P3 ENERGY MANAGEMENT SYSTEM BENCHMARK

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Motivation

With the ongoing transition towards renewable energies, EV charging becomes a significant element of a holistic smart energy ecosystem. EV batteries can be used as storage capacity to support the grid during times of fluctuation in renewable energy supply. So-called Vehicle-to-Home (V2H) use cases focus on local optimization behind the meter and require very close interaction between EV charging and other consumers, such as local battery storages, photovoltaic (PV) systems, or heat pumps. A core element for local optimization is the Energy Management System (EMS), which monitors and balances demand and supply behind the meter with the goal of optimizing the loads.

A selection of seven EMS solutions has been tested at the P3 Energy Lab – a Laboratory for Intelligent Charging and Energy Solutions. The objective of the EMS benchmark is to compare market-ready EMS solutions for B2C customers, to assess the effectiveness of energy control optimization (self-sufficiency and self-consumption), and to identify differentiating factors of EMS solutions in the German market (B2C). While EMS solutions can serve multiple smart charging use cases, the focus of this benchmark study is on the use case “PV surplus charging.” Furthermore, the benchmark results can help decision-makers in the energy and mobility industries develop successful service offerings and select suitable partners. The P3 Wallbox Benchmark, published in 2023, compared wallbox models in terms of their functionality, including the availability of smart charging functions. The EMS benchmark with a focus on "PV surplus charging" represents an extension of the use case ‘smart charging’ based on the results of the P3 Wallbox Benchmark.

The smart charging and energy ecosystem shows a high degree of complexity and consists of multiple ecosystem elements that must be harmonized to enable local optimization for use cases such as “PV-optimized charging.” It requires a seamless and close interaction of EV charging with other smart energy devices, such as local battery storage, PV system, heat pump, or smart home devices. The energy management system (EMS) is a key enabler for local optimization as it harmonizes all ecosystem element interfaces and further monitors and balances energy demand and supply between these elements. The EMS is usually a combination of hardware IoT devices (Local Gateway) and software (Cloud application), which implement the control algorithms and protocol communication. For residential use cases, the EMS operates in a Home Area Network (HAN), which can be described as a private wireless or wired network. The architecture of an EMS usually includes a monitoring and controlled device, a processor for storage and management of information, and a network gateway that facilitates remote access to cloud systems. Controlled devices can include EV chargers (wallboxes), PV systems, heating, ventilation, air conditioning, battery storage systems, domestic appliances, and other sensing devices such as smart meters. To let the user interact with the EMS and retrieve information, interfaces such as mobile apps can be used.

Core EMS functionalities include monitoring, logging, control, and management. Management is the most important functionality of the EMS and optimizes the efficiency of the household’s electrical power usage based on different objectives and priorities. Challenges of the EMS include the diversity of electrical devices in a household setting, the multi-objective nature of households, and the uncertainty of energy production and consumption patterns. In addition, communication between EMS and electrical devices is not standardized yet. Up to six different communication protocols are currently being used for EMS communication in Germany based on P3 analysis including industry expert interviews. The described lack of communication standards for EMS solutions causes proprietary and individual implementation efforts and can slow down a fast large-scale rollout of smart charging use cases in the industry.

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Selection of EMS Solutions in the German Market

After analyzing multiple EMS solutions in the German market, an EMS can be divided into two main categories: "cloud-based EMS" and "local gateway EMS." Most EMS solutions in the German market are "local gateway EMS," which require a device to be physically installed on-site. The physical device acts as an IoT gateway that connects the local EMS with the EMS cloud. These "local gateway" devices can be further categorized into two types, described here as "standalone" and "integrated" EMS:

"Standalone" EMS solutions are physical control boxes designed for intelligent energy control and local optimization of energy devices. For example, they are directly integrated into the household circuit (e.g., by installation in the electric cabinet). Alternatively, some "standalone" solutions can operate without direct integration into the circuit by using additional components such as a smart meter to obtain and then control all relevant data from the local grid.

"Integrated" EMS solutions are devices that have EMS functionality integrated into their main products. These include, for example, BEV chargers (wallboxes) with an integrated energy management system specifically for PV-optimized charging or home storage systems that enable grid-supportive charging and discharging through an integrated energy management system.

In addition to the "local gateway" EMS described above, there is also an increasing number of "cloud-based" EMS solutions (cloud and app only, no hardware device) on the market. These utilize the various API interfaces of the respective energy components (such as wallbox, inverter, and energy meter) and control them based on the measured energy flows. This results in lower costs and requires less effort for installation and on-site configuration. A stable online connection between all relevant energy devices and the EMS cloud is essential to ensure the successful operation of energy management for "cloud-based" solutions.

For the first P3 EMS benchmark, the following market solutions with a focus on "residential application" and "end-customer offering (B2C)" were selected based on previous analyses and expert interviews.

Hager | XEM470

EMS HW costs:	550 €
Add. HW costs:	550 €
License costs:	-

1 |

Go-e | Controller

EMS HW costs:	250 €
Add. HW costs:	-
License costs:	-

2 |

Smappee | Infinity

EMS HW costs:	1360 €
Add. HW costs:	-
License costs:	-

3 |

Solar Manager

EMS HW costs:	850 €
Add. HW costs:	115 €
License costs:	48€ p.a.

4 |

Smartfox | Pro 2

EMS HW costs:	900 €
Add. HW costs:	-
License costs:	20€ p.a.

5 |

Clever PV

EMS HW costs:	-
Add. HW costs:	115 €
License costs:	72€ p.a.

6 |

SMA | Sunny Home Manager 2.0

EMS HW costs:	620 €
Add. HW costs:	-
License costs:	-

7 |

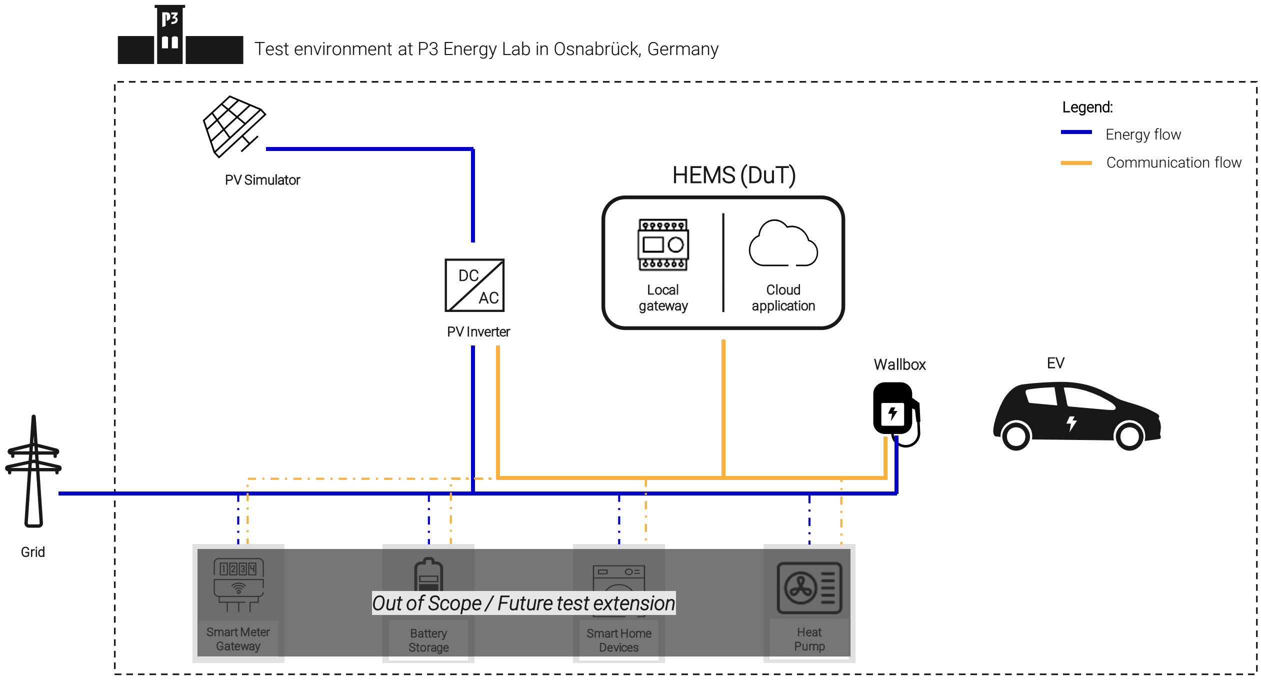
Alle prices are rounded to the nearest full euro.

agnostic system – designed to work with a variety of devices and manufacturers

proprietary system – designed to work with devices from the same manufacturer

Test Setup and Test Scenarios of the EMS Benchmark

The test environment of the HEMS benchmark aims to represent a typical residential household system to provide realistic conditions for the assessment of EMS in an experimental demonstration. The test environment is simplified and consists of a solar panel (PV) simulator, a PV inverter, and a BEV charger (AC wallbox). The electrical distribution cabinet contains the EMS, power measurement equipment, as well as fuses and circuit protection. All devices are connected to the distribution cabinet with a 3-phase 400V connection. The PV simulator simulates the PV panel's array and connects to the PV inverter through a DC connection. A PV simulator is used instead of a real PV panel array to ensure reproducibility and to allow the dynamic adjustment of the solar PV power system input.



Two different scenarios have been assessed for the performance benchmark over a period of 5 hours each using the PV simulator. These scenarios simulate the PV outputs of a sunny day and a cloudy day in which the solar panels are partially shaded. The respective curves have been compared with the energy charged by the AC wallbox, and from the data generated, the KPIs of self-sufficiency and self-consumption have been determined. Due to the test setup focusing on AC wallbox charging as the only load, the performance KPIs "self-sufficiency" and "self-consumption" are to be understood as solar coverage ratio (instead of self-sufficiency) and solar self-consumption ratio (instead of self-consumption).

The scope of the P3 EMS benchmark tests ranges from physical EMS commissioning, EMS configuration and ecosystem integration to EMS optimization performance and usability. During the tests, the physical commissioning was first examined. Subsequently, the EMS was integrated into the test environment. The EMS solutions were configured for PV surplus charging and tested with a PV simulator as well as the pre-defined inverter and AC wallbox. The test setup was only adjusted with the respective components in case of abnormalities or incompatibility. A Mini Cooper SE from the P3 fleet was used as the test vehicle for all tests.

Overview of Test Configurations for the EMS Benchmark

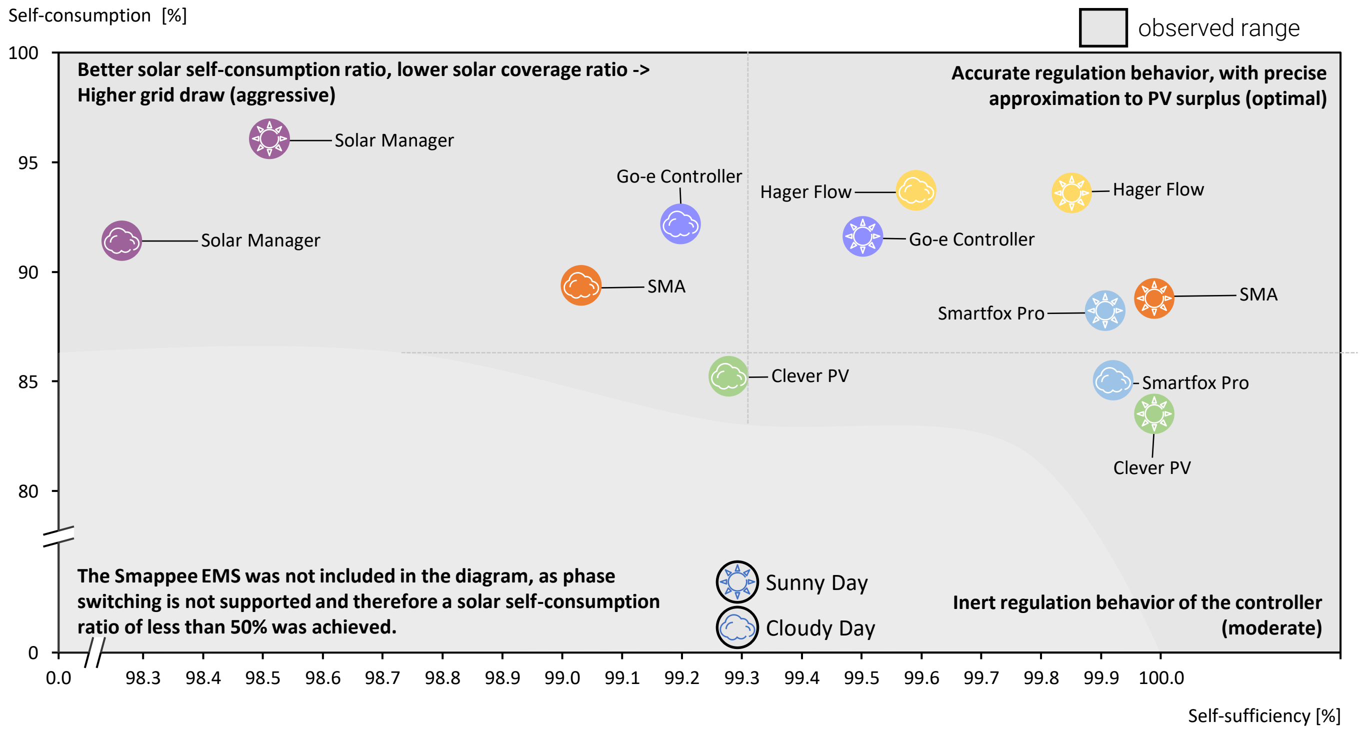
EMS Type	EMS	Inverter	Smart Meter	AC Wallbox	Vehicle (EV)
Agnostic	EMS (tested device)	Fronius Symo	Optional	Alfen Eve-Single Pro-Line	Mini Cooper SE
proprietary	Hager XEM470	Fronius Symo	Hager ECR380D	Hager Witty Solar	Mini Cooper SE
proprietary	Go-e Controller	Fronius Symo	n/a	Go-e Gemini Flex	Mini Cooper SE
proprietary	Smappee Infinity	Fronius Symo	n/a	Smappee EV Wall Business	Mini Cooper SE
agnostic	Solar Manager	Fronius Symo	Shelly EM3	Alfen Eve-Single Pro-Line	Mini Cooper SE
agnostic	Smartfox Pro 2	Fronius Symo	n/a	Alfen Eve-Single Pro-Line	Mini Cooper SE
agnostic	Clever PV	Fronius Symo	Shelly EM3	Go-e Gemini Flex	Mini Cooper SE
proprietary	SMA Sunny Home Manager 2.0	1) SMA Tripower 6.0	n/a	SMA EV Charger	Mini Cooper SE

Source: 1) SMA

Deviating from target configuration

- The target configuration of the EMS benchmark consists of an EMS in combination with the Fronius Symo PV inverter and the Alfen Eve-Single Pro-Line wallbox. Ideally, no additional smart meter is needed. The EV used for all tests is a Mini Cooper SE.
- To ensure comparability of results, the EMS under test should be tested with a predefined AC wallbox, Alfen Eve-Single Pro Line. If compatibility was not given, an alternative AC wallbox has been used. Proprietary EMSs have been tested then with their preferred AC wallbox.
- Most tests have been conducted with the predefined Fronius Symo PV inverter. Except for the Solar Manager, none of the currently tested EMS required a direct connection to the PV inverter. Instead, they could be read either through an additional smart meter, a direct connection to the EMS, or via current clamps, eliminating dependency on the inverter.
- The tests have been conducted with the Mini Cooper SE to standardize the results. It should be noted that the Mini Cooper SE onboard charger charges in plateaus, so not every possible charging value is fed into the test vehicle. The minimum charging current is 6 amperes, and phase switching is natively supported.

Summary of EMS Benchmark Results



In the test, self-consumption rates ranged from 47.71% (Smappee – Cloudy Day) to 95.99% (Solar Manager – Sunny Day), and self-sufficiency rates ranged from 98.28% (Solar Manager – Cloudy Day) to 100% (Smappee – Sunny Day). The values were presented in a chart showing the test results.

To provide a clear presentation of the individual results, the EMS from Smappee was not included in the chart because it showed too low self-consumption rates in the test due to the lack of phase switching.

Energy managers react rather than predict

The question of why manufacturers like Clever PV achieve a self-sufficiency rate of 100% in the sunny test and then "only" 99.28% on a cloudy day can be explained as follows: The maximum usable energy from the PV surplus is a reaction. This means that the current power of the PV system is measured, processed in the EMS, and then passed on to the wallbox. In the test with many fluctuations, the EMS does not react immediately and regulates with a delay.

EMS can achieve 100% self-consumption

Energy Management Systems can theoretically achieve 100% self-consumption; however, in the real test, the vehicle and other consumers are the limiting factors. The onboard charger (control unit for charging the vehicle battery) of the Mini Cooper SE used in the EMS benchmark cannot process any arbitrary charging power.

This is shown by the fact that the charged current energy is adjusted stepwise to the available PV energy. Only when enough power is available from the PV system is the charging power adjusted to the next level. The temporarily excess energy is then fed into the grid or additional energy is drawn from the grid, depending on the regulation. Systems like the Solar Manager quickly switch between levels, increasing self-consumption but also the energy drawn from the grid.

Matched systems perform better

Proprietary systems, which were tested with their own wallboxes, predominantly show an optimal ratio of self-consumption to self-sufficiency. The Hager and Go-e controllers performed very well in the test because these systems are matched to each other. In matched systems, factors such as communication and behavior for phase switching are crucial. In contrast, agnostic systems are merely compatible with certain wallboxes, and detailed tuning between components is usually not present.

Results overview

Hager | Energy Manager XEM470

Hager |
Energy Manager
XEM470

Inverter	Smart meter	Wallbox
		
Fronius | Symo	Hager | Energy Meter	Hager | Witty Solar

	Costs
EMS [1]	550,00 €
Additional components [2]	550,00 €
Software (per year)	-
	1.100,00 €

Installation

- The Energy Manager is designed for DIN rail mounting and is easy to install.
- In addition to the EMS, a smart meter from Hager is required to measure the power fed in by the PV system.
- The connection to the Energy Manager is made via an RS485 interface with Modbus-RTU protocol (wallbox & smart meter).
- The Hager Witty Solar wallbox is required for the commissioning of the Hager Flow Energy Management System, as it is exclusively compatible with Hager's EMS.
- The Energy Manager is integrated into the existing network with three phases and requires a connection to the neutral conductor.
- Commissioning is done via the online portal "Hager Flow," which can be easily accessed using a QR code in the operating manual.
- There are fixed costs for the EMS and the smart meter, while there are no additional ongoing costs for EMS usage.

Cloudy day

Self-consumption

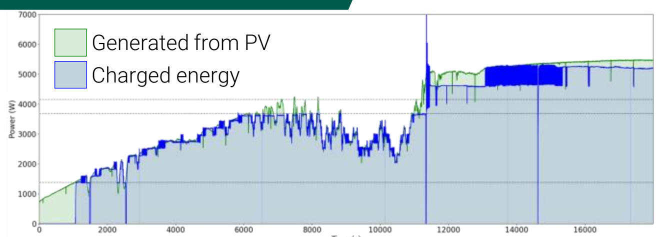
$$\frac{\text{Charged energy from PV}}{\text{Produced PV Energy}} = \frac{17{,}13\,kWh}{18{,}30\,kWh} = 93{,}62\%$$

Self-sufficiency

$$\frac{\text{Charged energy from PV}}{\text{Total charged energy}} = \frac{17{,}13\,kWh}{17{,}20\,kWh} = 98{,}28\%$$

Performance Cloudy Day

In the charging curve of the Hager Energy Manager, a slight noise can be observed. This noise in the upper curve is used to optimize the difference between charging power and PV input, thus making optimal use of the available energy. The noise must be captured finely enough to maximize the area under the curve (integral), making the most of the PV output. The Hager Energy Manager regulates very cautiously, resulting in only 0.07 kWh of energy being drawn from the grid. The charging power is regulated conservatively, so 1.31 kWh of energy is fed back into the grid. This conservative regulation leads to a lower self-consumption rate, achieving a value of 93.62%.



	Energy
Energy drawn from grid	0,07 kWh
Energy fed into the grid	1,31 kWh
Total charged energy	17,20 kWh
Charged energy from PV surplus	17,13 kWh

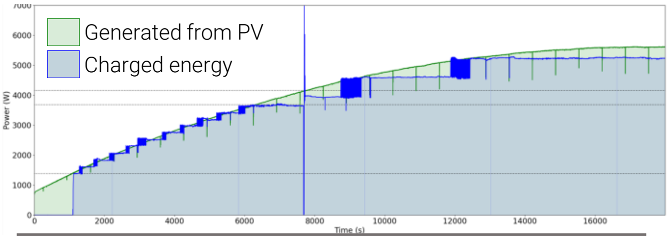
Sunny day

Self-consumption

$$\frac{\text{Charged energy from PV}}{\text{Produced PV Energy}} = \frac{19{,}08\,kWh}{20{,}37\,kWh} = 93{,}66\%$$

Self-sufficiency

$$\frac{\text{Charged energy from PV}}{\text{Total charged energy}} = \frac{19{,}08\,kWh}{19{,}10\,kWh} = 99{,}86\%$$



	Energy
Energy drawn from grid	0,03 kWh
Energy fed into the grid	2,41 kWh
Total charged energy	19,10 kWh
Charged energy from PV surplus	19,08 kWh

Performance Sunny Day

On sunny days, only 0.03 kWh of energy is drawn from the grid. Here too, the conservative regulation, which tries to maximize the PV surplus for charging without drawing from the grid, affects the self-consumption rate, which stands at 93.66%. The Hager Energy Manager exhibits a switching moment during the phase change from single-phase to three-phase operation and starts with the full power of 11 kW, explaining the outlier. Due to the conservative charging behavior, the Hager Energy Manager achieves a self-sufficiency rate of 99.86%. This is because energy is more likely to be fed into the grid rather than drawn from it.

Source: 1) Hager Website; 2) Hager Website

Results overview

Go-e | Controller

Inverter

Fronius | Symo

Wallbox

Go-e | Gemini Flex

	Costs
EMS 1)	250,00 €
Additional components	-
Software (per year)	-
	250,00 €

Go-e Controller

Installation

- The Go-e Controller is designed for DIN rail mounting.
- The EMS operates with the included current clamps, which are connected directly to the controller.
- The wallbox is integrated via a LAN connection over the network and can be operated accordingly.
- The Go-e Controller is connected and commissioned through 3-phases and a neutral conductor connection to an RCD.
- Configuration of the EMS is only possible via the Go-e app.
- The EMS primarily supports Go-e wallboxes. Other types can be integrated via an API interface, which was not considered in the test.
- Settings on the wallbox must be made through the wallbox app and cannot be done via the EMS.
- Apart from the purchase costs, there are no additional costs for using the EMS.

Cloudy day

Self-consumption

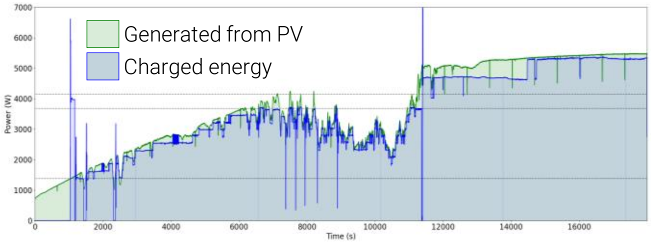
$$\frac{\textit{Charged energy from PV}}{\textit{Produced PV Energy}} = \frac{16{,}85\ kWh}{18{,}27\ kWh} = 92{,}25\%$$

Self-sufficiency

$$\frac{\text{Charged energy from PV}}{\text{Total charged energy}} = \frac{16{,}85\ kWh}{16{,}99\ kWh} = 99{,}2\%$$

Performance Cloudy Day

The PV charging curve of the Go-e Controller shows few overshoots, which reduces the grid draw of the wallbox. This leads to a good self-sufficiency rate of 99.2%, with a total of 136 Wh drawn from the grid. The regulation of the charging power results in a good representation of the PV curve, with only 1.42 kWh of the generated PV energy fed into the grid. During the charging process, there are almost no interruptions. When the threshold values for switching between single-phase and three-phase charging are not met, there are outliers in the charging curve that lead to increased grid draw.



	Energy
Energy drawn from grid	0,136 kWh
Energy fed into the grid	1,42 kWh
Total charged energy	16,99 kWh
Charged energy from PV surplus	16,85 kWh

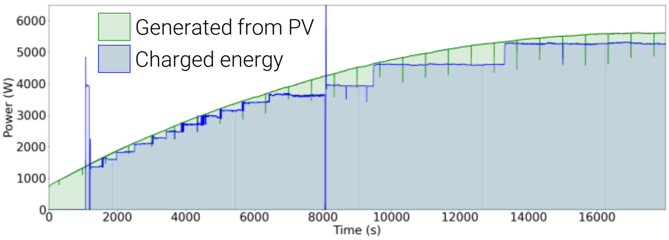
Sunny day

Self-consumption

$$\frac{\textit{Charged energy from PV}}{\textit{Produced PV Energy}} = \frac{18{,}62\ kWh}{20{,}34\ kWh} = 91{,}54\%$$

Self-sufficiency

$$\frac{\text{Charged energy from PV}}{\text{Total charged energy}} = \frac{18{,}62\ kWh}{18{,}71\ kWh} = 99{,}5\%$$



	Energy
Energy drawn from grid	0,093 kWh
Energy fed into the grid	1,72 kWh
Total charged energy	18,71 kWh
Charged energy from PV surplus	18,62 kWh

Performance Sunny Day

On a sunny day, the Go-e Controller also achieves a good result with a grid draw of 93 Wh. The self-consumption rate is very good at 91.54%, and the self-sufficiency rate can be increased to 99.5% on a sunny day. The charging curve shows that the wallbox can closely follow the PV curve in most areas.

Source: 1) Go-e Website

Results overview

Smappee | Infinity

Smappee | Infinity

Inverter

Fronius | Symo

Wallbox

Smappee | EV Wall Business

	Costs
EMS [1]	1.360,00 €
Additional components	-
Software (per year)	-
	1.360,00 €

Installation

- The Smappee Infinity Set can be easily mounted in the door of the control cabinet thanks to its magnetic back. The system's current clamp hubs can be mounted on the DIN rail using cable ties.
- The Infinity Set contains all the components required for PV surplus charging.
- By using two sets of current clamps on the grid and PV side, the Smappee EMS is compatible with all PV inverters but can only be used with Smappee's own wallboxes due to the proprietary solution.
- The set includes pre-assembled cables that simply need to be connected to an RCD. The other components are supplied with power through connecting cables.
- The system can be set up very quickly and easily using the Smappee app.
- Besides the purchase costs, there are no other costs for using the EMS.

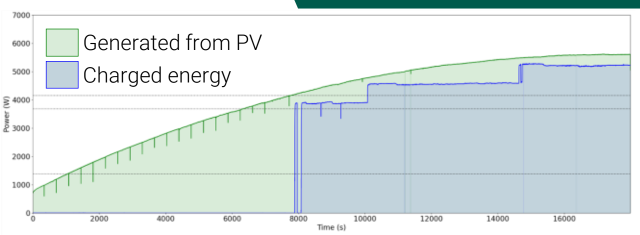
Sunny day

Self-consumption

$$\frac{Charged\ energy\ from\ PV}{Produced\ PV\ Energy} = \frac{12{,}86\ kWh}{20{,}34\ kWh} = \mathbf{63{,}23\%}$$

Self-sufficiency

$$\frac{\text{Charged Energy from PV}}{\text{Total charged energy}} = \frac{12{,}86\ kWh}{12{,}86 kWh} = \mathbf{100\%}$$



	Energy
Energy drawn from grid	0,0 kWh
Energy fed into the grid	7,48 kWh
Total charged energy	12,86 kWh
Charged energy from PV surplus	12,86 kWh

Performance Sunny day

The test revealed that, depending on the connection, charging only works with either one or three phases. After contacting the manufacturer, we were informed that the system supports a phase change on the hardware side, but that the software is not currently capable of doing so. The simulation of a sunny day shows that the Smappee EMS regulates very conservatively, and the charging power is always approximately 300 W below the PV power. As a result, the test was charged exclusively with PV energy and a degree of self-sufficiency of 100% was achieved, while self-consumption was 63.23%.

Cloudy day

Self-consumption

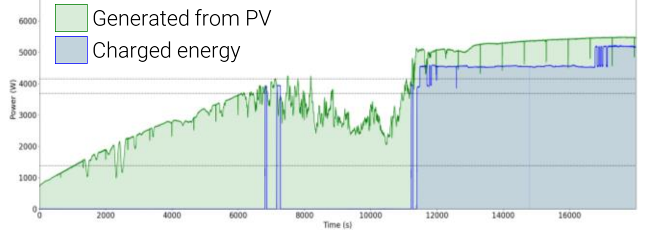
$$\frac{Charged\ energy\ from\ PV}{Produced\ PV\ Energy} = \frac{8{,}73\ kWh}{18{,}29\ kWh} = \mathbf{47{,}71\%}$$

Self-sufficiency

$$\frac{\text{Charged energy from PV}}{\text{Total charged energy}} = \frac{8{,}73\ kWh}{8{,}74\ kWh} = \mathbf{99{,}8\%}$$

Performance Cloudy day

Due to the lack of a phase change function, the system only starts charging approx. 1.5 minutes after the threshold value of 3.9 kW (3-phase) is reached. If the PV power falls below 3.9 kW for 1.5 minutes, the system is switched off again. This results in 9.61 kWh of the PV energy generated being fed directly into the grid, which is why self-consumption is low at 47.71%. However, due to the conservative control of the Smappee, the degree of self-sufficiency is 99.8%.



	Energy
Energy drawn from grid	0,2 kWh
Energy fed into the grid	9,61 kWh
Total charged energy	8,74 kWh
Charged energy from PV surplus	8,73 kWh

Source: 1) galaxus.de

Results overview

Solar Manager

Installation

- Depending on the version, the Solar Manager can either be mounted on a DIN rail or, as in our test, outside the meter cabinet. Installation is therefore very easy thanks to good documentation.
- An external smart meter is required to use the Solar Manager; in our test, we used the Shelly 3EM for €114.95 and integrated it into the system via WiFi.
- Communication with PV inverters and wallboxes takes place using Modbus TCP via Ethernet or WiFi. The DIN rail version of the Solar Manager also enables the integration of devices with Modbus RTU via an RS485 interface.
- Our version was connected using the enclosed power supply unit.
- The Solar Manager is configured via an app or web server; a distinction can be made between installer and user.
- A very large selection of manufacturers and devices is supported. In our test, the Alfen EVE Single Pro-Line was used.
- The Solar Manager offers a BASIC (€48/year) and a PREMIUM subscription (€72/year) for different applications. The first year of subscription is free of charge.

Solar Manager

Inverter	Smart Meter	Wallbox
		
Fronius | Symo	Shelly | EM3	Alfen | Eve Single Pro-Line

	Costs
EMS [1]	850,00 €
Additional components [2]	115,00 €
Software (per year) [3]	48,00 €
	1.013,00 €

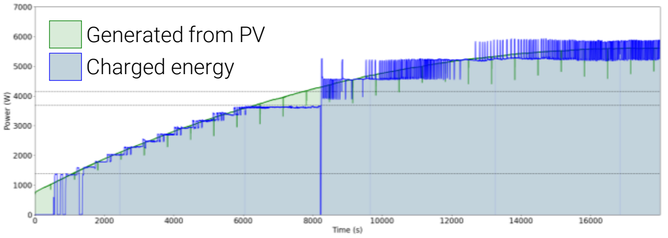
Sunny day

Self-consumption

$$\frac{\text{Charged energy from PV}}{\text{Produced PV energy}} = \frac{19{,}56\ kWh}{20{,}37\ kWh} = 95{,}99\%$$

Self-sufficiency

$$\frac{\text{Charged energy from PV}}{\text{Total charged energy}} = \frac{19{,}56\ kWh}{19{,}85\ kWh} = 98{,}51\%$$



	Energy
Energy drawn from grid	0,29 kWh
Energy fed into the grid	0,899 kWh
Total charged energy	19,85 kWh
Charged energy from PV surplus	19,56 kWh

Performance Sunny day

The PV load curve of the Solar Manager clearly shows many surges above the PV curve, a result of its control strategy to utilize excess PV power. The peaks of these surges correspond exactly to the next charging plateau of the On-Board Charger (OBC). The greater the difference between the next largest OBC charging plateau and the available PV power, the faster the Solar Manager regulates. As a result, the Solar Manager achieves a very high self-consumption rate of 95.99%. The degree of self-sufficiency is 98.51%, with 0.29 kWh drawn from the grid.

Cloudy day

Self-consumption

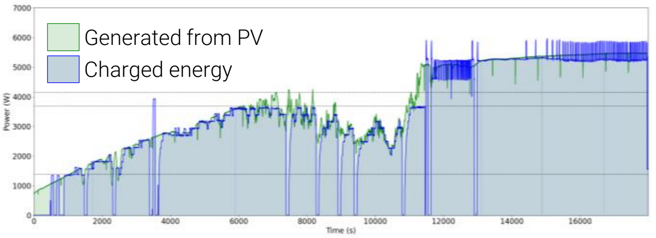
$$\frac{\text{Charged energy from PV}}{\text{Produced PV energy}} = \frac{16{,}69\ kWh}{18{,}26\ kWh} = 91{,}40\%$$

Self-sufficiency

$$\frac{\text{Charged energy from PV}}{\text{Total charged energy}} = \frac{16{,}69\ kWh}{16{,}97\ kWh} = 98{,}28\%$$

Performance Cloudy day

The Cloudy Day test shows some dips in the load curve, which indicates a low hysteresis. However, this only slightly reduces the degree of self-sufficiency to 98.28%. At the same time, the Solar Manager with its control strategy of surges to the next OBC plateau ensures a very good self-consumption of 91.40% even on cloudy days.



	Energy
Energy drawn from grid	0,29 kWh
Energy fed into the grid	1,67 kWh

	Energy
Total charged energy	16,99 kWh
Charged energy from PV surplus	16,69 kWh

Source: 1) mobilityhouse.com; 2) reichelt.de; 3) Solar Manager Website

Results overview

Smartfox | Pro 2

Smartfox | Pro 2

Inverter	Wallbox
	
Fronius | Symo	Alfen | Eve Single Pro-Line

	Costs
EMS [1)]	900,00 €
Additional components	-
Software (per year) [2)]	20,00 €
	920,00 €

Installation

- The Smartfox Pro 2 can be easily integrated into the cabinet by means of a DIN rail. The installation process is easy to follow thanks to the comprehensive documentation.
- For the current measurement, some cables must be disconnected and fitted with special current clamps, which are included with the Smartfox. This means that no additional components are required.
- The inverter and wallbox are integrated via the RS485 or Modbus TCP interfaces.
- Wallboxes from KEBA and Alfen, as well as inverters from Fronius and Kostal, are supported among others.
- The EMS can be configured either via the integrated display, app, or web portal.
- The system is agnostic and can therefore be used with different manufacturers.
- The use of the EMS is largely free of charge, but license costs are incurred for the control of third-party devices, such as wallboxes. In our test, this was €199 for a 10-year license.

Cloudy day

Self-consumption

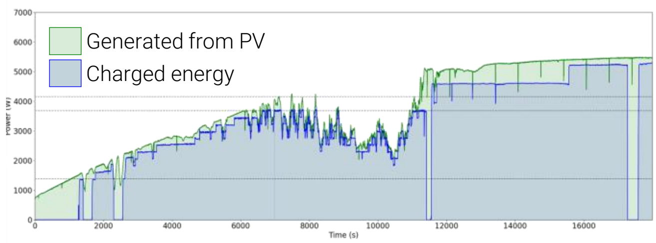
$$\frac{\textit{Charged energy from PV}}{\textit{Produced PV Energy}} = \frac{15{,}53\ kWh}{18{,}29\ kWh} = 84{,}91\%$$

Self-sufficiency

$$\frac{\text{Charged energy from PV}}{\textbf{Total charged energy}} = \frac{15{,}53\ kWh}{15{,}54\ kWh} = 99{,}91\%$$

Performance Cloudy day

The PV load curve of the Smartfox Pro 2 shows almost no surges, which reduces the grid consumption of the wallbox to a minimum. This leads to a very good degree of self-sufficiency of 99.91%, with only 15 Wh being drawn from the grid. The moderate regulation of the charging power also leads to a lower self-consumption of 84.91%, with around 15%, or 2.83 kWh, of the PV energy generated being fed into the grid. There are only a few interruptions in the load curve when the threshold values for switching between single-phase and three-phase charging are not reached and when charging is completely stopped. This indicates that the hysteresis and control values have been carefully set by Smartfox.



	Energy
Energy drawn from grid	0,015 kWh
Energy fed into the grid	2,83 kWh
Total charged energy	15,54 kWh
Charged energy from PV surplus	15,53 kWh

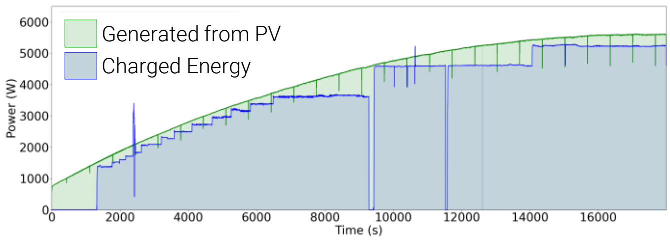
Sunny day

Self-consumption

$$\frac{\textit{Charged energy from PV}}{\textit{Produced PV Energy}} = \frac{17{,}91\ kWh}{20{,}32\ kWh} = 88{,}14\%$$

Self-sufficiency

$$\frac{\text{Charged energy from PV}}{\textbf{Total charged energy}} = \frac{17{,}91\ kWh}{17{,}93\ kWh} = 99{,}92\%$$



	Energy
Energy drawn from grid	0,015 kWh
Energy fed into the grid	2,48 kWh
Total charged energy	17,93 kWh
Charged energy from PV surplus	17,91 kWh

Performance Sunny day

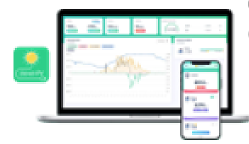
Like in the cloudy day performance test, only 15 Wh of energy are drawn from the grid on sunny days. At 88.14%, self-consumption on a sunny day is slightly better, and the already very good level of self-sufficiency of 99.92% is practically the same as on a cloudy day. The charging curve shows that the wallbox only charges at the maximum power provided by the PV simulator in very few instances. This once again indicates a rather moderate and cautious control in order to avoid drawing energy from the grid as much as possible.

Source: 1) mobilityhouse.com; 2) mobilityhouse.com – Lizenz pro Wallbox kostet 199€ und ist 10 Jahr gültig

Results overview — Clever PV

Installation

- Shelly EM3 electricity meter is required for the operation (€114.95).
- The EMS itself is cloud-based, so no physical installation is required. App and web server are available and can be accessed via QR code. Clear separation between user and installer.
- Connection of external devices is possible and well described, but in our test, it was faulty and time-consuming, as integration via OCPP did not establish an adequate connection and had to be connected via API interface.
- Parameterization of the wallbox works well, but not all setting options are available. In general, very straightforward settings were possible.
- Parameterization of the inverter or the smart meter is not possible; this must be done for the respective devices. Integration is feasible here via API.
- The basic version of the EMS, such as SOC-based charging, is free of charge; however, additional functions such as PV surplus charging must be activated via a monthly subscription. The costs for this currently amount to €6 per month.



Clever PV (Cloud based)

Inverter	Smart Meter	Wallbox
		
Fronius | Symo	Shelly | EM3	Go-e | Gemini Flex

	Costs
EMS	- €
Additional components [1]	115,00 €
Software (per year) [2]	72,00 €
	187,00 €

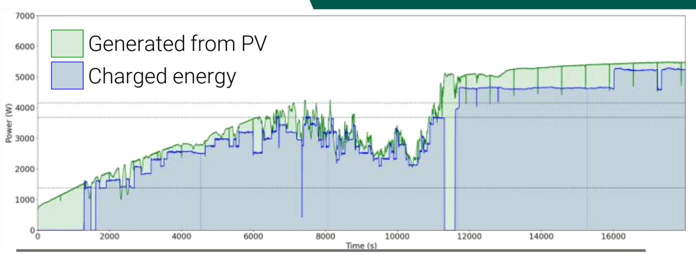
Cloudy day

Self-consumption

$$\frac{\textit{Charged energy from PV}}{\textit{Produced PV energy}} = \frac{15{,}52\ kWh}{18{,}38\ kWh} = \mathbf{85{,}18\%}$$

Self-sufficiency

$$\frac{\text{Charged energy from PV}}{\text{Total charged energy}} = \frac{15{,}52\ kWh}{15{,}73\ kWh} = \mathbf{99{,}28\%}$$



	Energy
Energy drawn from grid	0,69 kWh
Energy fed into the grid	2,71 kWh
Total charged energy	15,73 kWh
Charged energy from PV surplus	15,52 kWh

Performance Cloudy day

Even on cloudy days, the moderate control behavior of Clever PV leads to a high degree of self-sufficiency (99.28%) and low self-consumption (85.18%). Compared to a physical EMS solution, the cloud-based solution is not able to regulate as quickly due to a longer time delay. In addition, there is a comparatively high hysteresis for the phase change (1-phase to 3-phase), which in turn affects the self-consumption and thus reduces its value.

Sunny day

Self-consumption

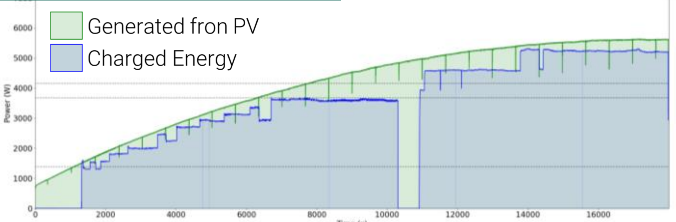
$$\frac{\textit{Charged energy from PV}}{\textit{Produced PV energy}} = \frac{16{,}93\ kWh}{20{,}34\ kWh} = \mathbf{83{,}24\%}$$

Self-sufficiency

$$\frac{\text{Charged energy from PV}}{\text{Total charged energy}} = \frac{16{,}930\ kWh}{16{,}932\ kWh} = \mathbf{99{,}99\%}$$

Performance Sunny day

The adaptation of the load curve to the PV curve is moderate. On the one hand, this strategy leads to a remarkably high degree of self-sufficiency of almost 100%. However, this is accompanied by a low self-consumption of 83.24%. This configuration means that a considerable amount of energy is fed into the grid. It should also be noted that the switch from 1 to 3 phases is associated with a relatively long interruption. The charging process only starts from a threshold value of around 1500 W.



	Energy
Energy drawn from grid	0,002 kWh
Energy fed into the grid	3,44 kWh
Total charged energy	16,932 kWh
Charged energy from PV surplus	16,930 kWh

Source: 1) reichelt.de; 2) Clever PV Website

Results overview

SMA | Sunny Home Manager 2.0

SMA | Sunny Home Manager 2.0

Inverter	Wallbox
	
SMA | Tripower	SMA | EV Charger 7.4 / 22

	Costs
EMS [1]	620,00 €
Zusätzliche Komponenten	-
Software (pro Jahr)	-
	620,00 €

Installation

- The Sunny Home Manager 2.0 (SHM) is designed for DIN rail mounting and has an integrated power meter.
- The wallbox is integrated via the network using a LAN connection and can be operated from there.
- The SHM is connected to an RCD via a 3-phase + neutral conductor connection and thus put into operation.
- The EMS can be configured both via the SMA 360° app and via a web server.
- In the first instance, the EMS supports its own SMA EV Charger Wallbox. In addition, Mennekes AMTRON wallboxes can also be integrated, but this was not covered by the test.
- The SHM supports the Modbus TCP, EEBUS, and SEMP (Simple Energy Management Protocol) protocols and interfaces.

Cloudy day

Self-consumption

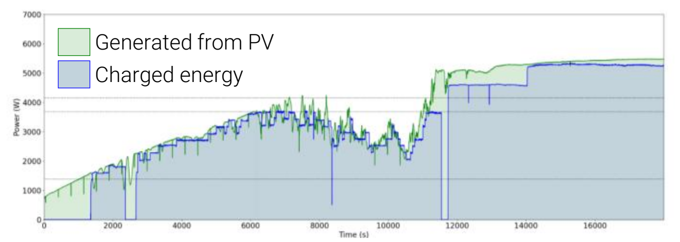
$$\frac{\text{Charged energy from PV Ü}}{\text{Produced PV energy}} = \frac{16{,}37\ kWh}{18{,}34\ kWh} = 89{,}27\%$$

Self-sufficiency

$$\frac{\text{Charged energy from PV}}{\text{Total charged energy}} = \frac{16{,}37\ kWh}{16{,}53\ kWh} = 99{,}03\%$$

Performance Cloudy day

SMA's Sunny Home Manager regulates the charging power of the wallbox closely to the PV power generated. At the same time, the control shows few overshoots, which keeps the grid consumption low and thus realizes a self-consumption of 89.27%. The system takes a comparatively long time to switch phases, which is why 2 kWh is fed into the grid. With a degree of self-sufficiency of 99.03%, the SHM ensures a very good ratio between the PV energy generated and the total energy charged.



	Energy
Energy drawn from grid	0,16 kWh
Energy fed into the grid	2,00 kWh
Total charged energy	16,53 kWh
Charged energy from PV surplus	16,37 kWh

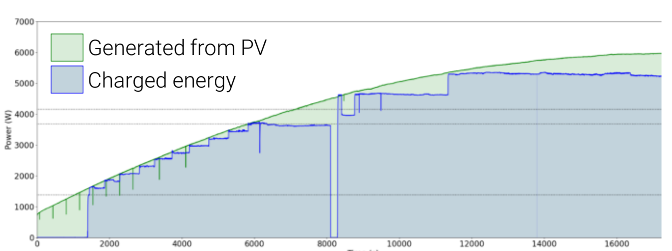
Sunny day

Self-consumption

$$\frac{\text{Charged energy from PV Ü}}{\text{Produced PV energy}} = \frac{19{,}11\ kWh}{21{,}49\ kWh} = 88{,}88\%$$

Self-sufficiency

$$\frac{\text{Charged energy from PV}}{\text{Total charged energy}} = \frac{19{,}11\ kWh}{19{,}11\ kWh} = 99{,}99\%$$



	Energy
Energy drawn from grid	0,002 kWh
Energy fed into the grid	2,43 kWh
Total charged energy	19,11 kWh
Charged energy from PV surplus	19,11 kWh

Performance Sunny day

The SHM controller ensures very low grid consumption of less than 2 Wh. As the PV load curve shows, the system regulates in small steps for charging capacities below 4 kW and thus enables very efficient use of PV energy. Above 4kW charging power, the control steps become significantly larger, so the system's self-consumption is 88.88% and 2.43kWh of energy is fed into the grid. Thanks to the conservative control, the system achieves a degree of self-sufficiency of 99.99%

Source: 1) sonnenshop.de

Lessons Learned

Lack of interoperability

During the benchmark, it became clear that there are major differences between EMS manufacturers in terms of interoperability with third-party suppliers of inverters, BEV chargers, and smart meters. Established market players often impose certain restrictions on their EMS solutions, which is reflected in the fact that they are either exclusively interoperable with the manufacturer's own peripheral devices or only with a selected small group of third-party manufacturers. New entrants often offer very broad interoperability without compromising on performance.

Automatic phase shifting is essential

For the test scenario of solar-optimized charging and the goal of achieving the highest possible solar self-consumption rate, the availability for a BEV charger to support automatic phase shifting is crucial.

If the charger used does not support automatic phase shifting, switching is usually carried out manually by the user. The wallbox is often initially operated in single-phase mode and then manually shifted to three-phase when the power requirement increases. However, this procedure has the effect that optimization potential remains unused.

Fewer differences in solar coverage percentages (degree of self-sufficiency) than in self-consumption percentages

The EMS solutions tested perform similarly and only differ slightly from each other if they support the automatic phase shift function. The solar coverage rates are between 98% and 99%, while the solar self-consumption rates for the cloudy day scenario differ significantly between 84% and 94%. This difference is due to the variability and control quality of the phase-shifting EMS products, such as the distinction between a moderate and aggressive control method, phase shifting (as described earlier), and the impact of time delays in cloud-based solutions compared to local gateway-based solutions.

EMS based on local gateways are the current standard, while cloud-only solutions are on the rise

Most of the EMS solutions available to date are hardware IoT devices (local gateways) that have to be installed on site. These solutions have the advantage of being particularly reliable as they are less susceptible to external influences such as network disruptions or cyber-attacks. As the control takes place directly on the hardware, local gateway-based EMS solutions also react quickly to changes in the local energy flow. In general, a continuous connection to external cloud services is not essential to function properly.

Nevertheless, new market entrants are increasingly turning to cloud-based EMS solutions. Compared to local gateway-based alternatives, these often offer much greater interoperability with third-party providers, do not require local installation, and new functions can usually be implemented more quickly. This means they can be installed by non-experts with just a few clicks. In addition, the time lag with cloud-based solutions could be an issue, as the physical limitations of data exchange via the cloud affect control performance, especially in terms of real-time response to load changes.

Still have questions? Feel free to contact us.

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