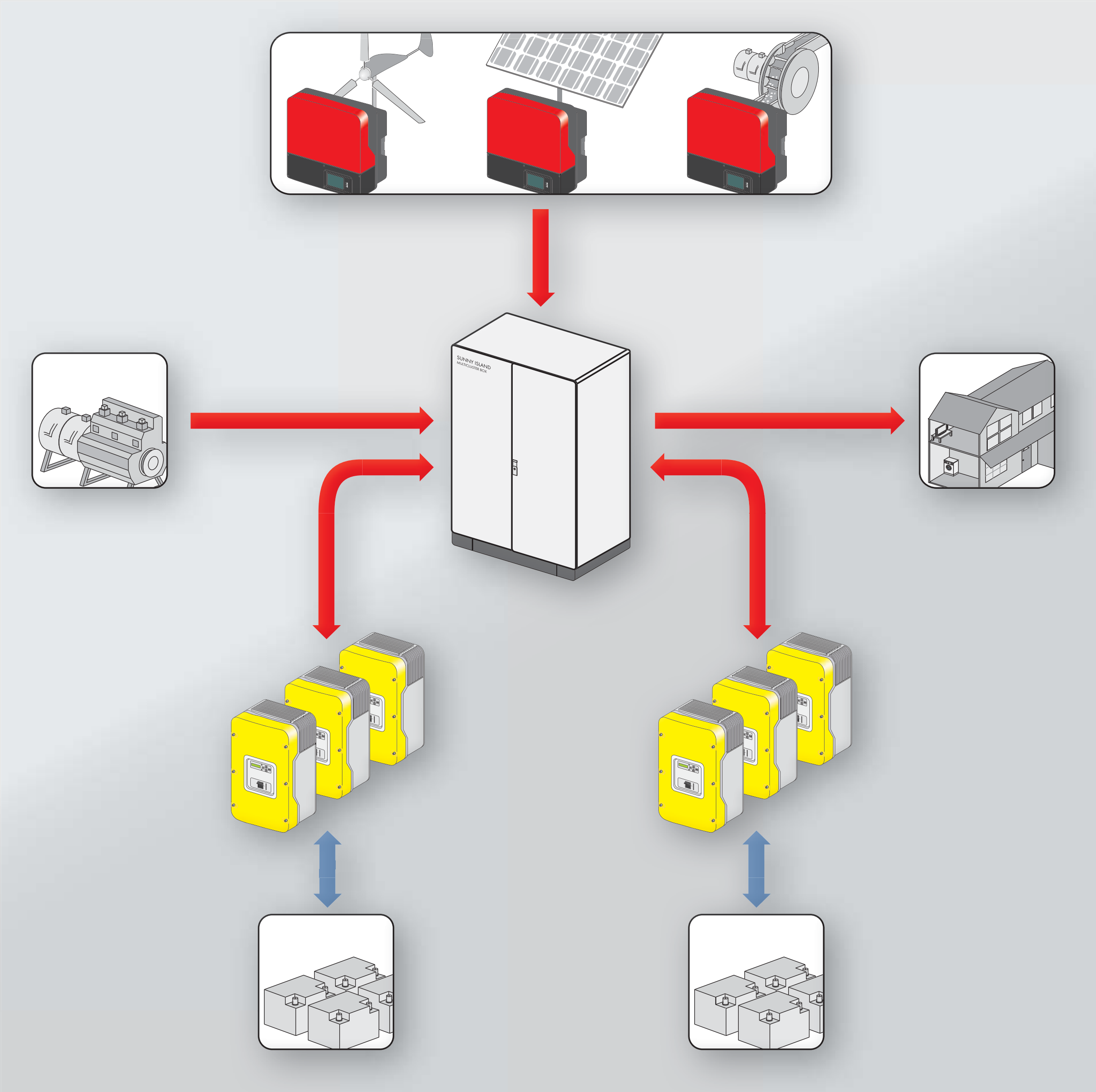
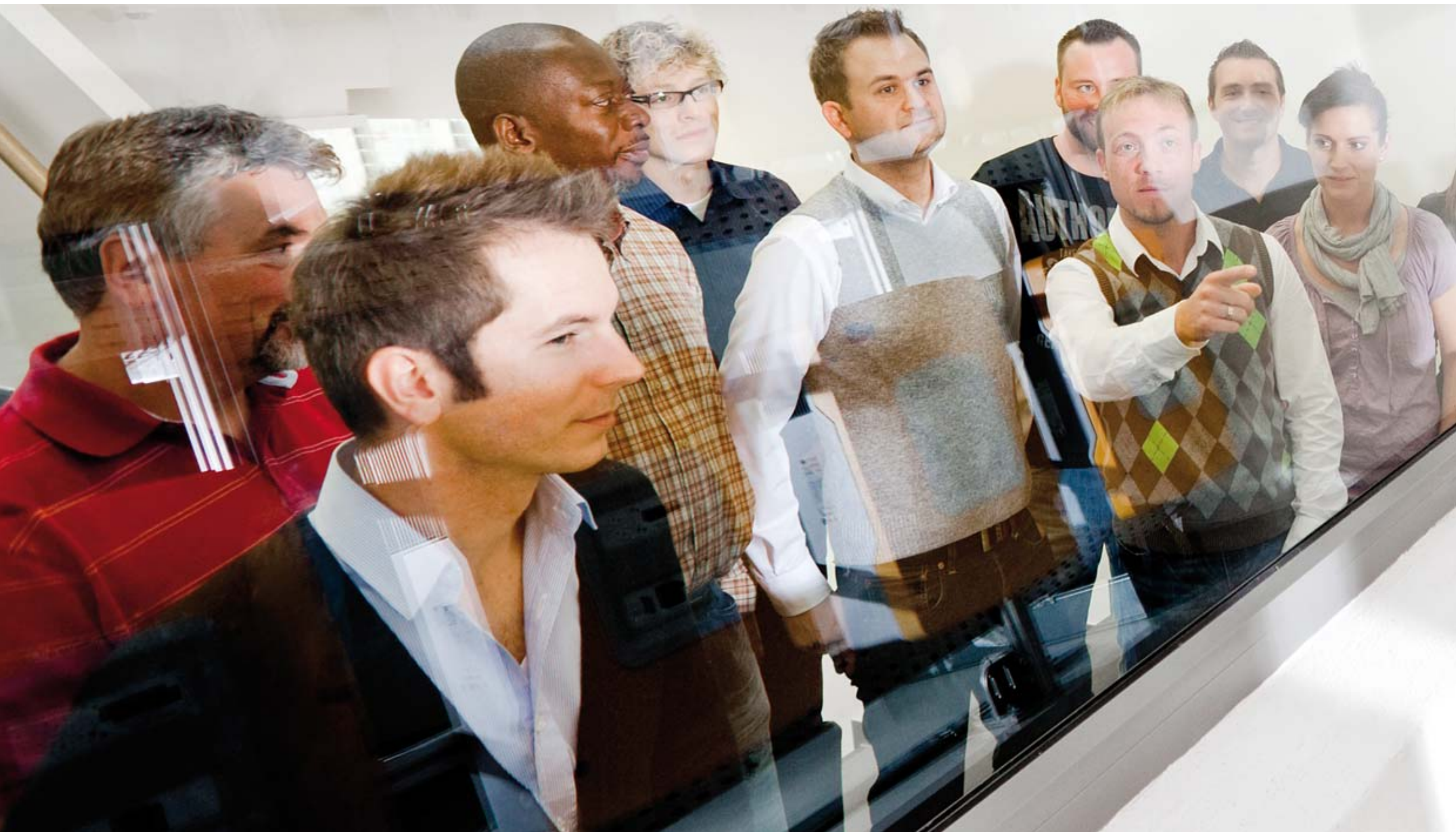
SMA Multicluster Technology



The path to your own power grid

Summary

AC based off-grid systems open up new possibilities for providing a stable and powerful energy supply independent of the power distribution grid, while at the time providing the customary supply quality usually associated with power distribution grids. Its modular structure allows for simple installation and easy expansion. Renewable energy sources are generally free of fuels costs and are therefore steadily becoming more economically viable, and at present are already much more cost-effective than conventional systems running on diesel generators. This brochure explains the technical aspects of stand-alone electricity supply systems and illustrates the structure and function using a large hybrid system with around 270 kW installed generating capacity as an example.



Why Alternating Current?

The basis of modular stand-alone power supply systems, up to 300 kW, is the AC coupling. In contrast to DC coupling, all the energy sources and loads are connected via an AC network which offers a number of advantages. For the consumer, this means that commercially available, and therefore cheaper, AC devices can be used. For the generator, any renewable or conventional energy source can be connected. AC grids can be set up without any special know-how and using standard components of universal availability. Subsequently they are significantly less expensive than those for DC networks, and despite having to withstand higher voltages the current strengths are substantially lower. Even large distances between generators, batteries and loads are easily managed which creates greater planning flexibility for grid implementation. In addition, the AC grid generator and loads are possible at nearly any point in the network thus providing optimum conditions for subsequent extensions.

Sunny Island:
The Grid and Battery Manager

The central component of the stand-alone grid is the battery inverter, the Sunny Island. In its role as grid former and manager, it maintains the stability of the AC network and ensures that voltage and frequency remain within permissible limits. The Sunny Island is a bidirectional battery inverter and is often referred to as a combined inverter/battery charger. It takes care of storing excess energy in the battery and supplying the grid with power from the battery. These devices are particularly cost-effective because they perform both functions via the same power semi-conductors.

The Sunny Island is equipped with both grid management and with a highly developed battery management function, which includes monitoring. Thus it is continuously updated on the exact battery charge and as system manager makes necessary ongoing decisions. When the batteries are empty and there is little generation capacity, it activates a permanently available backup energy source (e.g., a diesel generator) or even switch off certain consumer loads. It also determines the optimum strategy for charging the batteries, and in so doing, increases their lifespan. Furthermore, this compact device provides additional functions specifically geared for the requirements of stand-alone networks.

Automatic reactive power compensation

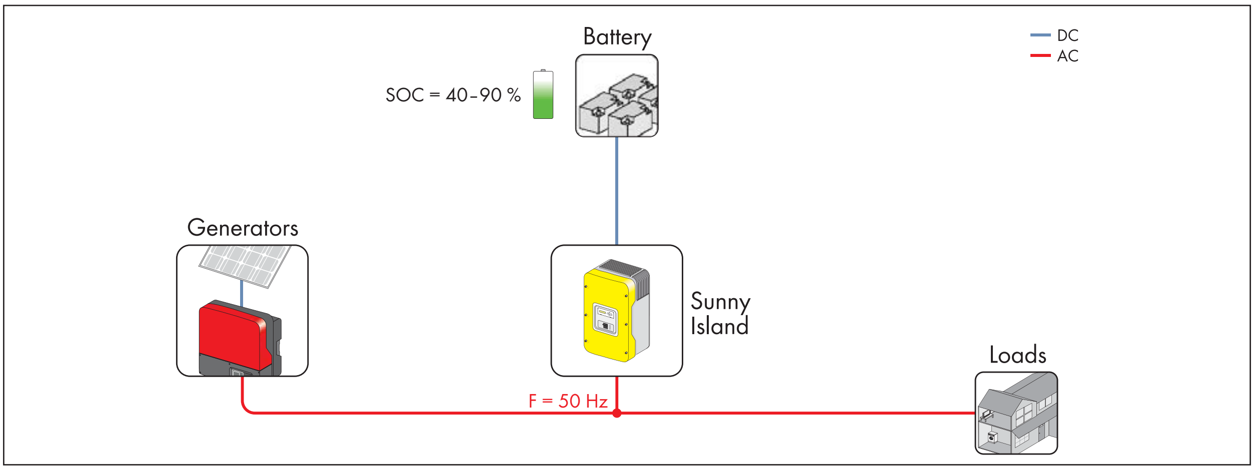
With a possible phase shift of −90 degrees to +90 degrees (shift factor from 0 to $1_{inductive/capacitive}$), the Sunny Island can, if necessary, convert its entire nominal power to reactive power. Thus, it is capable of compensating phase shifts in the stand-alone network brought about by inductive or capacitive loads (e.g., engines, transformers, cable lines).

Remote control PV management

When batteries are full and electricity demand is low, the Sunny Island automatically reduces the electricity produced by all renewable-energy generators whether solar, hydroelectric or wind turbine plants (providing all inverters are from SMA and their stand-alone grid mode is activated). If this is the case, the devices will no longer disconnect from the grid with rising frequency and instead systematically reduce the power output. As grid manager, the Sunny Island specifies the stand-alone grid frequency and therefore can limit all generator power and maintain the energy balance of the grid, and without any further lines of communication.

Extreme overload capability

When certain loads are switched on, high start-up currents are frequently encountered which can be well in excess of the normal operating current. In addition, some loads may require a lot of energy just for a short while creating short peaks on the load profile. As a result, when sizing an off-grid system it is extremely important to use battery inverters with a high overload capability. This will ensure that load peaks are dealt with ease. The Sunny Island 5048 can handle 6.5 kW for 30 minutes, 8.4 kW for one minute and as much as 12 kW for three seconds – i.e., approximately two and a half times its nominal power.



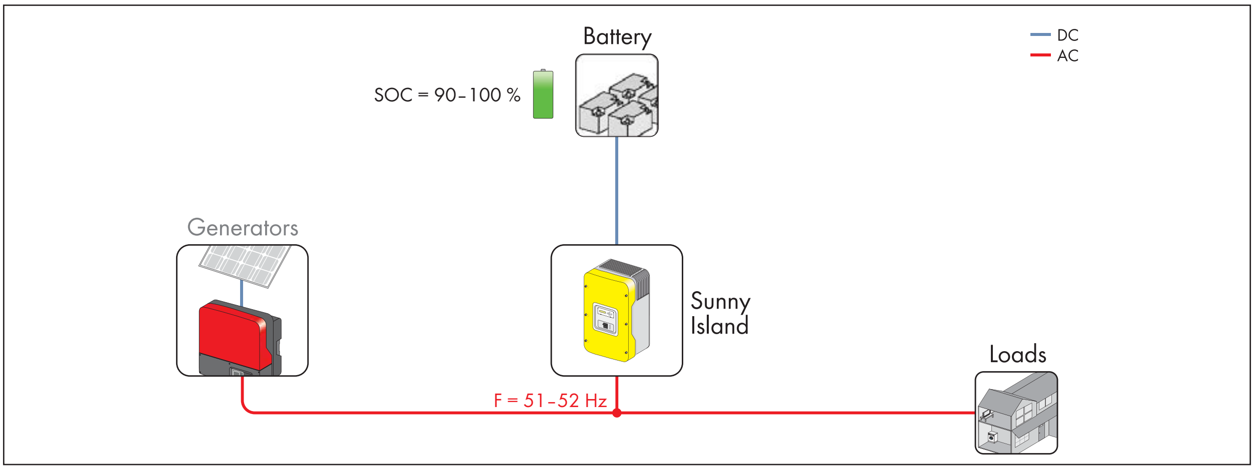


Fig. 1: At a charge of lower than 90 percent, the battery absorbs power surpluses at any time. When the battery is fully charged and power surpluses exist, the Sunny Island increases the AC frequency and the generators accordingly reduce their power output.

Three Phases – No Problem

Three-phase configurations have proven extremely effective in transmitting large capacities in AC electricity grids for both large power and stand-alone grids. Overlapping of the phase-shifted individual capacities gives three-phase loads nearly continuous power. While generators in diesel and wind turbine plants primarily deliver their output as three-phase power it is possible to set up single-phase systems up to a battery inverter power of 20 kW (parallel switching of four Sunny Island 5048 to one phase).

However, three-phase stand-alone grids are generally used for higher power outputs by connecting three Sunny Island inverters to a three-phase cluster. One inverter acts as master and specifies the target frequency, while the other two inverters, "slaves" comply with this frequency, working on a phase shift of exactly 120 or 240 degrees. Synchronization takes place via a special communication line between the devices. A significant advantage of this connection is that the configuration of the entire cluster can be carried out by the master inverter alone. Once the system is wired and configured, a three-phase stand-alone grid works just as well as the single-phase version. Furthermore, the high-load phase inverter automatically compensates for an unbalanced grid load caused by single-phase loads by taking correspondingly more power from the battery.

Even completely unbalanced operation is possible, for example when solar power is fed to phase 1 and there is consumption on phase 3. However, in this case, because the energy must be put through two additional Sunny Island inverters, to maximize efficiency it is still better to keep the distribution of loads and generators as balanced as possible.

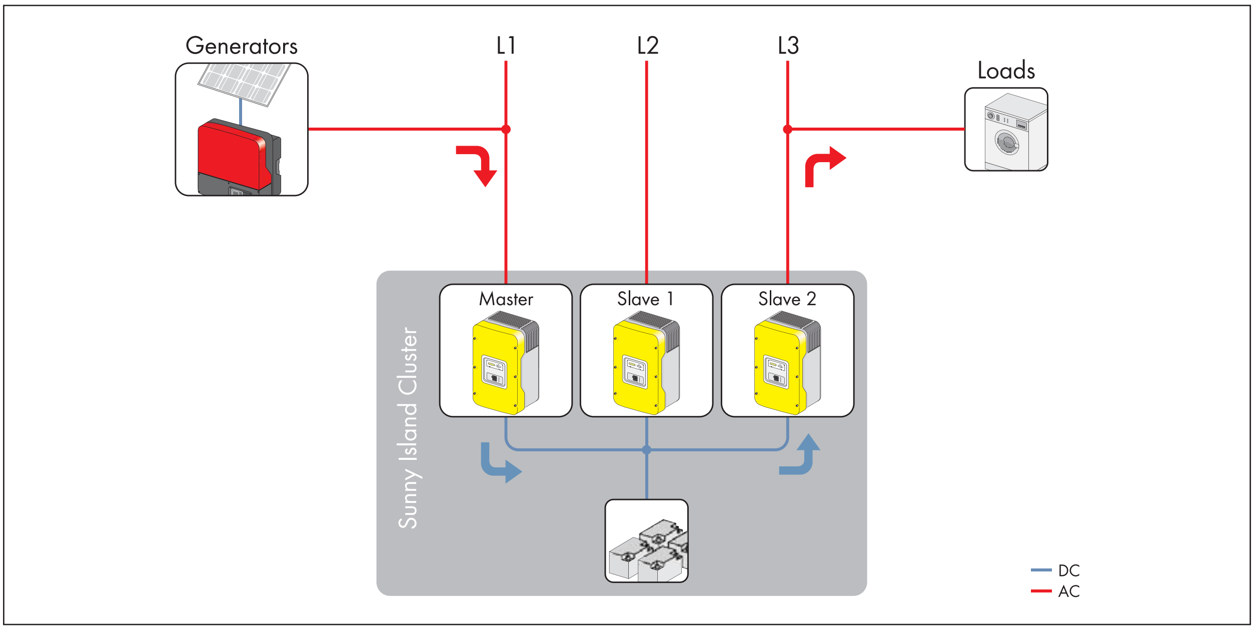


Fig. 2: Asymmetric load on the three-phase grid is no problem

Less Expense for Large Systems

The distinct advantage of SMA's off-grid system technology is its modular concept. Plants of any size can be configured from comparatively small, easy-to-handle components. Transport and assembly are therefore made easy, even in remote locations. By distributing the inverter power into clusters of three devices each, the planner has a high degree of flexibility in system capacity. In fact it can be scaled to nearly any size by simply connecting several parallel clusters. Subsequent expansion of off-grid systems are equally as simple. Service technicians who have once been through a training program just once are able to configure, operate and service plants of any size because the basic structure of the system and the installed devices are always identical.

Apart from the Sunny Island battery inverter, the heart of the modular system is the Multicluster Box. It is responsible for connecting all the components to a battery-buffered AC network with a variety of different power generators. The Multicluster Box is available in three power classes, ready wired and includes all necessary switching elements and monitoring devices. With its help, off-grid systems between 15 kW and 300 kW of power are possible.

Power made to measure: The Multicluster Box

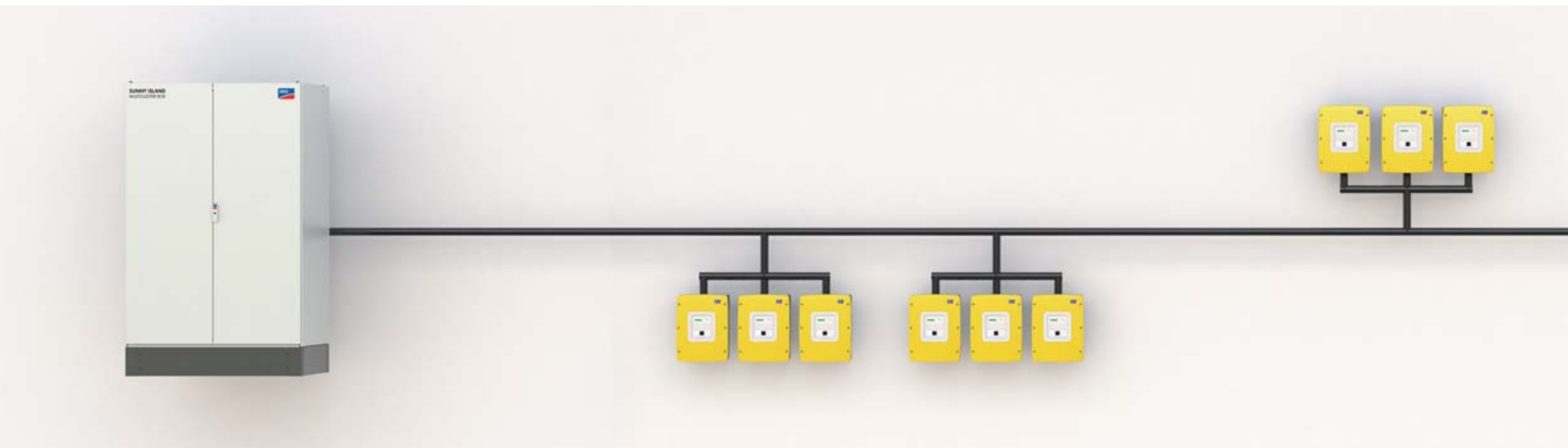
The core element of Multicluster technology is the Multicluster Box which is available in three power classes. As a pre-configured AC distribution, it enables easy connection of all AC components in the stand-alone network, including generator, renewable-energy generation plants (e.g., photovoltaic, wind turbine or hydroelectric power), loads and between two and twelve clusters, each made up of three Sunny Island inverters. The different Multicluster Box versions differ only by the number of connectable clusters and the corresponding sizing of all live components. The layout of the Multicluster Box is uniform. There are connections for each Sunny Island inverter, main connections for the generator, and for the renewable-energy generating plant and loads (these two usually require sub-distributions and require separate planning).

Multi-level security: Generator and load-shedding contactors

A power contactor is integrated into the Multicluster Box for both load and generator connections. The generator contactor connects grid-forming generators such as those used in more powerful diesel generating plants or combined heat and power plants (CHP). In contrast to generators in grid-parallel operation, they cannot synchronize with an existing grid, and therefore in this case, the generator specifies the grid parameters. The cluster group of Sunny Island inverters adjusts accordingly, meaning the connection is established as soon as voltage and frequency with the pre- and post generator contactor are synchronized.

If the Sunny Island cluster fails or is switched off, the generator contact closes automatically directly

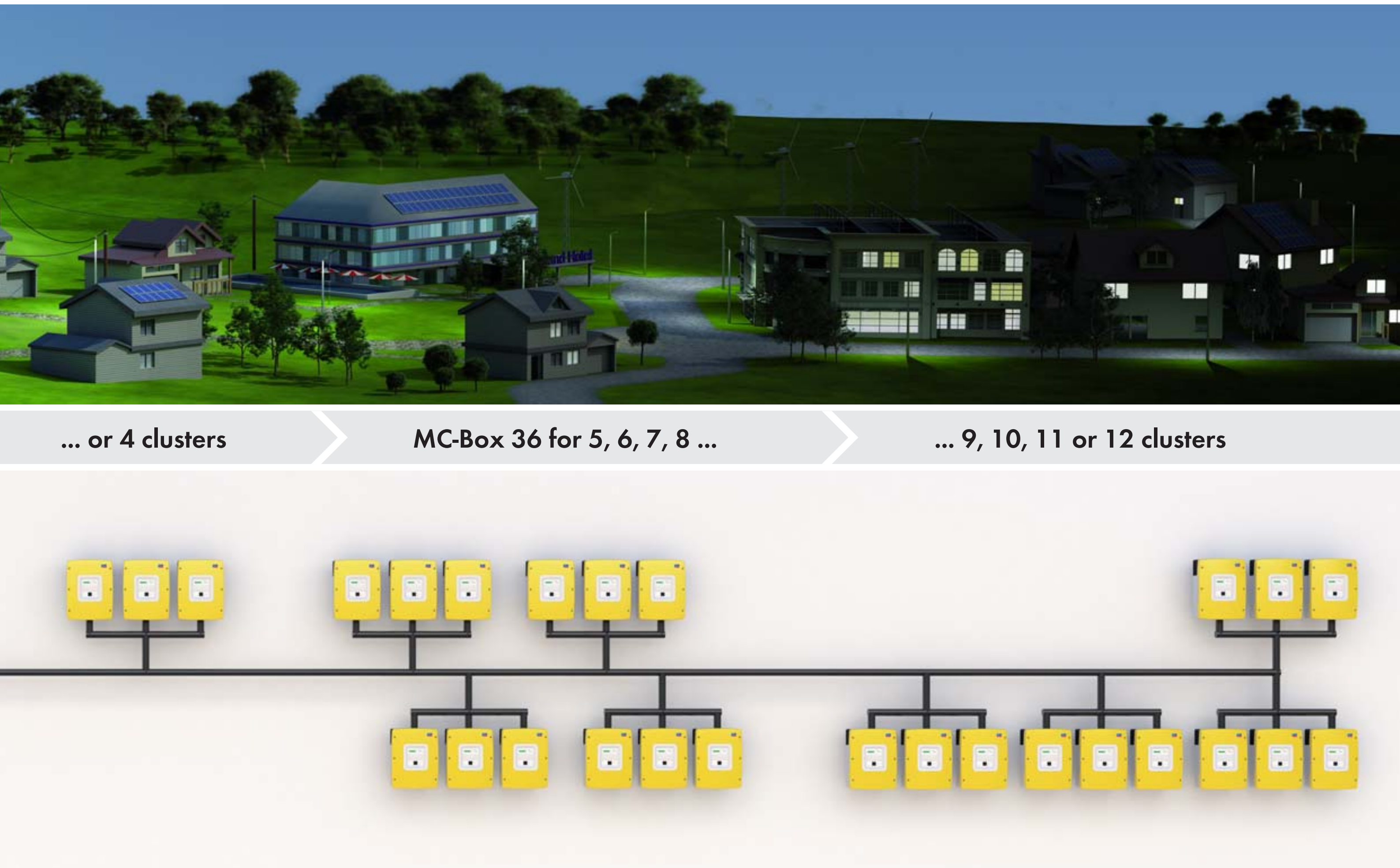
Multicluster Box 6 for a maximum of 2 clusters **MC-Box 12 for 3 ...**



linking the generator to the connected loads. On the other hand, in the event of a generator failure, the system immediately disconnects and maintains supply with battery power and the available renewable-energy generators. Thus, secure operation is assured even when one component fails.

If the generator stops working for an extended period and the regenerative sources do not provide sufficient energy to fully supply the loads, the energy stored in the battery will be used. When a lower discharge threshold is reached, the contactor on the load side opens and disconnects the line. This prevents an deep discharge of the battery and switching-off the cluster. Instead, the system stays active and utilizes the accumulating solar, wind or hydroelectric power to recharge the battery. Only once a sufficiently high charge is reached will the loads be automatically reconnected. This process ensures maximum supply stability and battery protection, even if a more serious failure occurs.

On the other hand, to avoid unnecessary load peaks, load management is managed by the Sunny Island inverter multi-function relay. Each device of the main cluster has two relays available, to which it is possible to assign one of 17 functions using the device menu. In addition to starting the generator when battery charge is low, it is also possible to connect individual loads via a separately installed contactor.



Flat hierarchy: Inverters linked into clusters

With up to 36 Sunny Island inverters in the stand-alone grid, it is imperative to have a regulative structure in order to provide effective control of the island network. As mentioned above, each of the maximum twelve clusters is made up of three inverters – one master and two slaves. Each of the three-phase unit clusters is responsible for controlling and monitoring a specific battery segment.

Furthermore, one of the clusters is designated as the main cluster. The corresponding main master device controls the entire system and communicates with the Multicluster Box. The main cluster is supported by up to eleven extension clusters, with each of these consisting of one master and two slaves. Thus, there is four level hierarchy established consisting of: (number of devices in brackets): main master (1), main slave (2), extension master (1 – 11) und extension slave (2 – 22).

Measurement and control: Communication lines

In addition to the contactors, the Multicluster Box also contains two interfaces for communication to the main cluster. Current strength, voltage and frequency at the generator connections to the three inverters of the main cluster are transmitted. This data is required, among other things, for the synchronization of the Sunny Island cluster to the generator.

Additionally, to trigger the contactors the Multicluster Box is connected to the internal communication bus of the main cluster. Apart from this, all the master inverters in the system are connected to each other. Through the multicluster bus, information is transmitted about the current cluster power output, battery charge and the nominal frequency.

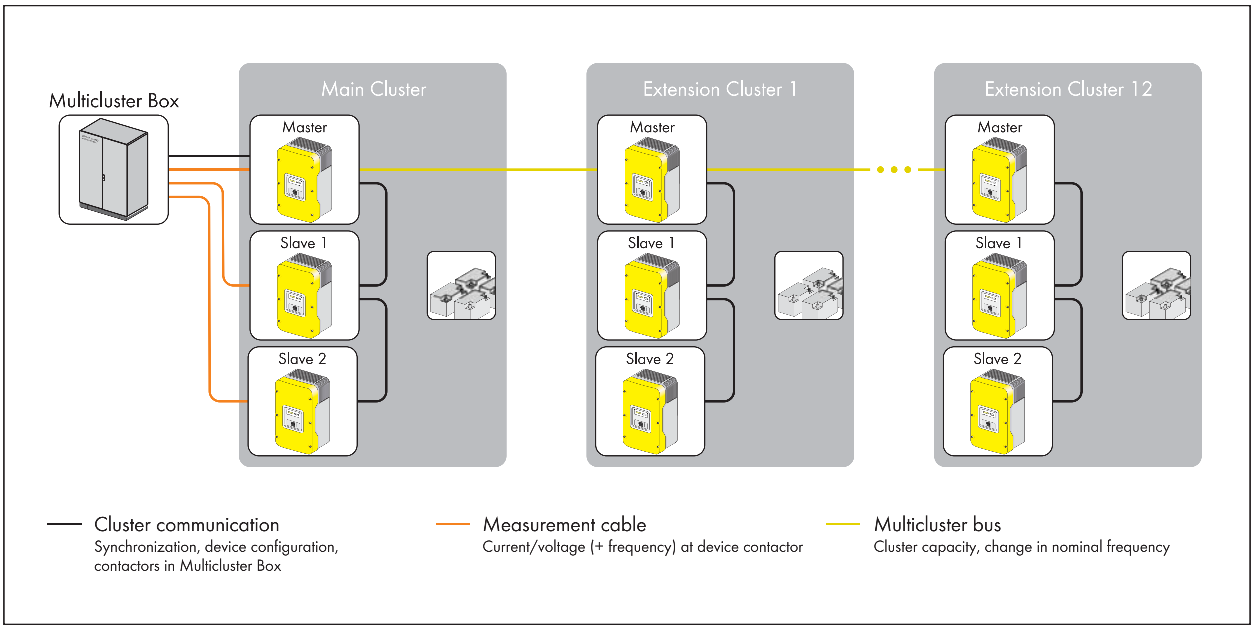


Fig. 3: Hierarchy and communication links in the clusters

Flexible in normal operation

The modular functionality of the off-grid systems in combination with the compact size of the devices creates a high degree of flexibility, offering numerous advantages in planning, system expansion and maintenance. Adding clusters to the Multicluster Box is possible at any time, and increasing the generation capacity from renewable energy sources is virtually effortless making it simple to expand and enhance each small system.

The only limitation is the number of Sunny Island connections possible on each Multicluster Box and the ampacity of its switching devices (see technical data of the Multicluster Boxes). With the exception of the main cluster, maintenance and replacement of individual Sunny Island inverters can take place while the system is operating and the only impact is that total system output is only correspondingly lower during this time.

The same is also true of the individual battery segments assigned to the various Sunny Island clusters. The intelligent battery management of the cluster group ensures all battery segments have regained the same state of charge within a very short time.

Easy maintenance and by local service technicians

Regular service on Sunny Island inverters is limited to cleaning the ventilation fans. The individual battery units only require service once a year, and a result of the protective low voltage used on the DC side, this maintenance can also be during normal operation and without any special knowledge. In the event of a Sunny Island inverter malfunction, any SMA trained service technician can replace the device. In the even more unlikely event of an error in the Multicluster Box, repair is a simple matter. There is no need to replace the entire cabinet instead a local service technician can simply replace the component.

The Island Solution: Modern Electricity Supply on Eigg Island

The Isle of Eigg is a perfect example of a powerful off-grid power supply. The island is part of the Scottish Hebrides, is approximately 30 km^2 in size and has around 90 residents. The costs to connect to the mainland (approximately 16 km away) are prohibitive therefore Eigg has never been connected to the public grid. Until 2008, the island's electricity supply was based entirely on diesel generators. This supply was very expensive, the generators were loud and regular power outages during service were common.

A power grid of their own

Since 2008, the islanders have been reaping the benefits of a modern three-phase electricity grid, 95 percent of which is supplied by renewable energy sources. This hybrid off-grid system uses three renewable sources integrating hydroelectric, wind and photovoltaic power, and only uses a backup generator at times of poor generating capacity. Although grid quality electricity is now available 24 hours a day costs for the residents have fallen by more than 60 percent.

The heart of this stand-alone network is a group of four Sunny Island clusters which connect to the various generators and loads via a Multicluster Box 12. Together three water turbines (with a total of 110 kW), four small wind turbines (24 kW) and a solar power plant that will be expanded from 10 kW peak capacity to 32 kW in 2011, generate eco-friendly electricity. Thus, the Sunny Island inverters with a rated power of 60 kW stand in relation to approximately 144 kW of electricity generated from renewable sources. This power ratio is typical for island systems, as the maximum output of the various generators is seldom available at the same time. Two diesel generators with a rated power of 64 kW each provide a backup supply in case the renewable energy capacity is not enough. However, only one generator is used at a time, even when it is being serviced or repaired the system switches to the other generator. The battery bank has a storage capacity of 212 kWh that can supply the island for about 12 hours. In order to avoid transmission losses resulting from the distance of several kilometers between loads and generators, the local power grid operates partially at a medium-voltage level of 11 kV. Locally generated power further relieves the

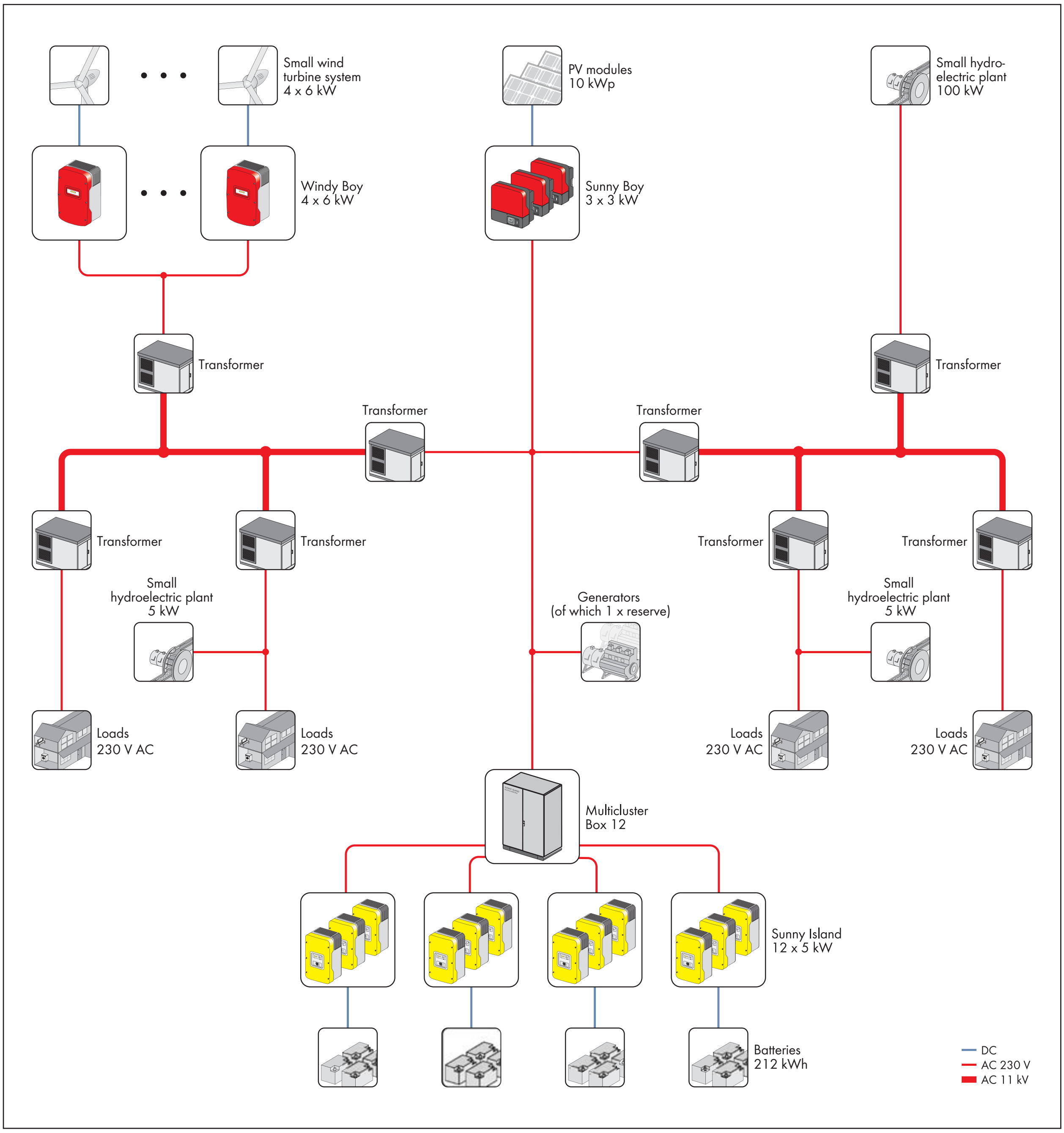


Fig. 4: Schematic of Eigg Island power supply structure

distribution grid, as some of the energy produced is consumed directly in the vicinity.

Operating principles

During normal operation, the main master of the Sunny Island inverters controls the entire network and ensures the energy balance is equalized at all times. When the generated power from renewable sources exceeds the current demand (15–60 kW), the surplus is stored in the battery.

When the battery is fully charged, the main master starts to increase grid frequency by a small amount. This serves two important functions. First, it activates remote-controlled electric heating loads that heat public buildings. Second, the renewable-energy generators carry out a frequency-controlled reduction of their capacity. If the power generated from renewables is not sufficient, the 60 kW power of the Sunny Island inverters is available for support and is taken from the battery.

Only when the state of charge has fallen below 60 percent will the main master start the diesel generator. In this case, the diesel generator presets the grid frequency and the Sunny Island clusters are synchronized to its grid parameters while at the same time they keep the energy balance stable. When large loads are activated or deactivated, the generator load is not changed immediately rather the inverters are able to compensate the load fluctuation by instantaneously changing their charge or discharge current.

A significant contribution is made by the enormous overload capacity of the devices – for three seconds they supply 144 kW of battery power to the grid.

In its role of grid manager, the main cluster weighs the alternatives of either operating the diesel generator with the highest possible efficiency, or charging the battery with the optimum appropriate charging current (the state of charge also plays a role in this equation).

As a result, the generator runs less frequently on inefficient partial loads and is burdened less with unnecessary, short start/stop cycles. By the way, Sunny Island inverters absorb sudden load changes so those generators with only a low power output (relative to the consumer loads) operate safely.

Frequently Asked Questions

Are DC-coupled systems generally more efficient?

No, in fact the opposite is true. If we calculate using realistic efficiencies, AC-coupled systems are more or less equal or even slightly better. Furthermore, the benefits of flexibility (feed-in and consumption at almost any location in the AC grid), cheaper grid infrastructure and the wide selection of inexpensive products (for instance, no exotic DC refrigerator needed, any standard device will do) all argue in favor of AC coupling.

In order to calculate system efficiency, the daily profile is sub-divided into three states with each corresponding to different efficiencies. In state A: consumption is covered by generation (direct consumption). State B: energy surpluses are stored in the battery. State C: the current energy demand is supplied from the battery. In state A, AC coupling offers more of an advantage since only one conversion step is needed (PV inverter), whereas with DC coupling two conversion steps are involved (charge controller plus island inverter). DC coupling is more advantageous in state B (charge controller instead of PV inverter plus island inverter), while in state C it makes no difference. With appropriate weighting these are then calculated to a total efficiency.

Which of the two systems is better? This depends on the ratio between the quantity of directly consumed and battery-stored PV energy. With a close time correlation between generation and consumption (for A/C systems or for industrial use), AC coupling is in general more efficient. For systems that are used almost exclusively for lighting purposes, DC coupling is more efficient. In this case, almost all the PV energy must be temporarily stored so that it is available in the evening and at night. Incidentally, the theoretical efficiency maximum is achieved

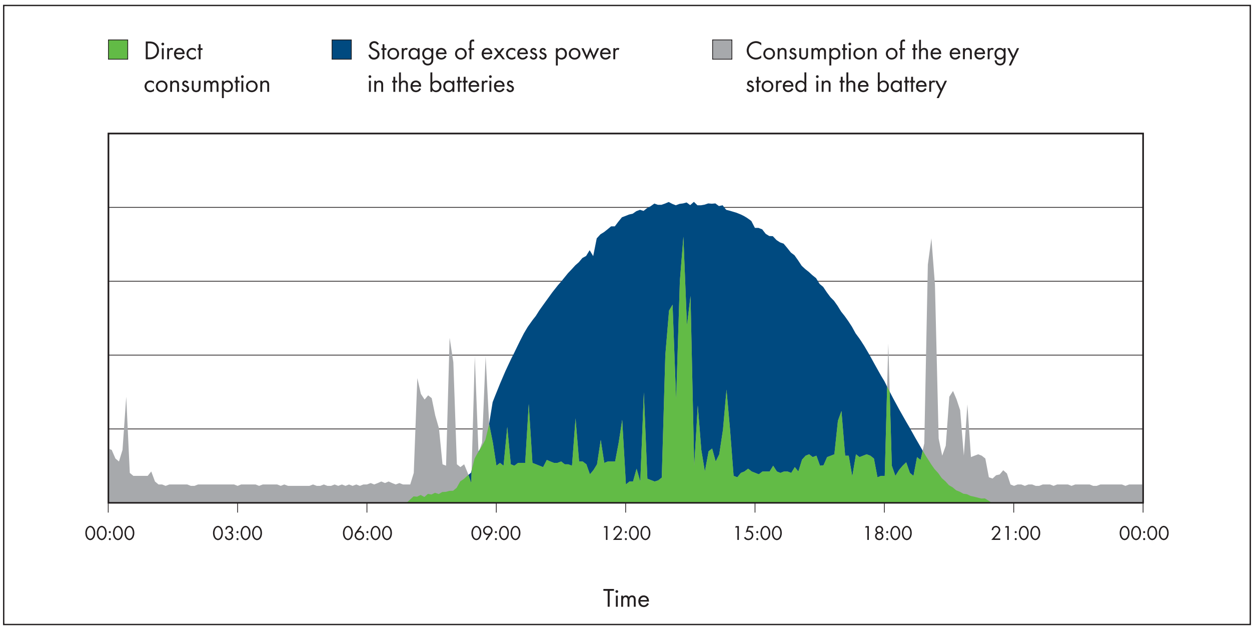


Fig. 5: Example of a daily overview of the three possible energy states of an off-grid system

with an AC/DC hybrid system. The regenerative generators producing energy which is used immediately feed directly into the AC grid. Only those generators whose energy is stored in the battery are coupled with the DC-side battery. However, there is usually only a slight difference in efficiency between the different kinds of coupling. Therefore economic viability depends more on system costs for planning, installation and service than by the differences in efficiency. Aside from this, the previously mentioned lack of flexibility offered by DC coupling now becomes apparent, since it is based on the assumption that generators and battery are located in close proximity to one another.

Is a modular system more expensive than one with central system technology?

A similar question is also asked about grid-coupled PV plants. What is the better choice, a powerful central device or a "decentralized" solution (i.e., a group of several inverters with lower output)? When considering manufacturing costs, there are two conflicting effects of scale: on the one hand, specific costs decrease with increasing device output, and on the other, smaller-sized inverters have the benefit of lower costs due to high-volume, largely automated production. The break-even point is between 200 kW and 500 kW plant power, so the modular concept is more cost-effective for almost all off-grid applications.

Apart from this, decentralized plant structures are always advantageous when the infrastructure for plant construction (e.g., roads, transport routes, heavy machinery) and for plant maintenance (short-term accessibility for specialists in case of failure) are not optimum. For example, if the last stretch of transport route consists of 30 kilometers of an unpaved, dirt road or can only be traveled using pack animals, this is incredibly unconducive for the actual transporting of large, bulky components – not to mention the costs involved. Another important aspect to consider is that, although the likelihood of error increases with the number of components, the probability of the simultane-

ous failure of several devices is in effect zero. Therefore, the reliability of the energy supply, which lies decisively in off-grid applications, is in general higher when the modular concept is used. Last but not least, the modular concept allows for a higher degree of flexibility both in the planning phase and for possible extensions at a later time.

How can emergency operation be ensured with just the generator?

If a generator is installed, contingency operation is automatically ensured. In the unlikely event of a complete Sunny Island system failure, the generator contactor will close automatically and connect the generator with the loads. It is only a matter of starting the generator.

Is the installation of modular systems not extremely complex?

Simply put, installation is simple. The individual components are easy to handle at any location in the world, and are extremely robust. The simple wall-mounting option means there are no special preparations required at the installation site. Configuration and operation do not require any special know-how, and can be carried out by any technically competent person after only one to two days' training, regardless of the system size. Moreover, the clearly arranged and ready-wired Multicluster Box serving as the central AC distribution also eliminates the need for any extensive cabling work.

If one of the Sunny Island inverters fails, does everything come to a standstill?

No, and it is precisely here that you will find another of the advantages of the modular concept. If one device of an extension cluster fails, only this cluster is out of action. In a system based on the Multicluster Box 12 (e.g., Eigg Island), this corresponds to a reduction in total capacity of the battery inverters of 25 percent – the generation power is maintained in its entirety.

The inverter in question can be repaired or replaced during normal operation of the stand-alone grid. Providing that the device configurations of the four possible hierarchy levels have been previously saved on SD cards, the applicable version can be transmitted to the replacement device at the push of a button. This way, the system can be up and fully running again in less than one hour.

Only in the unlikely event of a main master failure would the entire system be affected for a short time. If this were to occur, the emergency generator would provide for the initial supply. As a second step, you would need to define a random extension cluster as the new main cluster which merely involves reconnecting the communication cables to the Multicluster Box. Alternatively, the failed device can be replaced with any inverter from one of the extension clusters, configure it appropriately and the system restarts. Thus even the worst-case scenario can be remedied without problems. In addition, by simply keeping a single inverter as a reserve, you are almost completely safeguarded against possible failures.

What happens if there is a failure of the Multicluster Box?

Failure of the Multicluster Box is extremely unlikely. It is essentially an AC distribution which consists of incredibly durable components and has a high protection class. As long as the generator or load-shedding protectors are not defective, an emergency operation (i.e., the direct coupling of generator and loads) is possible in any case. Again as a result of its modular structure, all components of the Multicluster Box can be replaced on-site by a trained service technician.

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