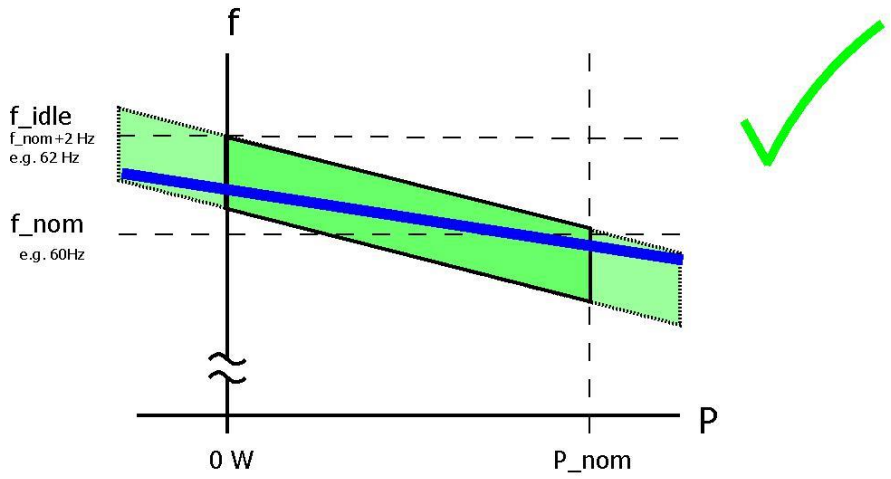

Figure 8.1: Generator behavior: frequency – linear – suitable

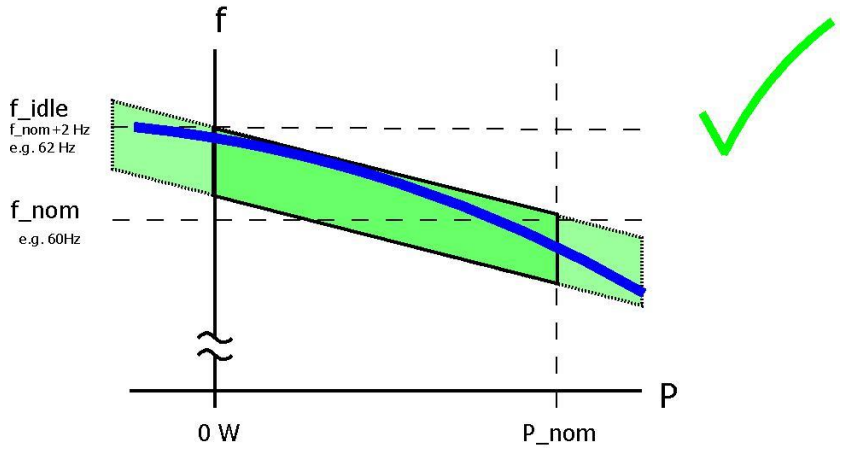

Figure 8.2: Generator behavior: frequency – continuous – suitable

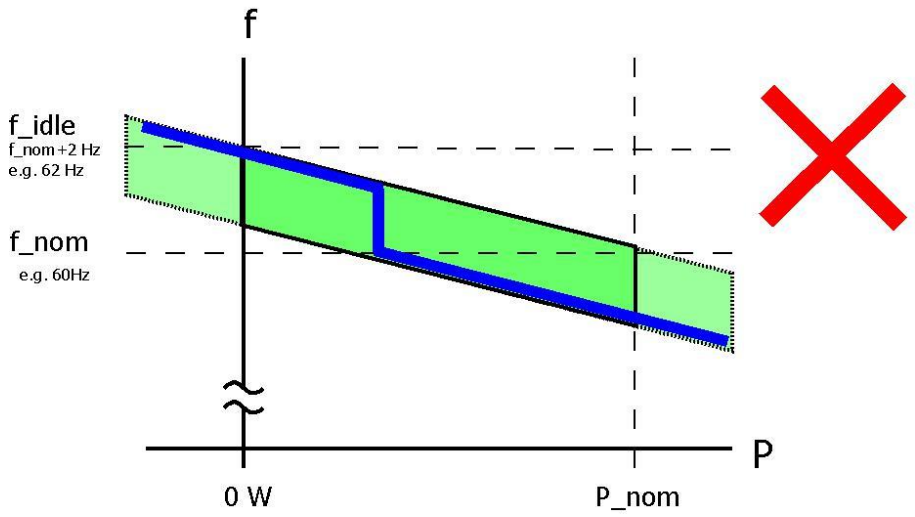

Figure 8.3: Generator behavior: frequency – discontinuous – not suitable

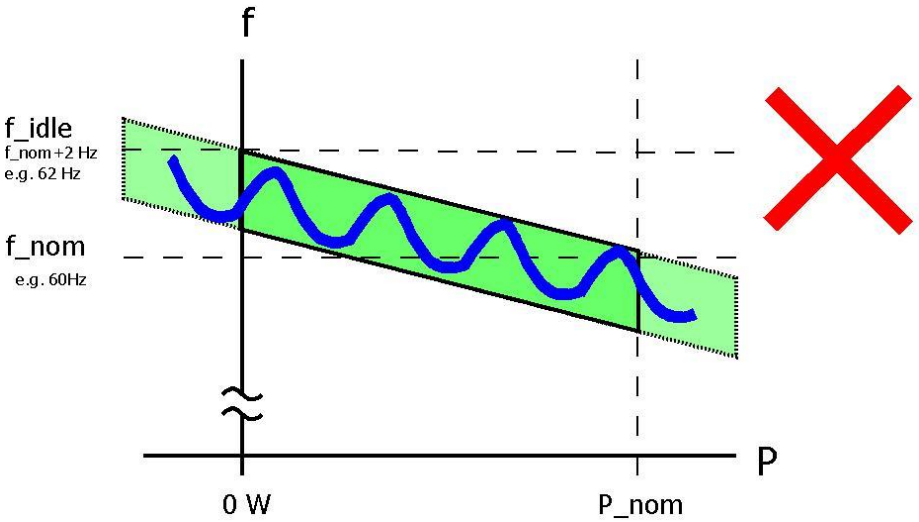

Figure 8.4: Generator behavior: discontinuous frequency – not suitable

If generators have different characteristics, it may lead to instability in the network with the Sunny Island. See Section 8.4 for a description.

"Soft" regulation behavior is highly compatible with the Sunny Island regulation. This also allows older generators or a simple proportional regulation to be effectively used with the Sunny Island.

8.1 Voltage Regulation

The generator regulates its voltage to a preset nominal voltage using the automatic voltage regulator (AVR) or depending on a characteristic curve. The generator's behavior (synchronous generator) must be observed depending on the generated or absorbed reactive power (voltage increase with leading load). This distributes the reactive power between sources connected in parallel during operation (several generators or the Sunny Island). The voltage is regulated at the generator by varying the excitation voltage.

This allows the voltage to be quickly regulated at the generator, since there are no mechanical time constants to consider here. This generally makes it considerably faster than the frequency regulation.

8.2 Frequency Regulation

The generator frequency is determined by the speed. The motor speed is regulated by the governor. It generally has a fixed speed (target frequency) or a load-dependent speed/frequency.

The frequency regulation at the generator must always take into consideration the generator's mechanical time constants (inertia). This generally makes it considerably slower than the voltage regulation.

8.3 Generator Regulation using a Sunny Island

The regulation aim for a Sunny Island when operating with a generator is to deliver the total active power through the generator where possible and to deliver the total reactive power for the connected loads through a Sunny Island where possible. If possible, the battery is to be charged with maximum charging power. The reason behind this is to make optimum use of the generator and as a result, limit the generator running time (keyword: fuel consumption) to the required extent.

- A Sunny Island regulates its frequency within the limits so that the active power is provided by the generator during stationary operation.

- A Sunny Island regulates its voltage within the limits so that the reactive power is provided as much as possible by a Sunny Island and that the generator only delivers active power, where possible, during stationary operation.

- It is also generally possible to operate generators that do not supply reactive power. In this case, a Sunny Island must supply all of the reactive power (in particular, temporarily). It strongly depends on the loads to be supplied.

During operation, a Sunny Island measures the generator voltage and the current generated by the generator. The Sunny Island takes into consideration a configured current limit (for the generator) and the power absorbed in the battery is reduced if necessary or the generator is supported by feeding in power from the battery to prevent the generator from being overloaded.

A Sunny Island or Sunny Backup uses the self-sync mechanism illustrated in Figure 8.5, also referred to as droop, for distributing the load of inverters connected in parallel and for parallel operation with the generator. The more precise the generator behavior corresponds to these statics, the more uniformly the power supplying components (i.e,. generator and the Sunny Island) are involved in the sudden load variation.

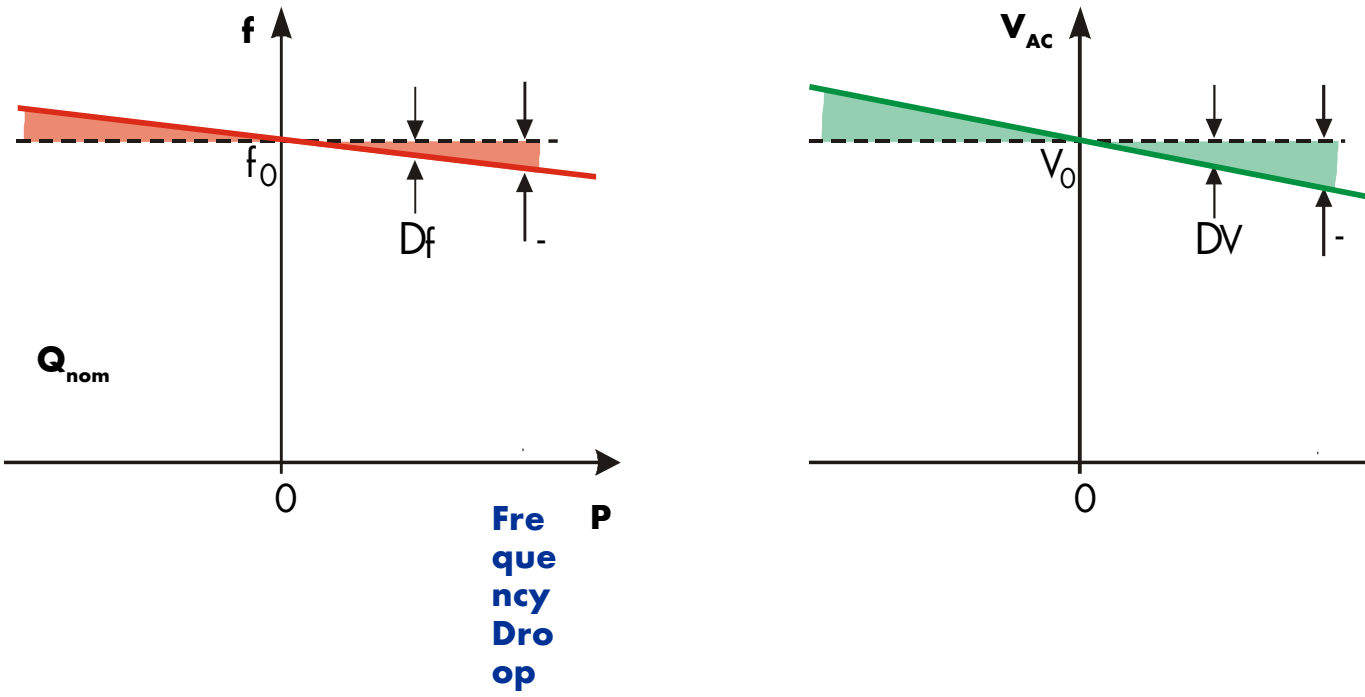

Figure 8.5: Self-sync - droop

As you can see, generators that keep their voltage and frequency stable must absorb all of the load changes. If they are not capable of this, it may lead to regulation disturbances.

8.4 Known Problems and their Solution

Systems consisting of one Sunny Island and generator may tend to vibrations under certain circumstances.

If the generator has a characteristic curve that reverses the desired behavior, i.e., for example, a frequency higher than the idle frequency is generated when loading the generator, this generator does not operate with a Sunny Island. No stable operating point is established. It leads to instabilities and vibrations.

Generators with discontinuities and non-linearities in the characteristic curves are only poorly suitable or not at all for operation with a Sunny Island.

Generators that have very stable frequencies and voltages ("rigid") tend to present problems. These generators frequently have a regulation whose time constant is comparable to those in the Sunny Island. This state tends to cause vibrations.

If the generator regulation has a D gain, it also promotes vibration.

With very small and simple generators that have nominal power of only a few 100 watts, the regulation fluctuations in the reactive power have overproportionately strong effects so that stable operation cannot be achieved over the long term.

A setting option for the generator regulation with regard to voltage and frequency (in particular, on-site during commissioning) has proven very helpful to eliminate any problems. The documentation for the regulation (regulation structure and P, I and D gains) and the tools (e.g. software) should therefore be available for any required adjustments during commissioning.

In particular, it does not make sense to adjust the entire Sunny Island system in the way it is regulated to the generator, since it has already been precisely matched to load behaviors, battery regulation, regulation of connected PV, parallel operation, etc.

9 Operating several Generators on Sunny Island Systems

A Sunny Island's regulation structure is designed for parallel operation. However, the Sunny Island cannot start and synchronize more than one generator on its own – generator request relay function. The function for the staggered starting and synchronizing of several generators, for distributing the loads between them and for stopping several generators must be configured externally for the Sunny Island.

If the available generator power is variable, e.g. because generators of varying sizes can be started, the value for the generator current limit must be adjusted respectively in the Sunny Island. Of course, the easiest way to do this is manually (manual switchover between the generators used), using a control on the device (via the operating menu) or by adjusting a parameter via serial communication using SMA data (e.g. using a Webbox, etc.).

If several generators are to be simultaneously operated on the Sunny Island, they must first be configured with each other for parallel operation. In particular, this refers to the generator regulation. It must support parallel operation, start and stop the generators according to the corresponding criteria and manage the actual parallel operation, i.e., distribute the active and reactive power between the generators.

All the requirements specified in this document for operating a generator on the Sunny Island of course also apply for the parallel operation of several generators on the Sunny Island.

10 Generator Connection

A Sunny Island is generally installed so that the connected loads are protected against indirect contact by a residual-current device (RCD). To achieve this, the star point of the source, the neutral conductor of the off-grid system near the Sunny Island installation is connected with ground to rule out any loop impedance.

If a generator is connected to such a system, the generator's star point is usually also connected to the ground. This does not present a problem as long as the generator output is not protected by the RCD. It is generally triggered when the Sunny Island and the generator are connected (Multicluster Box).

RCDs should only be arranged in the outputs for the loads.

11 Special Operating Modes of a Sunny Island together with Generators

In addition to normal operation for a Sunny Island, there are also special emergency charge and manual operation modes.

11.1 Emergency Charge

A Sunny Island cannot provide voltage with full amplitude with a deeply discharged battery and may no longer synchronize with an existing electricity grid or generator. Using the emergency charge mode (ECM), it is possible to charge the batteries in current-controlled mode. The exact procedure is described in the Sunny Island manual under Troubleshooting.

Please observe the information for small generators in Section 8.4.

11.2 Manual Operation

If a generator is started manually, directly at the generator, the Sunny Island detects this through the generator voltage measurement. The generator's sequential control integrated into the Sunny Island starts and ensures that the Sunny Island connects to the generator and that the batteries are charged. The Sunny Island remains connected to the generator until it is manually stopped (at the generator). The Sunny Island detects when the generator stops, disconnects the connection and supplies the loads from the battery.

If the Sunny Island should not be allowed to connect to the generator that is manually started, the generator control must be explicitly set to stop using the control. This may be wise if the generator is to be repeatedly started and stopped for testing purposes or only used for directly supplying a load connected to the generator.

12 What to do if the Generator and Sunny Island do not operate immediately

12.1 What can I do myself?

We are of course happy to assist you in rectifying any problems if a generator does not operate correctly with a Sunny Island system. Unfortunately, our experience in the past has proven that generator manufacturers are not very willing to provide us with the necessary information, since we have not purchased the generator ourselves.

Here, you as a buyer are in a considerably stronger position. Contact the generator manufacturer and firmly request that he provide you with detailed information on all setting options, in particular for the AVR. We can only efficiently provide you with fastest support possible with this information.

If required, a behavior as described in Section 8.4 can be achieved by setting the governor(s).

12.2 When should I contact SMA and what Information is required for this?

Contact SMA if the above measures for adjusting the generator have not been successful.

If you have questions on how the regulation functions or the generator operates, please contact SMA.

To effectively help you, we usually require at least the following information:

- Plant configuration
- Generator manufacturer and type
- Generator governor manufacturer, type and configuration
- Connected loads
- Observed behavior where possible
- Measured and/or recorded data where possible