



# Balancing act

Microgrid optimization control stabilizes production in solar and hybrid microgrids

CELINE MAHIEUX, ALEXANDRE OUDALOV – Traditionally, remote, off-grid microgrids have relied on diesel generators to produce electricity. Diesel oil is usually delivered by conventional land or sea transport, which results in transportation costs and a higher cost of electricity for end consumers. But with the environmental benefits and increasing cost-competitiveness of renewable energy, it is now more and more common to find solar photovoltaic and wind power integrated with diesel generators to form a hybrid microgrid. Energy storage devices such as flywheels and lithium-ion battery systems may also be included. Accommodating fluctuations in photovoltaic production and coordinating the operation of the diesel generators, feeder loads, energy storage and grid stabilization devices in response to these fluctuations is a tricky task that requires an advanced control system.

## 1 What is a microgrid?

A microgrid is a smaller version of a larger (macro) power grid. It is a collection of power generation sources, loads and energy storage devices that operate as a single unit and are kept in balance by a control system. Some types of microgrids are connected to the surrounding power (macro) grid; in addition to generating their own power, microgrids can also receive power from, or transfer power to, the main grid. Other types of microgrids are self-sufficient – they are “off grid” or “islanded” and have to generate their own power.

Microgrids are suitable for a wide variety of different applications. They are the obvious solution for islands like the Azores or Canaries and for communities in remote locations like the Australian outback, as well as for research stations in far-off places like the Antarctic. Military bases, university campuses, mines, onshore oil and gas fields, theme parks and tourist resorts are other typical applications, as are rural electrification programs in countries lacking power.

It is becoming increasingly common for traditional off-grid microgrid generators – usually powered by diesel oil – to be supplemented by one or more solar power plants and a number of wind turbines → 1–2. The microgrid might also include energy storage devices like flywheels and lithium-ion battery systems. Flywheels can provide instantaneous power to the microgrid to counteract variations in output caused by passing clouds or sudden changes in wind speed. Battery systems store energy in larger amounts and over longer periods to handle energy time shifts. They can store solar energy produced during the day when demand is low and release it in the evening when demand is high.

The challenge of integrating solar photovoltaics (PV) with diesel generators has two aspects: handling fluctuations in the photovoltaic production level, and coordinating the operation of the diesel gen-

erators, feeder loads, energy storage and grid stabilization devices in response to these fluctuations. This requires an advanced control system that can connect and disconnect generators and loads, provide set points to generators and charge or discharge the flywheel or battery system. By doing this, the control system will maintain maximum PV penetration, reduce operating costs and keep the microgrid stable.

### ABB microgrid solution

ABB's Microgrid Plus System™ is a distributed control platform that automates and manages microgrids that consist of fossil-fueled generators and renewable energy generation from one or more sources. It also integrates other microgrid components such as energy storage and grid stabilization systems, and distribution feeders. Further, it connects and communicates with the adjoining power grid, if there is one → 3–4.

The Microgrid Plus System is designed to work with ABB's other microgrid product – the PowerStore™ flywheel-based or battery-based grid stabilization and energy storage system. Together, these two technologies calculate the most economical microgrid configuration that achieves a proper balance of supply and demand – one that maximizes renewable penetration (up to 100 percent), reduces the operating cost and maintains the

highest level of power quality, grid stability and reliability of power supply.

ABB's MGC600 controllers are the building blocks of the Microgrid Plus System. They enable communication between all the electrical devices in the microgrid and use the data communicated by the devices to make local decisions that work cohesively for the benefit of the whole microgrid. The range of MGC600 controllers is comprehensive in scope and uses a common hardware platform that runs different types of firmware according to the electrical device concerned → 5.

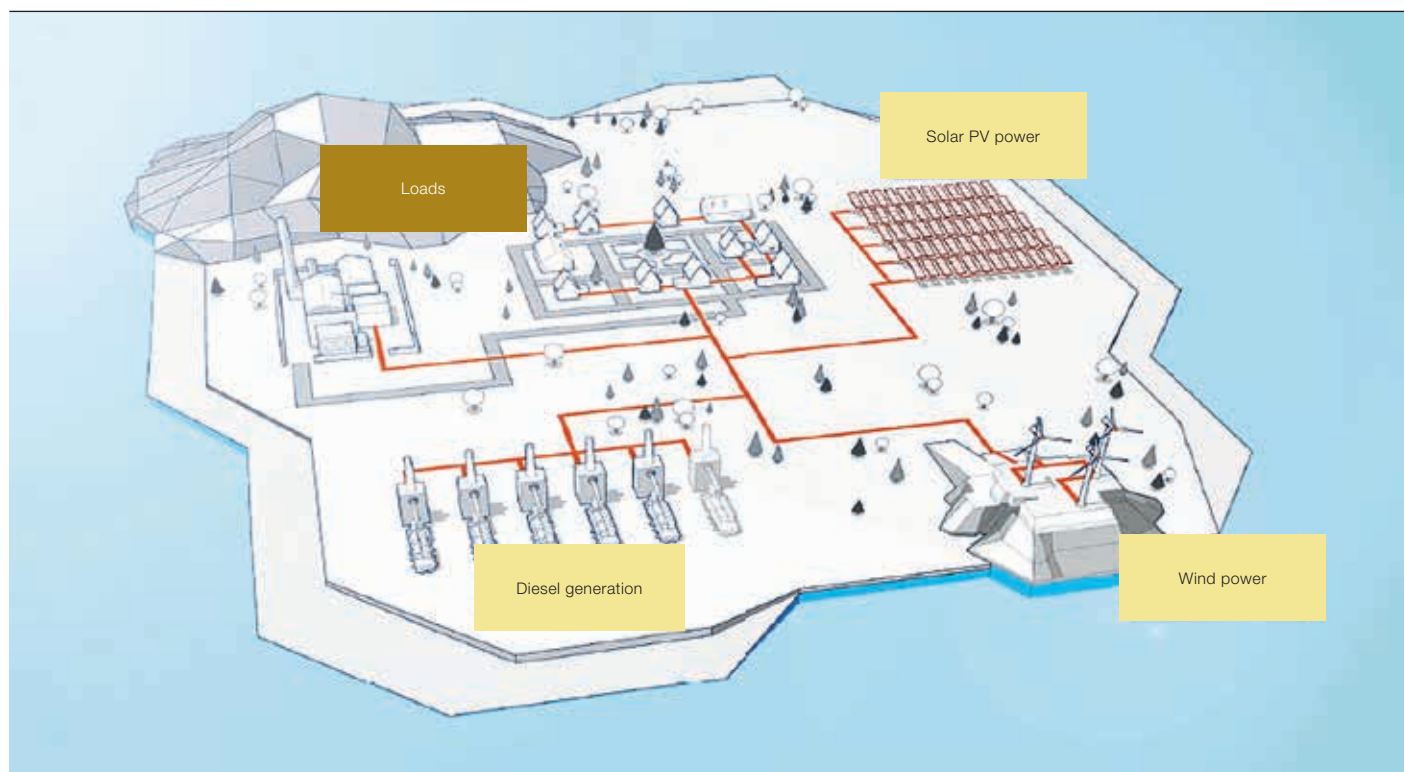
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These firmware packages contain the core control logic of the MGC600. They work in harmony with one another within the Microgrid Plus System. For instance, the PV control and monitoring system (MGC600-P) schedules and controls the PV plant in conjunction with the controllers that control the diesel generators (MGC600-G) and energy storage system (MGC600-E).

### Title picture

Microgrids may comprise a mixture of diesel generators, solar power, wind turbines, battery or flywheel storage units and the electrical devices to connect them all together. How can such a disparate collection of equipment be effectively controlled and coordinated? Shown are the PV panels, and diesel and flywheel containers at Marble Bar, Western Australia.





### Comprehensive functionality

The MGC600 has a number of unique features and benefits that improve the availability of the microgrid and reduce its consumption of fossil fuel by maximizing the penetration of renewable energy generation:

- Automatic starting and stopping of the PV generator
- Active power limitation based on the generator's optimal load
- Active power limitation based on system step load
- PV generator control for islanded mode or grid connection
- Active power limitation sharing between multiple PV generators

The MGC600-P monitors and controls the PV generator either with a PV plant controller or with an inverter. It provides manufacturer-independent control and monitoring to allow different makes of inverters and plant controllers to be integrated into the microgrid system. For low- and medium-penetration systems (ie, those without storage and stabilization devices), the MGC600-P monitors the power output of the fossil fuel generators via an MGC600-G controller. Based on the load levels of the fossil fuel generators, the MGC600-P determines whether the power limitation set point of the PV plant should be increased or

decreased. This enables the fossil fuel generators to run at their optimal load, while ensuring that the maximum amount of renewable energy is utilized.

### Control strategy examples

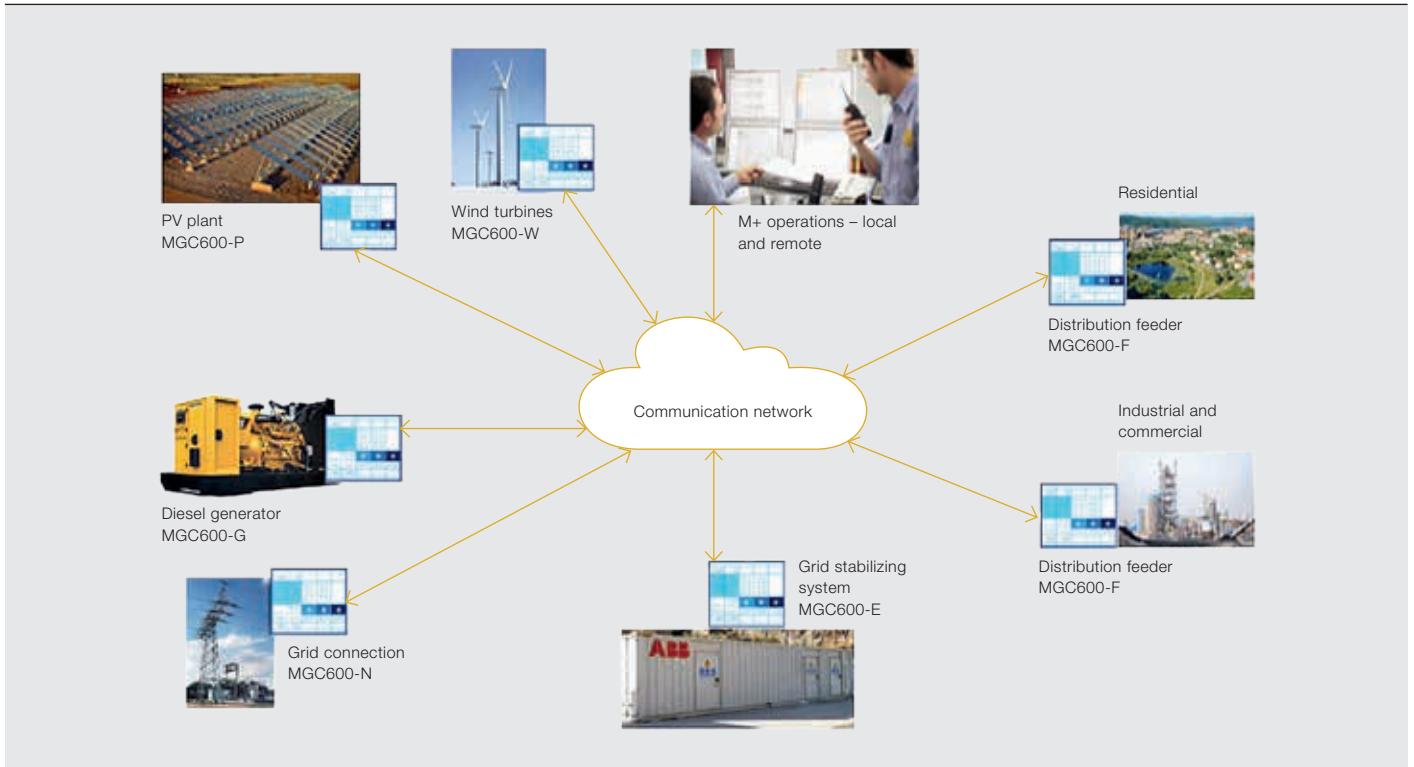
The Microgrid Plus System has a long and successful record of operating in various types of microgrids. The following two theoretical case studies illustrate how different levels of solar PV penetration require different control strategies. These, in turn, necessitate a control system that has the flexibility and functionality to accommodate different control strategies and to integrate varying levels of renewable energy.

In the first case study, the microgrid owner wants to reduce exposure to diesel price volatility and the high cost of running the microgrid on fossil fuel. A PV power plant has been integrated into the microgrid; it has the capacity to cover almost 100 percent of instantaneous grid demand at maximum production. However, because solar PV is intermittent in

nature, the diesel generator must run in parallel to the PV plant to provide system frequency and voltage references. In this particular case the increased generation of solar PV could drive diesel generator output to a very low level. Diesel generator suppliers usually advise that the generator should not operate below 20 to 30 percent of its nominal capacity for more than a few hours, as doing so may damage the engine. Load sharing coordination between the solar PV system and diesel generator is, therefore, necessary.

**An advanced control system that can connect and disconnect generators and loads, provide set points to generators and charge or discharge the flywheel or battery system is needed.**

In a Microgrid Plus solution, both the PV system and the diesel generator are equipped with MGC600 controllers: the MGC600-P for the PV system and the MGC600-G for the generator. These two



sets of controllers exchange information with each other in real time. Based on the load levels of the fossil fuel generators, the MGC600-P automatically adjusts the set point and enables the generators to run at their optimal load, while ensuring the maximum amount of renewable energy is utilized by the microgrid.

If the microgrid connects to a larger power grid, the grid operator may not accept reverse power flow, ie, not allow power from the microgrid to be transferred into the transmission or distribution network. In this case the microgrid will most probably run with the diesel generator switched off. The MGC600-P controller that controls the solar PV plant will coordinate a power infeed from the main power grid with an MGC600-N controller at the point of common coupling.

In the second case study, the production capacity of solar PV in the microgrid is substantial and exceeds demand during the peak production hours. However, solar PV peak production and local load peaks do not always occur at the same time. The evening peak, when demand is usually the highest, does not coincide with PV production, which occurs during daylight. The solution to this quandary is to store some of the PV energy produced during the day for use during the evening

when the PV plant has stopped production. This can be done with a lithium-ion battery system. The cost of these has fallen significantly in recent years and many different studies and manufacturers' data forecast further cost reductions in the near future.

The addition of an energy storage system to the microgrid means that the microgrid control system now has an additional component to manage. This is not a difficulty for the distributed control concept of the Microgrid Plus System: It is easy to install a dedicated MGC600-E controller for the energy storage system that exchanges information with the other controllers in the Microgrid Plus System. The MGC600-E controller continuously informs the other controllers about its status and the battery state of charge and state of health, while receiving critical operational information from the diesel generator, solar PV and network controllers.

#### Stable operation with PowerStore

ABB's PowerStore is a compact and versatile flywheel-based stabilizing generator that reduces instabilities in microgrids or weak grids due to fluctuations in solar PV power output caused by passing clouds. It is able to operate in a grid support mode for large networks or in virtual generator mode for isolated microgrids.

ABB's Microgrid Plus System is a distributed control platform that automates and manages microgrids that consist of fossil-fueled generators and renewable energy generation from one or more sources.

The Microgrid Plus System also integrates energy storage and grid stabilization systems, and distribution feeders. Further, it can connect and communicate with the adjoining power grid.

#### 4 ABB's microgrid expertise

<p>ABB offers turnkey solutions for, and has references for, all types of microgrid requirements: Greenfield hybrid power plants consisting of renewable and diesel power generation; the integration of renewable energy generation with an existing fuel-based microgrid; optimizing the performance of an unstable microgrid that combines renewable energy and fossil fuel generation; stabilizing the</p>	<p>connection of an existing renewable energy plant to a weak power grid; and power grid stabilization.</p> <p>ABB has 25 years of experience developing microgrid technologies and has delivered more than 80 microgrid solutions worldwide – more than any other supplier.</p>
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#### 5 The MGC600 controller range uses a common hardware platform that runs different types of firmware according to the electrical device concerned.

Firmware/controller	Description
Diesel generator (MGC600-G)	Controls, monitors and interfaces with diesel generators
Distribution feeder (MGC600-F)	Controls, monitors and interfaces with feeders and their protection relays
Photovoltaic solar (MGC600-P)	Controls, monitors and interfaces with solar array inverters
Single/multiple load (MGC600-L)	Controls, monitors and interfaces with large loads like crushers, boilers, etc.
Energy storage system (MGC600-E)	Controls, monitors and interfaces with battery-based ABB PowerStore
Network connection of microgrid (MGC600-N)	Controls, monitors and interfaces with other microgrids or larger grids
Wind turbine (MGC600-W)	Controls, monitors and interfaces with wind turbines

→ 6 shows how stable power output is ensured by a quick power injection and the efficient absorption capability of PowerStore. The power fluctuations are caused by variations in solar PV generator output due to passing clouds. Two diesel generators (“Gen 2” and “Gen 4”) are involved in power balancing but the speed of the solar PV output variation causes stress to their prime movers, which results in faster wearing and more maintenance. PowerStore intervenes precisely during these short variations and helps the diesel generators ramp up and down in a sparing mode.

In addition, → 6 illustrates how MGC600 controllers coordinate their actions. For instance, Gen 2 is switched on and off by the MGC600-G controller in accordance with PowerStore's state of charge and power output, which is reported by the MGC600-P. In other words, when repetitive solar PV fluctuations are detected and PowerStore's state of charge is getting low after assisting Gen 4 (green curve), Gen 2 is switched on. Then both generators share the power balancing control while PowerStore is recharging.

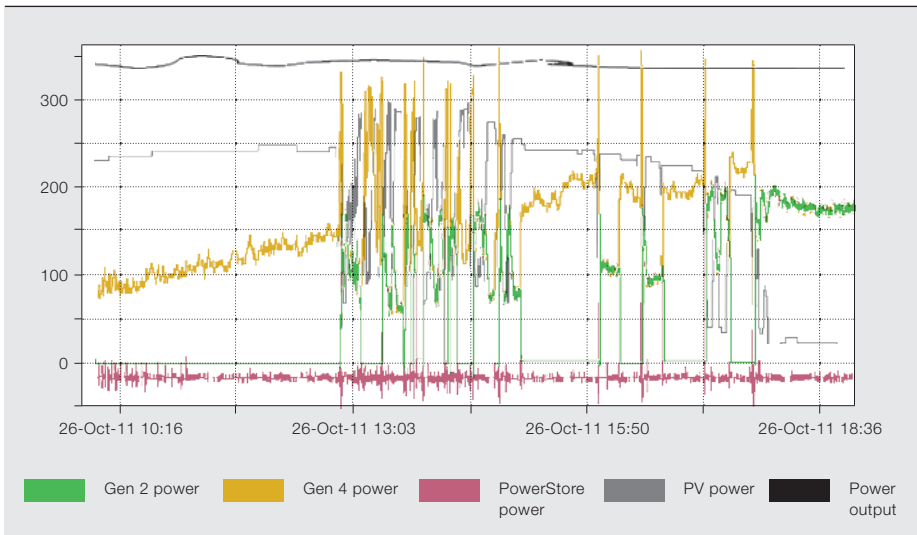
#### Advanced control functions

Several advanced control functions are included in ABB's microgrid optimization products.

#### Cloud tracking

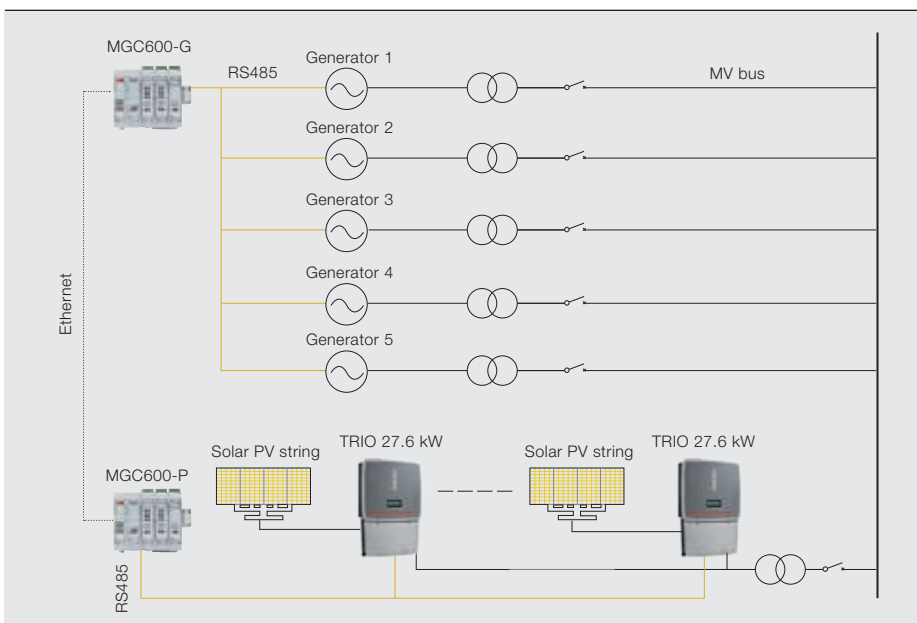
In order to guarantee the stable and economic operation of a microgrid with a high penetration of solar PV, ABB has developed algorithms that track the movement of clouds in the vicinity of the microgrid. The algorithms predict the time of arrival and duration of cloud cover over the PV plant, and calculate the expected fall and subsequent rise in output (ramp rates). Very large ramp rates of solar PV can cause instability if they exceed the ramp rate capability of the diesel generator. Accurate short-term prediction of solar PV ramp rates will allow a proactive control action and reduce the effects of disturbance. If there is not enough energy stored in the battery system to cover the shortfall in PV production, a single generator or several generators can be scheduled in advance for start-up. If production shortfalls are long, then an optimal amount of energy could even be purchased from the market (for grid-tied microgrids) during low-cost tariff hours, stored in the battery system

## 6 Power generation profiles in an isolated microgrid



PowerStore is a compact and versatile stabilizing generator that reduces instabilities in microgrids or weak grids due to fluctuations in solar PV power output caused by passing clouds.

## 7 ABB's low-cost and low-complexity control concept to save fuel in PV/diesel microgrids



MGC600 controllers are the building blocks of the Microgrid Plus System.

and then released during the day to meet contracted quotas.

### Hybrid energy storage

A hybrid energy storage system made up of various energy storage technologies with different characteristics (cycle life,

response speed, efficiency, cost and so on) can potentially help integrate larger-scale solar PV at a lower total cost than if the technologies were deployed separately. ABB is analyzing the advantages and disadvantages of such a system and is developing control solutions for it.

### Diesel fuel-saving solution

ABB is developing a low-cost and low-complexity control solution to save fuel in PV/diesel microgrids with a capacity ranging from a few hundred kilowatts up to a couple of megawatts. One MGC600-G controller will coordinate several small-scale diesel generators and a single MGC600-P controller will manage several small-scale solar PV inverters → 7.

### Alexandre Oudalov

ABB Corporate Research  
Baden-Dättwil, Switzerland  
alexandre.oudalov@ch.abb.com

### Celine Mahieux

ABB Power Generation  
Zurich, Switzerland  
celine.mahieux@ch.abb.com