New Energy Grid

⚡ FIELD INSTALLATION & COMMISSIONING MANUAL

GEMS Installer Manual

Complete Field Engineering Guide: Hardware Assembly, Local Subnet Discovery, 140 Device Templates, Multi-Phase Grid Limits, Dynamic Contract Wizards, and Optimization Strategy

SYSTEM FIRMWARE / BUILD
v9.25.3-release (Official Tag)

HARDWARE ARCHITECTURE
Raspberry Pi 5 (ARM64) + M.2 NVMe HAT

TARGET AUDIENCE
Certified Electricians, Solar & Battery Installers

DOCUMENTATION REVISION
September 2026 • 140 Templates Edition

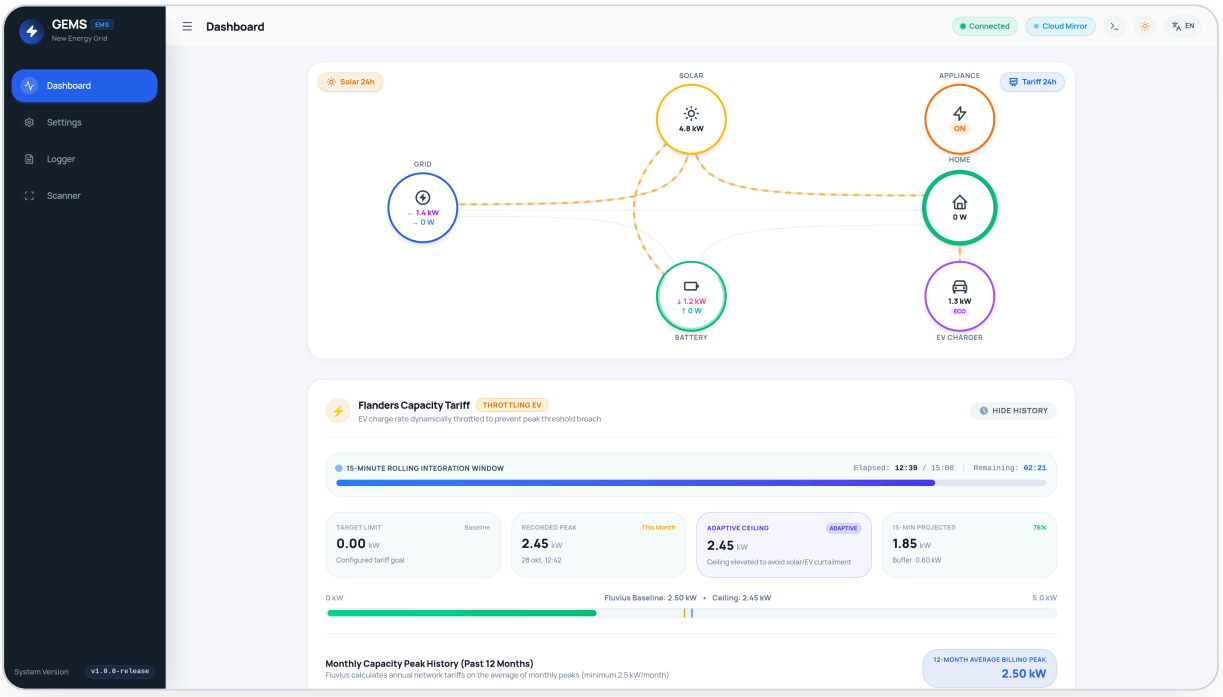


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1. Hardware Architecture & Bill of Materials (BOM)

GEMS is an autonomous, lightweight edge controller engineered in Go (Golang) and Vue 3. It runs entirely on the customer's local network without requiring cloud subscription dependencies. To eliminate the historical failure point of MicroSD card wear in electrical cabinets, GEMS operates exclusively from an **M.2 NVMe SSD** utilizing SQLite configured in Write-Ahead Logging (WAL) mode.

Reference Hardware Bill of Materials

Component	Specification & Part Reference	Field Selection Guidance & Trade-offs
Host Single Board Computer	Raspberry Pi 5 (4GB or 8GB RAM, Broadcom BCM2712 Quad-core Cortex-A76)	**Why Pi 5:** Features an exposed 16-pin PCIe 2.0 interface. Memory footprint remains < 150MB RAM during 100 concurrent Modbus polls. 4GB is ideal; 8GB provides extra headroom for local telemetry history.
Internal Solid State Drive	128GB to 512GB M.2 2280 or 2230/2242 PCIe NVMe SSD (TLC / 3D NAND)	**Why NVMe:** Delivers 450+ MB/s sequential write speed and 50,000+ IOPS. Eliminates flash wear from high-frequency time-series database logging. *Do not use MicroSD cards for production installations.*
M.2 PCIe HAT Adapter	Official Raspberry Pi M.2 HAT+ or Pimoroni NVMe Base	Mounts directly atop the 40-pin GPIO header or beneath the Pi. Ensure the 16-pin FPC ribbon cable is seated with gold pins oriented toward the board contacts.
Power Supply Unit (PSU)	Official Raspberry Pi 27W USB-C PD (5.1V / 5.0A Power Delivery)	**Critical:** Standard 15W phone chargers will cause under-voltage brownouts when the NVMe drive draws peak write current.
Enclosure & DIN Mounting	Aluminium Armor Enclosure with Active Cooler fan + DIN-Rail adapter clip	Sustains core temperature below 48°C inside closed distribution panels. Active Cooler fan speed is managed dynamically via PWM by the Linux kernel.
Serial Fieldbus Adapter	FTDI FT232R / FT232RL USB-to-RS485 with 2.5 kV Galvanic Isolation or DIY P1 cable	Required for Modbus RTU (Eastron, Carlo Gavazzi) or direct RJ12 P1 port reading. Galvanic isolation prevents ground loops between the inverter and the Pi.

2. NVMe Bootloader Setup & EEPROM Flashing

Factory Raspberry Pi 5 units ship configured to boot solely from MicroSD (boot order `0×f41`). When booting directly from an M.2 NVMe SSD without a MicroSD card inserted, the Raspberry Pi EEPROM must be updated.

📋 **DECISION GUIDE: HOW SHOULD YOU PREPARE THE HARDWARE?**

Option 1: In the Workshop (Fastest)
Use a USB M.2 NVMe enclosure connected to your laptop. Flash the pre-configured OS image directly to the SSD using BalenaEtcher or Raspberry Pi Imager. Takes 2 minutes.

Option 2: On-Site in the Field
Keep a spare MicroSD card containing the Raspberry Pi EEPROM boot utility in your toolbag. Boot the Pi once with this SD card to permanently enable PCIe NVMe booting.

🌟 **3-Minute EEPROM Setup Procedure**

1. Insert any temporary MicroSD card into your laptop.
2. Open **Raspberry Pi Imager** → Choose Device: **Raspberry Pi 5**.
3. Choose OS: **Misc utility images** → **Bootloader** → **NVMe/PCIe Boot**.
4. Select the MicroSD card, click **Write**, and insert into the Pi 5.
5. Power on with the official 27W power supply. Within 5 seconds, the green ACT LED will flash rapidly and the HDMI screen will turn **solid green**.
6. Disconnect power and remove the MicroSD card. The Pi 5 is now permanently set to `BOOT_ORDER=0×f461` and will automatically boot from the NVMe SSD!

Enabling PCIe Gen 3.0 Speeds (Optional Workshop Optimization)

By default, the Pi 5 operates PCIe at Gen 2.0 speeds (500 MB/s). To unlock PCIe Gen 3.0 (up to 850 MB/s), edit `/boot/firmware/config.txt` and add:

```
# Enable PCIe Gen 3.0 speeds
dtparam=pciex1
dtparam=pciex1_gen=3
```

3. OS Deployment & System Service Management

Installers can deploy GEMS using two approved methods:

Deployment Method Comparison

Feature	Method A: Pre-built GEMS OS Image (.img.xz)	Method B: Debian Package (.deb) on Stock OS
Recommended For	New turnkey hardware installations	Existing Debian / Raspberry Pi OS installations
Kiosk Touchscreen	Pre-configured Wayfire Wayland fullscreen browser	Manual browser configuration required
Reverse Proxy	Pre-installed Nginx (Port 80/443 → 8080) with WebSockets	Standard direct backend on Port 8080
Remote Web Console	Pre-installed Cockpit on Port 9090	Can be installed via `apt install cockpit`
Installation Time	~3 minutes (direct disk flash)	~5 minutes (package download and dpkg install)

Method B: Debian Package Installation Commands

```
# 1. Download official ARM64 package
wget https://github.com/webdotpulse/GRID-EMS/releases/download/v9.13.2-
release/gems_9.13.2_arm64.deb

# 2. Install package and dependencies
sudo dpkg -i gems_9.25.3_arm64.deb
sudo apt-get install -f

# 3. Verify systemd background service
sudo systemctl status gems.service
```

📂 **System File Locations**

- **Binaries:** `/opt/gems/gems`
- **Configuration File:** `/etc/gems/config.json`
- **SQLite Database:** `/var/lib/gems/gems.db` (with `gems.db-wal`)
- **System User:** Runs under unprivileged user `gems` with dialout group access.

4. Remote Access, Cockpit & Kiosk Display

Once installed in an electrical panel, physical keyboards and monitors are unnecessary. The technician can access all diagnostic and operational tools remotely:

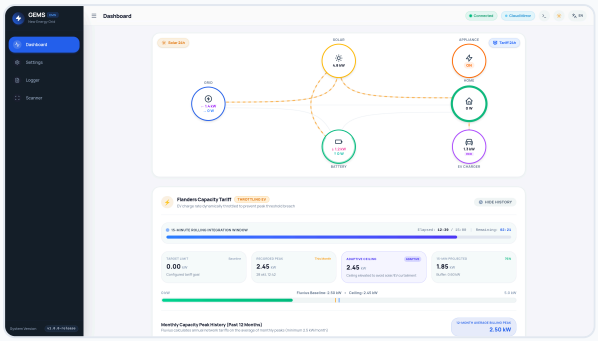


Figure 4.1: Primary Web Interface (Port 80 / 8080).

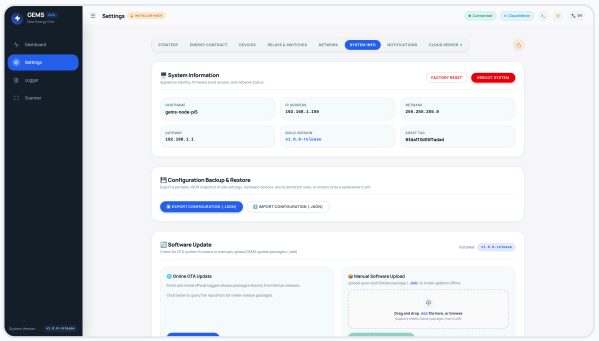


Figure 4.2: System Identity, Network Configuration & Build Version.

Access Interface	URL / Endpoint	Default Credentials	Primary Purpose
GEMS Web UI	`http://ems.local` or `http://<IP-ADDRESS>`	No password on local LAN	Daily energy dashboard, device configuration, tariffs, and strategy rules.
GRID-EMS-SERVER (Cloud)	`https://ems.newenergygrid.com`	Pairing Token (Settings → Cloud)	Optional remote multi-site fleet management, remote client diagnostics, and mobile app access.
Cockpit Web Console	`https://<IP-ADDRESS>:9090`	Provisioned Linux Admin Account	Browser terminal, NVMe drive SMART health, OS diagnostics, reboot.
Raspberry Pi Connect	`https://connect.raspberrypi.com`	Installer's Raspberry Pi ID	Secure remote desktop view without port forwarding or VPNs.

4.1 Optional Cloud Synchronization (GRID-EMS-SERVER)

Installers can link customer units to the central cloud platform **GRID-EMS-SERVER** (`https://ems.newenergygrid.com`).

> 💡 **Edge Autonomy & 100% Optional Cloud Connectivity**
>
> GEMS is built with a **local-first architectural guarantee**. Cloud connectivity is **100% optional**: the unit operates with full autonomy, executing sub-second DLB, inverter curtailment, battery arbitrage, and relay automation with zero cloud dependency. When paired, it adds encrypted remote fleet oversight and remote command dispatch without requiring open router ports.

- **Fast Commissioning:** Navigate to **Settings → Cloud Server**, enter the 16-character pairing token, and click *Pair & Connect Now*. Registration completes in under 15 seconds.
- **Outbound-Only TLS 1.3:** Edge controllers initiate outbound HTTPS telemetry pushes. Inbound router port forwarding, static public IPs, and DDNS are strictly unnecessary.

- **Remote Fleet Orchestration:** Fleet managers can remotely update strategy modes, adjust battery operational states, throttle EV charging currents, and trigger diagnostics.

4.2 Local CA Certificate & Zero-Warning HTTPS (localhost, ems.local & Custom Domains)

Browsers natively reject standard self-signed certificates with security warnings (such as `NET::ERR_CERT_AUTHORITY_INVALID`). To ensure a smooth, secure customer and technician experience with green padlock verification, GEMS includes a dedicated **Local Certificate Authority (CA) engine**.

> **🔒 Automatic SAN Coverage & Dynamic Zero-Downtime Reloads**
> GEMS automatically populates Subject Alternative Names (SANs) for all loopback addresses (`localhost`, `127.0.0.1`, `::1`), default mDNS hostnames (`ems.local`, `gems.local`, `*.ems.local`, `*.gems.local`), active local interface IPs, and any configured custom local domains (e.g. `myems.lan`). When custom domains are added, GEMS regenerates the certificate on the fly and hot-reloads it with zero service interruption.

Task	Method / Endpoint	Action Details
Download Root CA	`http://<ip>:8080/api/ca.crt` (or `/ca.crt`)	Download public Root CA certificate directly to client device or laptop.
Automated Linux / NSS Setup	`./scripts/setup-local-ca.sh [custom domains ...]`	Automates certificate generation and registers CA into Chrome NSS (`~/.pki/nssdb`) and Firefox.
Web UI Custom Domains	**Settings → System Information → Local CA & SSL**	Enter comma-separated domains and click *Save & Regenerate Certificate*.

5. Subnet Hardware Discovery (The Scanner)

Instead of guessing IP addresses assigned by the customer's router, use the built-in **Scanner** in the primary navigation sidebar.

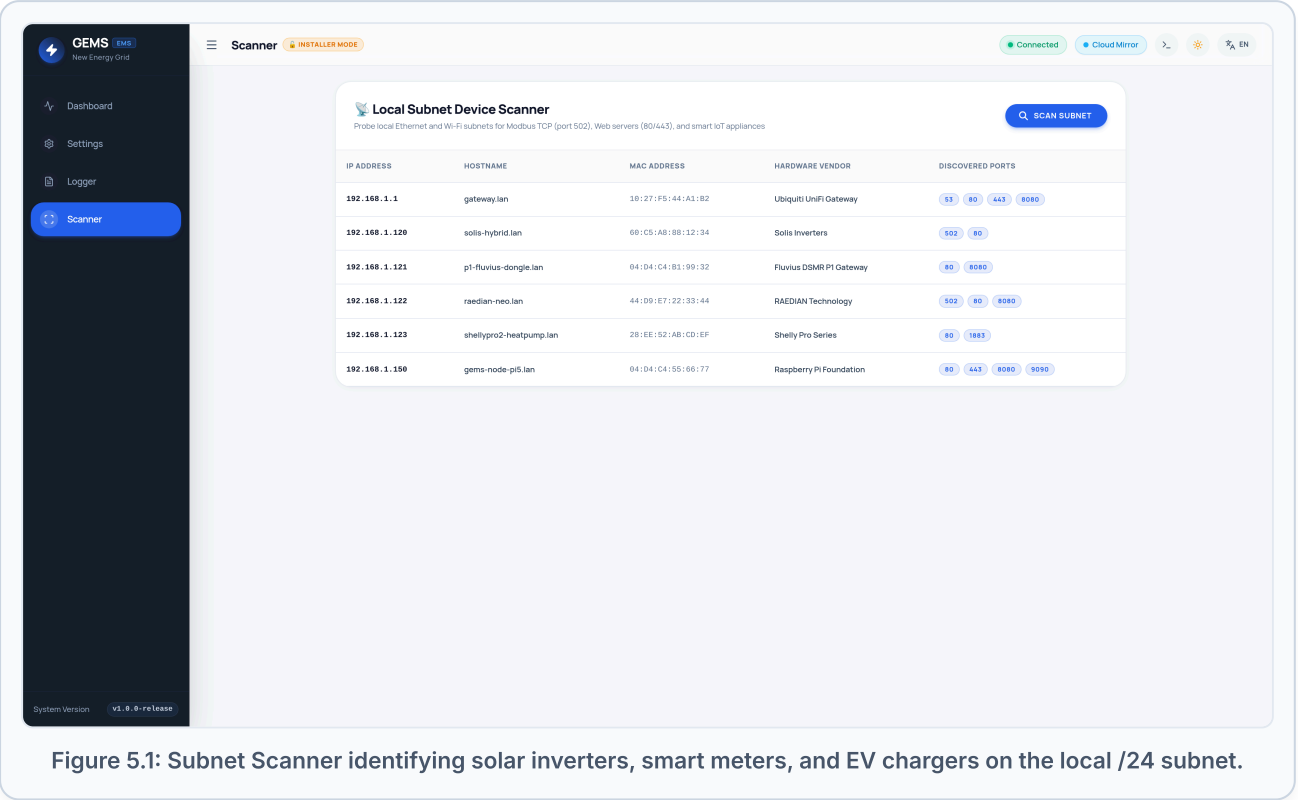


Figure 5.1: Subnet Scanner identifying solar inverters, smart meters, and EV chargers on the local /24 subnet.

How the Scanner Operates

When you click **"Scan Subnet"**, GEMS initiates a parallel sweep across the local `/24` subnet (254 host addresses):

1. **ARP Resolution:** Queries MAC addresses and resolves them against IEEE vendor OUI registries (e.g. *Huawei Technologies*, *SMA Solar Technology*, *Shelly / Allterco*, *Alfen*).
2. **Port Probing:** Tests open TCP ports associated with energy hardware:
    - **Port 502 / 1502:** Modbus TCP (Inverters, Batteries, EV Chargers, Eastron meters).
    - **Port 80 / 8080 / 443:** REST APIs (Shelly relays, HomeWizard P1 meters, Fronius Solar API).
    - **Port 8887:** GEMS embedded OCPP WebSocket server.
3. **One-Click Onboarding:** Clicking **"Add Device"** next to any detected host automatically pre-fills the IP address, Port, and relevant template in the Device Wizard!

6. Device Onboarding & The 140 Hardware Templates

GEMS contains a built-in library of **140 native hardware templates** spanning all major European solar, battery, smart meter, EV charger, and smart relay brands. Configuration is 100% UI-driven without touching configuration text files.

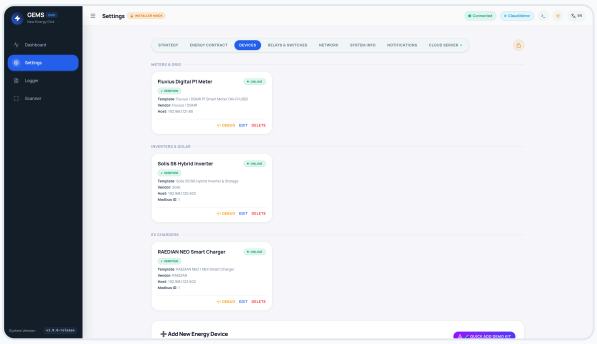


Figure 6.1: Active devices list showing live health tags and polling status.

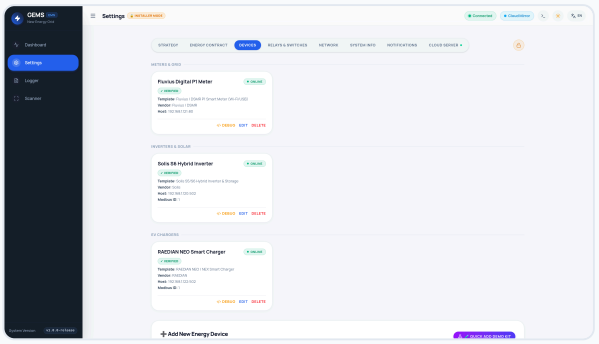


Figure 6.2: Device Category Picker Wizard.

Step-by-Step Device Onboarding Walkthrough

1. Navigate to **Settings** → **Devices**.
2. Click **"+ Add New Energy Device"**.
3. Select the hardware category (*Inverters & Solar*, *Smart Meters*, *EV Chargers*, or *Smart Relays*).
4. Select the appropriate hardware template from the dropdown list.
5. Configure the communication parameters according to the tables below.
6. Click **"Save Device"**. The backend initiates immediate polling and updates status to ● **Online**.

> **Testing & Simulation: 1-Click Demo Devices**
>
> To test the EMS control loop, verify dynamic load balancing, or demonstrate the hero energy flow diagram before physical hardware is connected, click **"🧪 Quick Add Demo Kit"** in the Devices tab. This provisions a coordinated 4-device test suite (Smart Meter, Solar Inverter, Battery Storage, and EV Wallbox) running realistic physics simulations with variable real-life values. Individual demo templates (`demo_meter`, `demo_solar`, `demo_battery`, `demo_charger`, `demo_relay`) can also be selected directly from each category picker.

Category A: Solar & Hybrid Inverters (Modbus TCP)

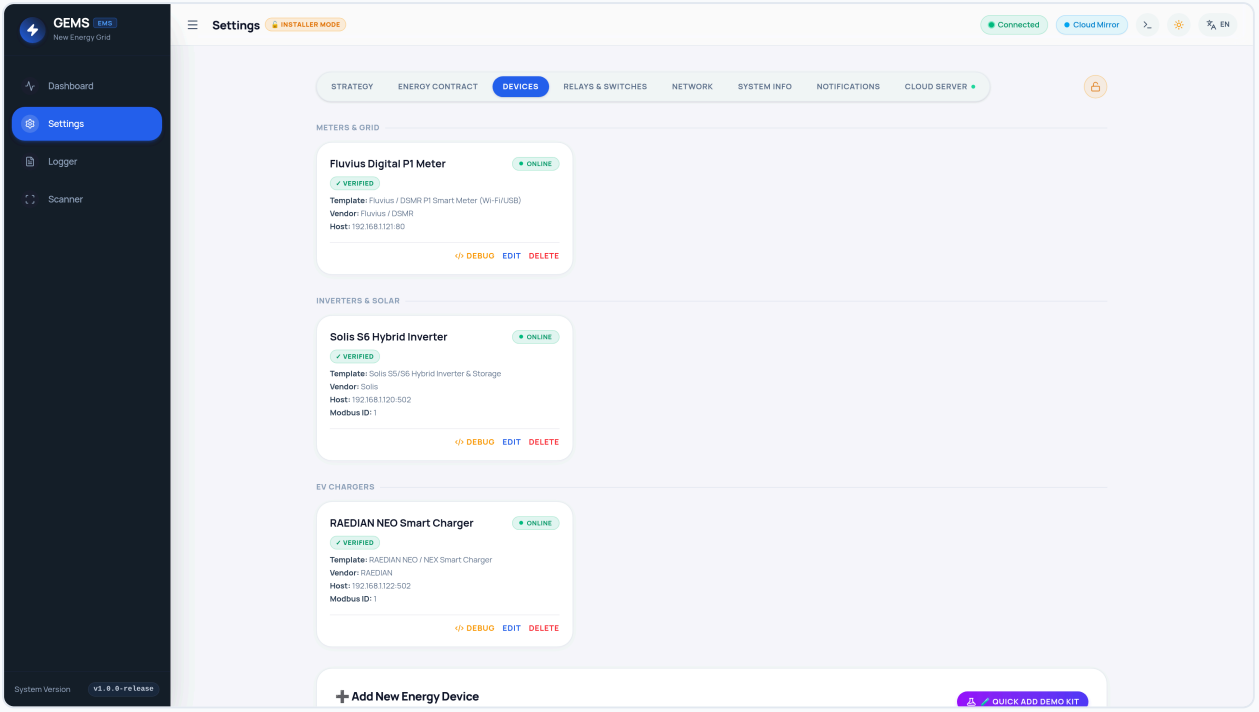


Figure 6.3: Inverter configuration modal showing Modbus TCP, slave ID, rated power, and battery flags.

Field Name	Field Type	Installer Explanation & When to Choose
`Device Name`	Text	Descriptive label displayed on the dashboard (e.g. *"Huawei SUN2000-10KTL"*).
`Device Template`	Dropdown	Select your manufacturer: *Huawei SUN2000*, *SMA Sunny Boy / Tripower*, *Solis 5G/S6*, *Fronius Gen24*, *SolarEdge SunSpec*, *Sungrow SG*, *GoodWe ET*, *Victron GX*, or *Generic SunSpec*.
`Host IP`	IPv4 Address	Local IP of the inverter's Wi-Fi or Ethernet dongle (e.g. Huawei SDongleA-05 at `192.168.1.120`). Set a static DHCP reservation in the home router.
`Modbus Port`	Integer	Standard Modbus TCP port is **502**. Third-party gateways or bridges occasionally use **1502** or **5020**.
`Modbus Slave ID`	Integer (1-247)	Unit ID on the internal RS485 loop. Huawei defaults to **1** (inverter) or **2** (secondary). SolarEdge defaults to **126**. SMA defaults to **126** or **3**.
`Rated Power (kW)`	Decimal (kW)	**Crucial:** Enter the nominal AC power rating of the inverter (e.g. `10.0` for a 10 kW inverter). GEMS uses this value to scale percentage-based active power curtailment commands.
`Allow Curtailment`	Checkbox	**When to Check:** If the customer has a dynamic contract and you want GEMS to throttle inverter production during severe negative export price events. If unchecked, the inverter produces freely regardless of grid tariffs.
`Has Grid Meter?`	Checkbox	**When to Check:** If an inverter-attached CT meter (like Huawei DTSU666-H) is connected to the inverter. GEMS can read grid import/export directly from the inverter registers!
`Has Battery?`	Checkbox	**When to Check:** If a DC-coupled storage battery (e.g. Huawei LUNA2000, BYD Battery-Box) is connected. Enables battery charge/discharge telemetry and state-of-charge tracking.
`Poll Interval (s)`	Integer (seconds)	Default is **2 seconds**. For Huawei dongles, 2s or 3s provides smooth responsiveness without overwhelming the dongle's internal microprocessor.

Category B: Grid Smart Meters (P1 Serial, Wi-Fi Bridges & Modbus)

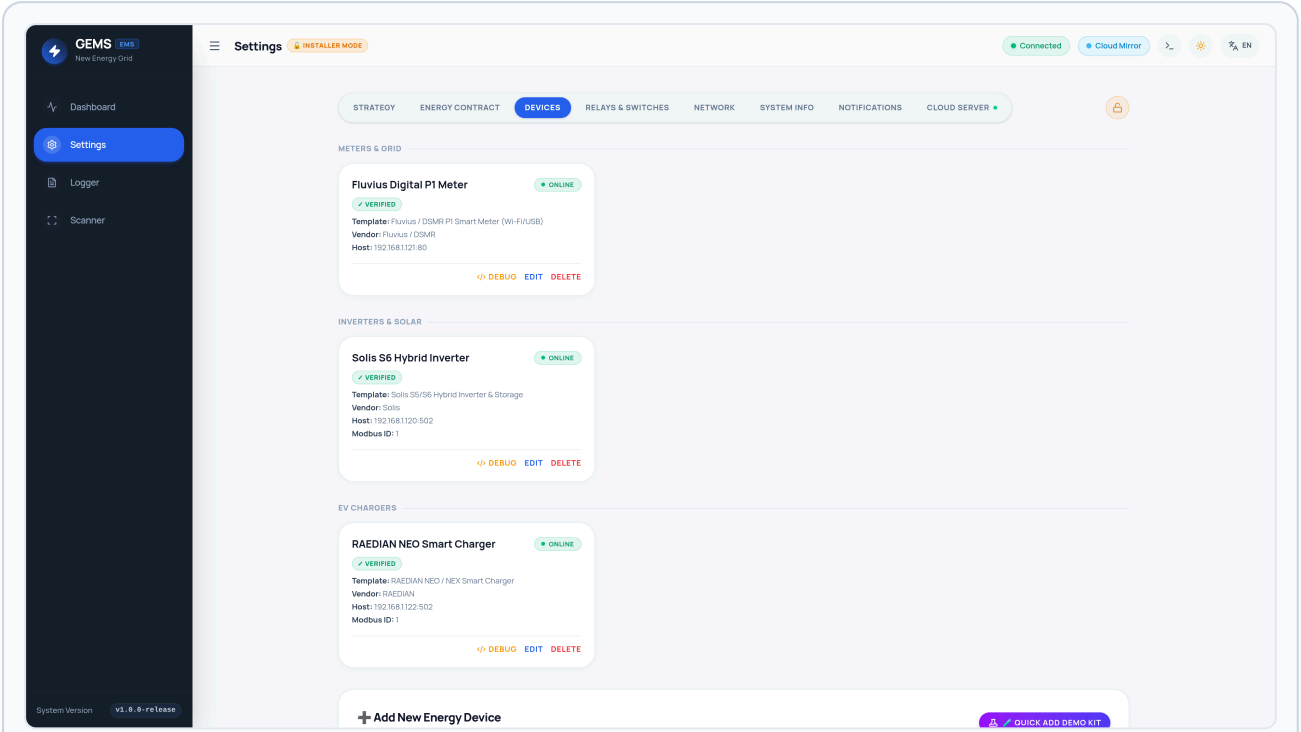


Figure 6.4: Smart Meter configuration modal supporting P1 serial cables, Wi-Fi dongles, and Modbus DIN meters.

Meter Connection Type	Supported Templates	Field Values & Setup Notes
Direct P1 Serial Cable	Fluvius / DSMR P1 Serial (Belgium & Netherlands)	Set Serial Port to `/dev/ttyUSB0`. Baud rate: `115200` (DSMR 5.0.2 / e-MUCS v1.4) or `9600` (DSMR 4.2). GEMS automatically parses telegram CRC checksums.
P1 Wi-Fi Dongle (REST/TCP)	HomeWizard P1 Meter, ESP8266/ESP32 P1 Bridge	Enter dongle IP (e.g. `192.168.1.121`). Port `80` (REST API) or Port `8234` (raw TCP serial stream). Zero physical wiring to the Pi!
Modbus RTU / TCP DIN Meters	Eastron SDM630 3-Phase, Carlo Gavazzi EM24, Schneider iEM3000, Shelly 3EM / Pro 3EM	Modbus RTU: USB-to-RS485 adapter at 9600 baud, 8N1, Slave ID `1`. Modbus TCP: Enter bridge IP and port `502`. Shelly Pro 3EM: Enter device IP and port `80`.

Category C: EV Charging Stations (Modbus TCP vs Native OCPP)

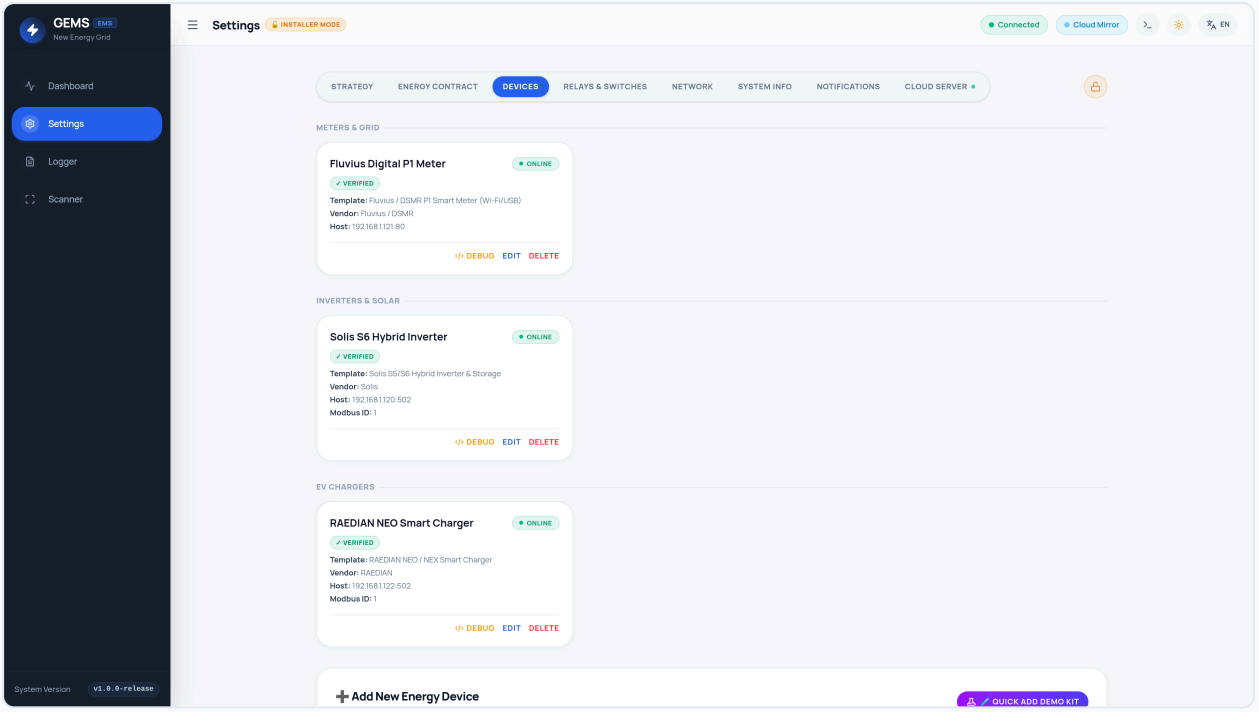


Figure 6.5: EV Charger configuration modal supporting preferred Modbus TCP and native OCPP 1.6-J.

⚡ DECISION GUIDE: MODBUS TCP VS OCPP FOR EV CHARGERS

Modbus TCP (Recommended & Preferred)

Sub-second response: Throttles from 6A to 32A in under 200ms.

Employer billing coexistence: Does NOT interfere with the charger's cloud OCPP connection (external CPO billing services). Both work simultaneously!

Native OCPP 1.6-J (Alternative / Proxy)

Use when the charger does not support Modbus TCP, or when using the Straight-Through OCPP Proxy. The charger points its WebSocket directly to GEMS on port `8887` (`ws://<GEMS-IP>:8887/<ID>`) or port `8080` (`ws://<GEMS-IP>:8080/api/ocpp/<ID>`).

7. Grid Connection, Multi-Phase Setup & Earthing

Navigate to **Settings → Strategy → Grid Connection & Limits**. Accurate configuration of the physical main breaker prevents tripped utility fuses and allows dynamic load management.

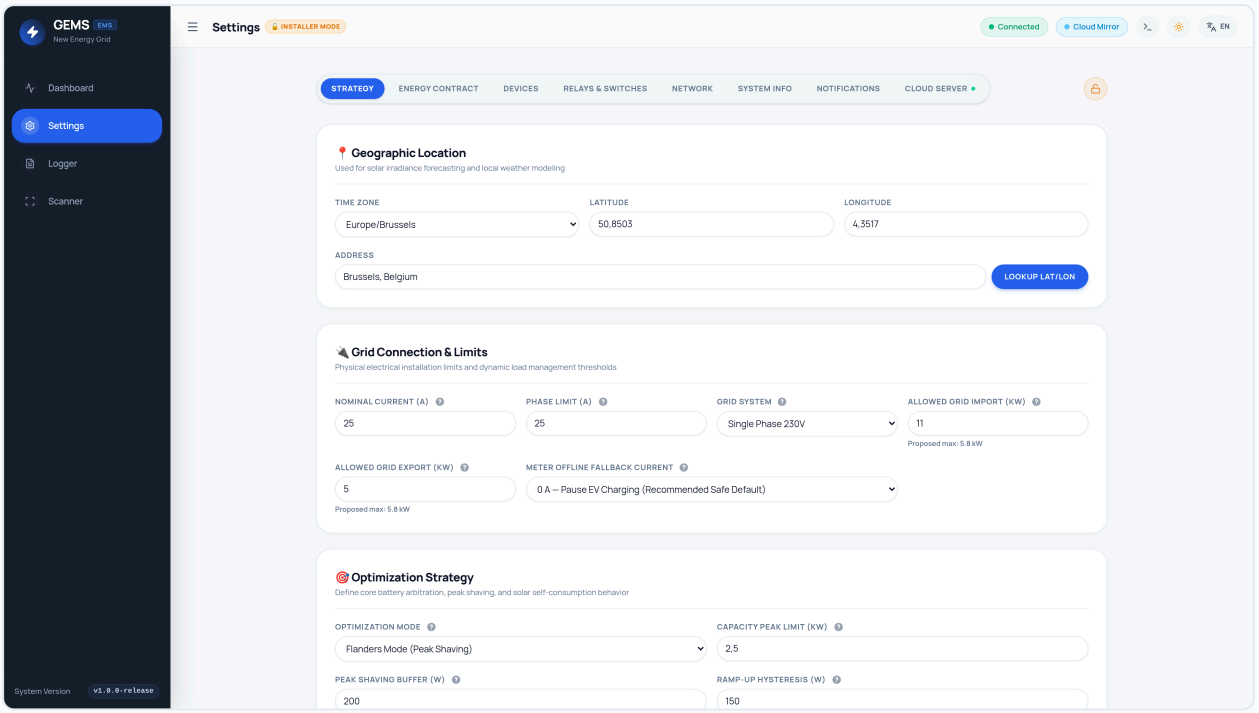


Figure 7.1: Physical electrical installation limits and dynamic load management thresholds.

Parameter Name	Default / Range	Field Explanation & When to Select
`Grid System`	Dropdown	**Single Phase 230V:** Standard residential connection (Phase + Neutral, 230V AC). **Three Phase 400V (+N):** Standard 3-phase European TN/TT network (3x 400V line-to-line, 230V line-to-neutral). **Three Phase 230V Delta:** *Legacy Belgian network* (Brussels, parts of Flanders & Wallonia). 3× 230V between phases with **NO neutral wire**. *Warning:* Requires dedicated delta-compatible inverters and EV chargers!
`Nominal Current (A)`	25.0 A (16A – 125A)	The rated trip amperage of the main utility circuit breaker (e.g. `25A`, `32A`, `40A`, `63A`). GEMS uses this to calculate total allowable site power.
`Phase Limit (A)`	25.0 A (16A – 125A)	The hard safety ceiling per individual phase. If asymmetric household loads (e.g. an induction hob on Phase 1) push L1 current near this limit, GEMS immediately throttles EV charging current to prevent the main utility breaker from tripping!
`Allowed Grid Import (kW)`	Auto (or manual kW)	Maximum continuous power allowed to be imported from the grid. On 3×400V 25A connections, proposed max is `17.2 kW`.
`Allowed Grid Export (kW)`	Auto (or manual kW)	Maximum continuous power allowed to be injected into the utility grid. Set to `0.0 kW` for strict **zero-export compliance** (inverter is dynamically throttled to match house consumption).

8. Energy Contracts & The 5 Tariff Wizards

Under **Settings → Energy Contract**, GEMS models the customer's utility contract to compute net electricity costs, injection returns, and optimal battery charge windows. GEMS fetches hourly EPEX Spot Day-Ahead prices daily at 13:00 CET.

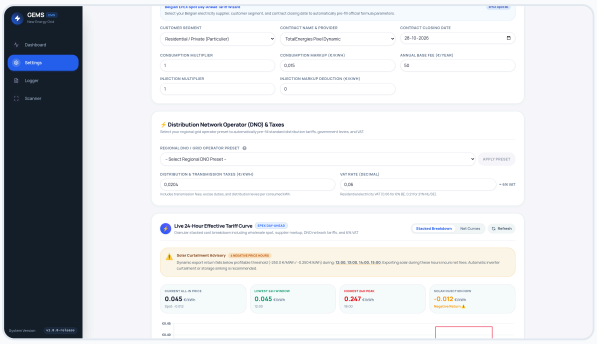


Figure 8.1: Contract Wizard selector and regional parameters.

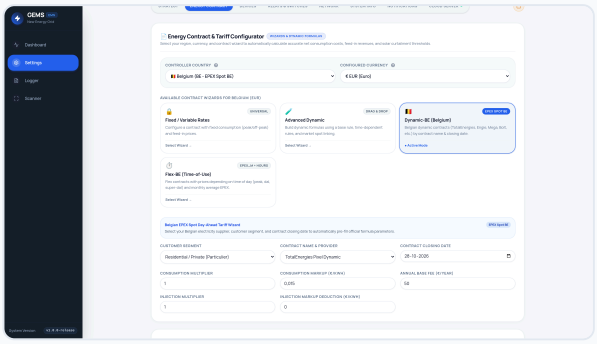


Figure 8.2: 24-Hour effective retail tariff breakdown curve.

The 5 Contract Wizards: When to Choose Each

Wizard	Target Contract Type	Supported Presets & Parameters	When to Select
Wizard A: Fixed / Variable	Traditional utility contracts with fixed or monthly variable flat rates	- Peak Consumption (€/kWh) - Off-Peak Consumption (€/kWh) - Fixed Feed-in Return (€/kWh)	Choose when the customer does **not** have a dynamic contract. Set uniform rates for flat tariffs or enter Day/Night rates for dual-meter setups.
Wizard B: Advanced Dynamic	Custom dynamic contracts with visual formula builder	- Linked EPEX Spot auction feed - Drag & drop formula tokens (`Spot` , `Markup` , `Multiplier` , `DNO` , `VAT`) - Time-of-day and Day-of-week rule overrides	Choose for unlisted international suppliers or specialized commercial contracts requiring custom mathematical formulas.
Wizard C: Dynamic-BE	Belgian EPEX Spot Day-Ahead hourly contracts	**Pre-mapped suppliers:** TotalEnergies Pixel Dynamic, Mega Smart/Cosy, Bolt Dynamisch, Engie Dynamic, Dats 24, Luminus, Eneco, Frank Energie, Ecopower, Octa+, Trevion, Aspiravi.	**Default for dynamic contracts in Belgium.** Select customer segment (Residential vs Business) and closing date to pre-fill the exact formula.
Wizard D: Flex-BE	Belgian monthly variable contracts with Time-of-Use markups	- Engie Flextime monthly EPEX average - Peak, Off-peak, and **Super-Dal (01:00-07:00)** markups - Automated battery overnight charging	Choose if the customer has an Engie Flextime contract. Enables automated battery pre-charging during deeply discounted Super-Dal hours.
Wizard E: Dynamic-NL	Dutch dynamic contracts with statutory energy taxes	**Supported contracts:** All Dutch EPEX Day-Ahead dynamic electricity contracts. Includes Energiebelasting (0.1316 €/kWh) and Terugleverkosten.	**Standard for installations in the Netherlands.** Correctly accounts for Dutch feed-in penalty fees (terugleverkosten).

9. Optimization Strategy & Flanders Peak Shaving

Navigate to **Settings** → **Strategy** to configure the core optimization engine.

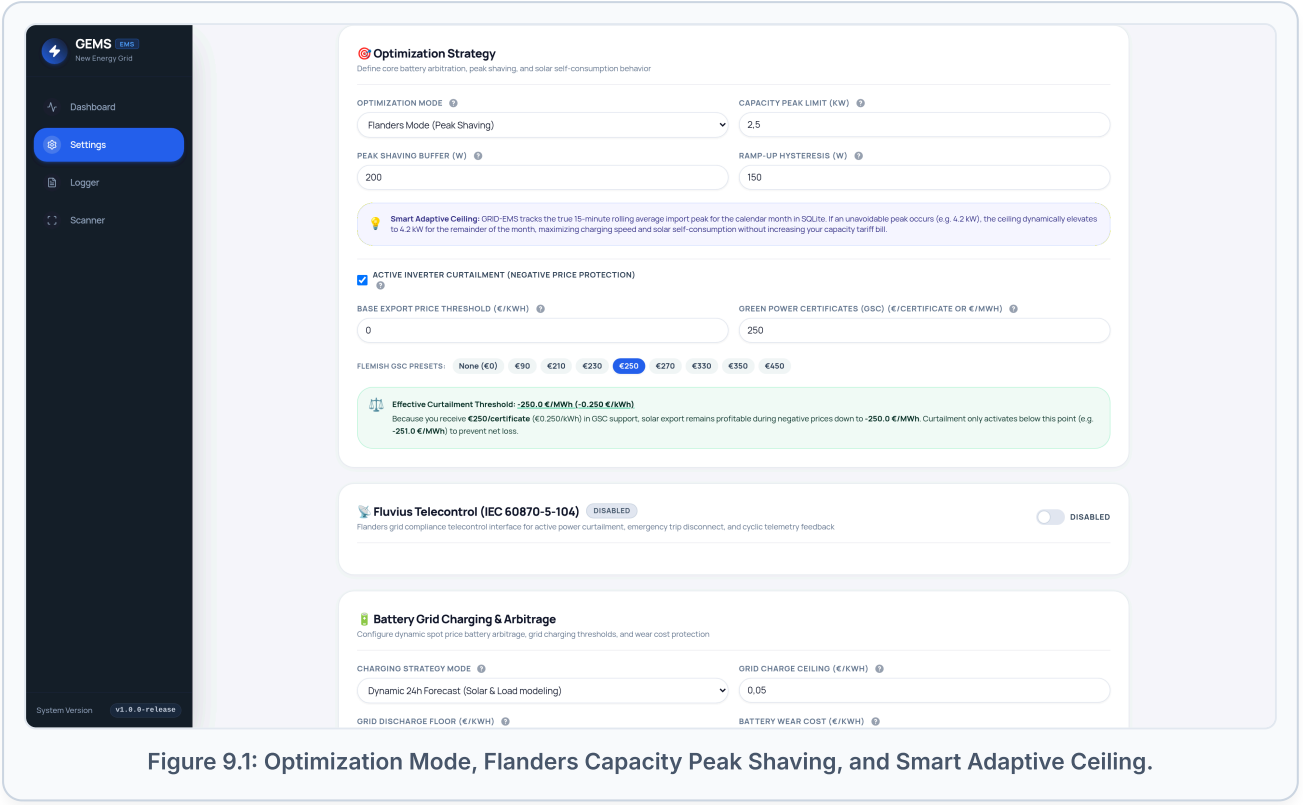


Figure 9.1: Optimization Mode, Flanders Capacity Peak Shaving, and Smart Adaptive Ceiling.

The Three Core Strategy Modes

🎯 CHOOSING THE RIGHT STRATEGY MODE

Mode 1: Eco (Max Self-Consumption)
Best for: Wallonia, Brussels, Germany, or regions without capacity tariffs.
Stores 100% of excess solar yield into the home battery and electric vehicle. Minimizes grid import without enforcing peak kW power ceilings.

Mode 2: Flanders Mode (Peak Shaving)
Best for: Flanders (Belgium).
Enforces the 15-minute rolling average *Capaciteitstarief* ceiling (default 2.50 kW). Discharges battery and throttles EV charging whenever household appliances breach the target peak.

Mode 3: Netherlands Mode (Smart Saldering)
Best for: The Netherlands.
Actively monitors dynamic feed-in fees (*terugleverkosten*) and prioritizes local storage over grid injection during low or negative price intervals. Setting country to NL or choosing a Dutch contract automatically synchronizes regional parameters and completely suppresses Belgian-specific features (Flanders Capaciteitstarief peak shaving and Elia Green Grid Boost) across the entire UI.

Flanders Capacity Tariff Parameters (Capaciteitstarief)

Parameter	Recommended Value	Installer Explanation & Operation
`capacity_peak_limit_kw`	**2.50 kW**	The baseline monthly peak ceiling. In Flanders, Fluvius bills a minimum capacity baseline of 2.50 kW regardless of consumption. Keeping peaks at or below 2.50 kW minimizes the distribution bill.
`peak_shaving_buffer_w`	**200 W**	Proactive safety margin subtracted from the peak ceiling (e.g. 2.50 kW - 200W = 2.30 kW trigger). Enables the EMS to start throttling EV charging or discharging batteries *before* the 15-minute meter average is breached.
`peak_shaving_rampup_w`	**150 W**	Hysteresis deadband power drop required below the ceiling before re-accelerating throttled EV chargers. Prevents rapid on/off cycling of EV charging relays.
Smart Adaptive Ceiling	Automatic (Enabled)	If an unavoidable heavy household peak occurs (e.g. oven + heat pump simultaneously reaching 4.2 kW for 15 minutes), GEMS **dynamically adapts its operational ceiling to 4.2 kW for the rest of that calendar month**. Because the customer will already be billed for 4.2 kW by Fluvius, GEMS allows faster EV charging and greater convenience without increasing the electricity bill by a single cent! On the 1st of the next month, the ceiling automatically resets to 2.50 kW.

10. Active Inverter Curtailment & Flemish GSC Protection

Under dynamic contracts, European wholesale power prices occasionally drop below zero during sunny weekend afternoons. Exporting power during negative price hours incurs feed-in penalties. However, legacy Flemish PV systems receive guaranteed **Groenestroomcertificaten (GSC)** subsidies.

> ⚠️ **Why Blindly Shutting Off Inverters Destroys Customer Earnings**
>
> Simple energy managers shut down inverters as soon as the grid feed-in price drops below €0.00/kWh. If a customer receives **€250/certificaat (€0.250/kWh)** in Flemish green certificates, shutting down the inverter when the price is -€0.05/kWh causes the homeowner to lose +€0.20/kWh in net profit!

The GSC Mathematical Formula

```
Effective Curtailment Threshold (€/kWh) = Base Threshold - (GSC Value €/MWh / 1000.0)

Example (€250 GSC):
Effective Threshold = €0.00 - (€250.0 / 1000.0) = -0.250 €/kWh (-250.0 €/MWh)
```

Flemish GSC Preset	Subsidy Value per kWh	Effective Curtailment Threshold	Installer Action
Geen GSC (€0)	€0.000 / kWh	≤ **0.0 €/MWh (0.000 €/kWh)**	Select for systems installed after 2021 without GSC subsidies. Curtailed immediately when price drops below zero.
€90 GSC	€0.090 / kWh	≤ **-90.0 €/MWh (-0.090 €/kWh)**	Inverter continues exporting during negative prices down to -€0.090/kWh. Curtailed only below -€0.090/kWh.
€250 GSC	€0.250 / kWh	≤ **-250.0 €/MWh (-0.250 €/kWh)**	Protects legacy Flemish PV installations (2009–2012). Full production maintained through almost all negative hours!
€350 GSC	€0.350 / kWh	≤ **-350.0 €/MWh (-0.350 €/kWh)**	Protects high-value legacy installations. Production maintained down to -350 €/MWh.
€450 GSC	€0.450 / kWh	≤ **-450.0 €/MWh (-0.450 €/kWh)**	Protects early 2006–2008 Flemish PV installations. Maximum subsidy revenue guaranteed.

11. Fluvius Telecontrol (IEC 60870-5-104) Compliance

For commercial or residential installations requiring compliance with Fluvius distribution grid telecontrol directives, GEMS includes an embedded **IEC 60870-5-104 slave server**.

Telecontrol Configuration Parameters

Parameter	Default	Technical Description
`iec104_enabled`	Disabled	Master toggle for the IEC 60870-5-104 telecontrol server daemon.
`iec104_port`	`2404`	Standard TCP communication port specified by the IEC 104 standard.
`iec104_common_address`	`1`	ASDU Common Address (broadcast station identifier assigned by Fluvius).
`iec104_allowed_ip`	`0.0.0.0`	Hardware IP whitelist. Enter the static IP of the Fluvius Remote Terminal Unit (RTU) to reject unauthorized connections.
`iec104_curtailment_mode`	`kw`	Format of incoming setpoint commands: Absolute Kilowatts (`kw`) or Percentage of Nominal (`percent`).

Installer Telecontrol Compliance Simulation Controls

Installers can verify plant emergency response directly in the GEMS UI without waiting for grid operator test signals:

- 🚨 **Trip Plant (ASDU 45 Disconnect):** Simulates an emergency disconnect command. GEMS sends an instantaneous zero-power setpoint to all connected inverters.
- ✓ **Reset Trip:** Restores normal operating state after a trip test.
- 📉 **Set 4.0 kW Limit (ASDU 50):** Injects a 4.0 kW active power ceiling command to verify rapid plant curtailment within 5 seconds.
- **Release Curtailment (100 kW):** Restores unconstrained plant generation.

12. Battery Arbitrage & Rule-Based Cost Optimization

GEMS supports automated spot price battery arbitrage and deterministic installer rules under **Settings → Strategy → Battery Cost Optimization**.



Figure 12.1: Rule-based priority list for automated battery charging, discharging, and hold behavior.

Arbitrage Parameters & Battery Wear Protection

Setting	Default / Range	Field Explanation & Trade-offs
`battery_grid_charge_strategy`	`dynamic_forecast`	**Dynamic 24h Forecast:** Simulates day-ahead solar yield (Open-Meteo) and household baseline load to determine exact battery pre-charge needs. **Price Threshold Only:** Charges purely when price ≤ configured ceiling. **Super-Dal Only:** Charges exclusively between 01:00 and 07:00. **Hybrid:** Combines solar forecast with spot price thresholds.
`force_charge_below_euro`	`0.08 €/kWh`	Ceiling below which the battery will force-charge from the grid (e.g. night hours or negative spot hours).
`force_discharge_above_euro`	`0.35 €/kWh`	Floor above which the battery will force-discharge to the grid during evening peak hours to capture high feed-in profit.
`battery_wear_cost_eur`	**0.040 €/kWh** (3–6 ct)	**Critical Wear Guard:** Every lithium battery cycle degrades cell health. GEMS requires that the market price spread (Discharge Price - Charge Price) exceeds the cell wear cost before executing grid arbitrage, preventing uneconomical micro-cycling!

13. EV Charging Controls & Belgian Elia Green Sync Boost

GEMS coordinates directly with connected EV chargers to optimize charging currents dynamically:

Charging Mode	Current Range	Operation & Recommended Application
ECO / Solar Only	6A to 16A / 32A (Dynamic)	Charges strictly using solar surplus. If clouds reduce solar, charging automatically throttles or pauses to avoid pulling costly power from the grid. *(Note: 6A is the minimum standard EV charging current under IEC 61851: 1.4 kW single-phase or 4.1 kW three-phase).*
FAST / Now	16A or 32A (Fixed Max)	Draws simultaneously from solar, battery, and utility grid up to the configured circuit breaker phase limit. Use when departing immediately.
Smart Dynamic	Dynamic (Spot Driven)	Automatically schedules charging during the configured **Cheapest Spot Price Hours (1 to 8 hours)** of the customer's Day-Ahead contract.

Belgian Elia Green Grid Sync Boost

When enabled under **Settings → Strategy**, GEMS ingests live 15-minute national renewable energy data from the Belgian transmission operator **Elia**. When total national green share (wind + solar) exceeds the threshold (e.g. **65%**), EV charging and battery pre-charging are automatically boosted, aligning residential consumption with true green energy availability!

14. Smart Relays & Heat Pump SG-Ready Automation

GEMS integrates smart relays (like Shelly Pro 2 or Shelly Plus 1PM) to automate domestic hot water boilers, pool pumps, and SG-Ready heat pumps.

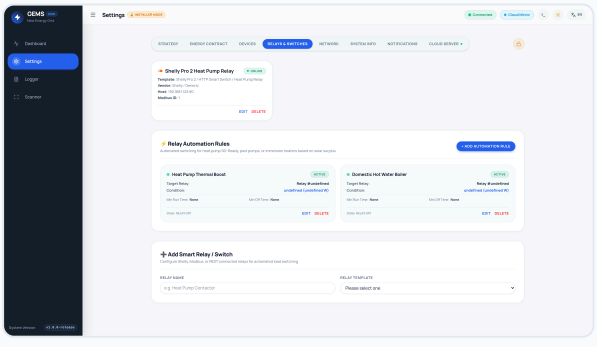


Figure 14.1: Configured relays and live status.

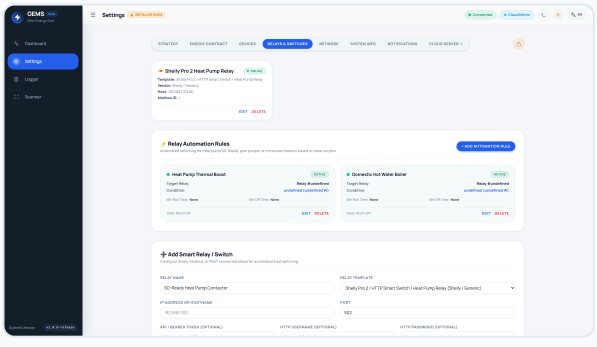


Figure 14.2: Excess solar and tariff trigger rules.

Trigger Condition	Threshold Setting	Hysteresis Deadband	Typical Electrical Application
`excess_solar`	Surplus > `1,200 W`	Minimum ON: **10 mins** Minimum OFF: **5 mins**	SG-Ready Heat Pump thermal boost. Elevates buffer tank water temperature using free daytime solar power.
`negative_spot_price`	Price ≤ `0.02 €/kWh`	Minimum ON: **15 mins**	Electric immersion heating element in domestic hot water boiler.
`time_window`	13:00 to 16:00 Daily	Fixed schedule	Swimming pool filtration pump scheduled during peak solar hours.

> ⚠️ **Compressor Protection Notice**
>
> Always configure a **Minimum ON Time of at least 10 minutes** for heat pumps. Rapid cycling (turning a compressor on and off repeatedly during fleeting clouds) can damage the compressor and void the manufacturer's warranty!

15. Alerts, Webhooks & Automated PDF Reports

Configure external monitoring under **Settings → Notifications**:

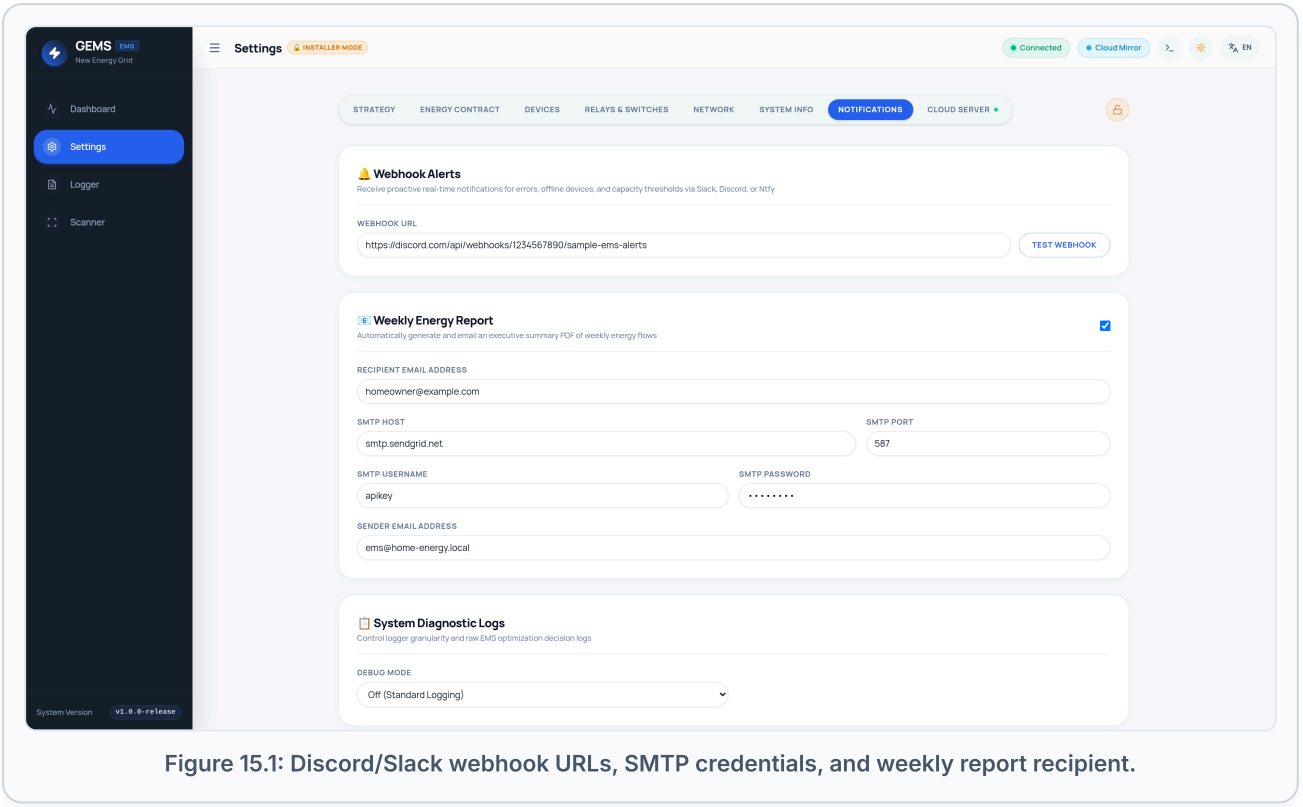


Figure 15.1: Discord/Slack webhook URLs, SMTP credentials, and weekly report recipient.

- **Webhook Alerts:** Paste a Discord, Slack, Microsoft Teams, or Ntfy webhook URL. GEMS dispatches instantaneous notifications for consecutive polling failures, breaker limit warnings, or meter communication timeouts.
- **Weekly Homeowner Email:** Enter customer email and SMTP details. Every Sunday at 20:00, GEMS compiles and emails an executive PDF summary of weekly solar yield, self-consumption %, and capacity peaks.

16. Commissioning Wizard, Network Safety Rollback, Backup & Sign-Off

Commercial GEMS appliances include built-in field-commissioning safeguards under **Installer Mode** (unlocked via the discreet padlock icon in the Settings header):

- **Guided First-Boot Commissioning Wizard:** Automatically launches on unconfigured units to guide language/location setup (`NL`, `FR`, `EN`), main breaker & wiring topology, grid meter discovery, reference hardware onboarding (**Solis** & **RAEDIAN**), and energy contract selection.
- **Persistent USB Serial Binding (`/dev/serial/by-id/*`):** Selecting persistent hardware symlinks ensures USB-P1 and USB-RS485 adapters never swap device numbers across power cycles.

- **Appliance Ethernet Network UI with 60-Second Rollback:** Assign DHCP or static IPv4 addresses on wired Ethernet (`eth0`) interfaces under **Settings → Network**. If the new IP is not confirmed within 60 seconds, GEMS automatically restores the prior working NetworkManager profile.
- **JSON Configuration Backup, Restore & Hardware Watchdog:** Export portable JSON site backups before hardware swaps, execute verified Factory Resets, and rely on integrated `systemd` `WatchdogSec=30` + Raspberry Pi hardware watchdog supervision for unattended recovery.

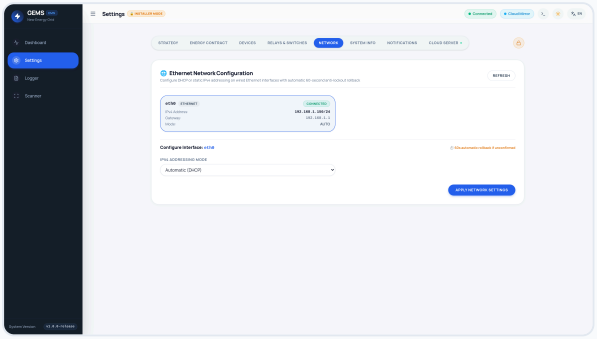


Figure 16.1: Wired Ethernet IPv4 configuration with 60-second automatic lockout rollback protection.

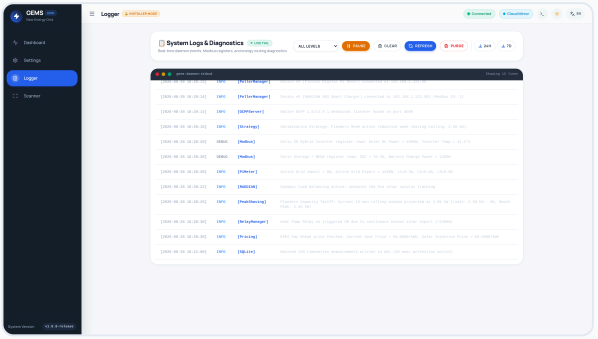


Figure 16.2: Real-time diagnostics logger displaying raw Modbus transactions and controller decisions.

Field Commissioning Sign-Off Checklist

Status	Inspection Item	Verification Procedure
[ ]	**Hardware & Cooling**	Raspberry Pi 5 active cooler spinning, NVMe boot confirmed, operating temperature < 50°C in Cockpit.
[ ]	**Smart Meter Polling**	P1 serial or Modbus meter online. Import/Export power matches utility meter display.
[ ]	**Inverter Telemetry**	Modbus TCP responding. Solar production wattage and battery SOC displaying correctly on Dashboard.
[ ]	**EV Charger Setpoint**	Connected via Modbus TCP (or OCPP). Mode toggles successfully between Eco and Fast.
[ ]	**Grid Limits Configured**	Nominal Amps and Phase Limits configured to match customer's main circuit breaker.
[ ]	**Flanders Peak Limit**	If in Flanders: Capacity peak limit set (default 2.50 kW), buffer set to 200W.
[ ]	**GSC Protection Value**	If customer receives Flemish GSC: Verified certificate value (€90, €250, €350, €450) saved.
[ ]	**Contract & Tariffs**	Correct supplier preset or DNO selected. 24-hour tariff visualizer displaying current spot prices.
[ ]	**Logger Verification**	Checked Logger tab: Zero repeating communication errors or Modbus timeout exceptions.