



OPEN AQUARIUM PROJECT SPECIFICATION

Power Module

PRE-DRAFT

Revision	0.3
Status	Pre-Draft. A candidate document submitted for consideration.
Date	2026-10-18
Identifier	power-module
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Editors	Trent Scholl
License	Community Specification License 1.0

Pre-Draft. This is a proposed initial draft. The Working Group has not approved it, and it will change. It defines what a power module does and declares, not how one is built, and it does not make any product safe: safety certification does (Section 12). Every number marked provisional needs confirming with measurements on real power modules (Appendix E). Comment by opening an issue with the `power-module` label.

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Notes:

1. Appendices are informative (non-normative) unless an appendix is explicitly marked normative.

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2 Compliance with Open Aquarium Tenets

2.1 Openness

The Specification is published under the Community Specification License 1.0, and its checks file, schema, and examples under the Apache License 2.0. It defines what a power module does and what it declares, not how it is built, so any maker can conform with its own design or with an open one. A power module declares its ratings, the state of each outlet without power, its protective functions, and its safety certifications, with the standards they name, in its device description and in published documentation, so that owners can check a product’s claims before they buy it (Sections 7.3 and 14.3). Every requirement that can be tested has a published test procedure (Section 16.4).

2.2 Interoperability

A power module is a device of the Device Classes specification: each outlet is a `switch` endpoint with the `power-monitoring` feature, so any conforming controller can operate any conforming power module, on the module bus or on the local network. This Specification adds no class. The ratings, unpowered states, and backup thermostats of outlets are attributes and a feature of `switch` [OAP-DC Section 9.1], and this Specification adds only what describes the module as a whole and its sockets. Its temperature probe port is a Probe Interface port, so any conforming temperature probe fits it, and its outlets are each market’s standard socket-outlets, so owners plug in the equipment they already have.

2.3 Local Control

A power module needs no network service, account, or app. Its outlets keep their fail-safe behavior when the controller or the network is lost, a backup thermostat keeps the water in range with no controller at all, and local controls switch outlets off without one (Sections 8.5, 8.6, and 11.5). Its measurements are the owner's data.

2.4 Safety

Mains power, water, and livestock share one cabinet, so this Specification is written around failure.

- Protection against the module's electrical hazards (overcurrent, overheating, and electric shock) is in hardware, and never depends on firmware, so it holds whatever firmware runs, including an owner's own (Section 12.3).
- Every power module holds the safety certification that each market where it is sold requires, and declares the standards it was certified to (Section 12.1).
- Every outlet has a defined state without power. An outlet meant for a return pump stays on without power, and no controller binds a heater to one (Sections 8.3 and 13.1).
- An outlet that is off passes no current that could keep equipment running, and an outlet that draws power while off, such as a heater whose relay has welded shut, is reported within seconds (Sections 8.2 and 9.2).
- A backup thermostat with its own probe holds a heater off when the water is too hot, whatever its controller commands, and can open a second contact when the first has welded (Section 11). It regulates the water by itself only while its outlet follows it as its program, which an interlock's stop takes away, so a heater stopped for low water stays off when its controller fails (Section 11.5). It cannot be switched off while it is what keeps a heater safe without its controller (Section 11.3).
- Outlets that stop by themselves when they lose contact, and a backup thermostat's cutoff, need no radio link, so a radio link need not be the only path for the safety functions of a power module's outlets; where an outlet has no other path, such as one that keeps a return pump running, or a heater on that nothing else regulates, its controller warns (Section 7.2).
- Outlets switch on one at a time, never cycle faster than every 5 s, and never chatter when mains dips (Sections 8.4 and 10.4).
- Instructions require a residual-current device on the supply, drip loops, and mounting above the water (Section 14.2).

2.5 Sustainability

Any conforming controller operates any conforming power module, so owners keep their modules when they change controllers. Each outlet reports the energy its equipment uses, and counts its switching operations against its rated endurance, so that owners see what their equipment costs to run, and can replace a worn module before a contact welds (Sections 9.1 and 9.5). Standby power is declared (Section 7.3), and an overload trips a breaker that the owner resets rather than a fuse that must be replaced (Section 9.3).

Revision History

Revision	Date	Description	Authors
0.1	2026-10-15	Initial Pre-Draft.	Trent Scholl
0.2	2026-10-16	A wired connection stays RECOMMENDED, and a module on radio conforms because it fails safe by itself when it loses contact; a backup thermostat cannot be disabled, nor its setpoint removed, while its outlet uses <code>continue</code> ; a REQUIRED check for cutoff contacts, and a limit of 3 s on the cutoff; one rule for outlets while the processor is not running, with the time to the unpowered state; faults reported within 2 s after their delays, so <code>stuck-on</code> within 7 s; readings reported at least once a second on every binding; the shorter <code>failSafeTimeout</code> for a module on both bindings; changes of backup thermostat settings recorded, as Security and Access requires; the provisional extensions settled for a later revision of Device Classes, with commands held back by a cutoff carried out as its Section 7.8.3 says; a test procedure for every requirement; references cited by tag; one sentence per line; every open issue given a status; the	Trent Scholl

Revision	Date	Description	Authors
		Project Lead's decisions of 16 October 2026 applied: certification by a certification body recommended until approval, a backup thermostat an operating control, electronics on mains recommended, Fail-Safe Behavior's defaults unchanged with a controller that may propose <code>continue</code> for an outlet its backup thermostat regulates, the facts a controller shows about owner firmware with example wording, and the cutoff within 3 s; and a power module that supplies the module bus within the total the bus allows.	
0.3	2026-10-18	The Project Lead's decisions of 17 October 2026 applied: an outlet's rating, switching device, unpowered state, endurance, count of operations, and backup thermostat, the presence of mains, and the cutoff's fault are the attributes, the feature <code>backup-thermostat</code> , and the fault <code>cutoff</code> of Device Classes revision 0.5, in place of this Specification's provisional extensions, which keep only what describes the module and its sockets; a backup thermostat regulates only while its outlet follows it as its program, which <code>runProgram</code> starts and an interlock's stop ends, so that with <code>continue</code> a heater stopped for low water stays off when its controller fails; no latching relays; outlets sold where plugs fit either way round switch both conductors (recommended); ± 1 W stays, provisional. Also: an outlet is in its unpowered state within 1 s of its processor ceasing to control it; a module with a status light or a display shows lost contact; outlets that are on without power and have no power-on delay do not wait after power-up; a radio path judged as Fail-Safe Behavior judges it; test criteria that check only what their requirements ask; "A pass criterion that checks what a SHOULD asks applies to a product that does it"; the schema's <code>\$id</code> ; a test for each; references to the final revisions of the other specifications; issues 13, 14, 15, and 18 deferred beyond revision 1.0.	Trent Scholl

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3 Scope

This Specification defines, for power modules, which are devices with mains socket-outlets that a controller switches:

- how a power module presents its outlets to a controller, as Device Classes endpoints, and what it declares about its ratings, outlets, protection, and safety certifications;
- outlet sockets, ratings, switching devices, unpowered states, and how outlets switch;
- measurement of each outlet's voltage, current, and power, and the faults found from them;
- behavior when mains power is lost, returns, or dips;
- an optional backup thermostat, which holds a heater or chiller outlet off beyond a limit read by the module's own probe, and can regulate the temperature without a controller;
- requirements for electrical safety: safety certification, protection that does not depend on firmware, insulation, and residual-current protection;
- what controllers do with power modules;
- labels, installation instructions, and published documentation; and
- a test procedure for every requirement that can be tested.

This Specification does not define:

- a design of a power module, or of any circuit in one; Appendix D gives informative guidance for makers;
- which safety standards apply to a product, which a certification body decides; Section 12.2 lists the most likely;
- the `switch` and `sensor` classes, which the Device Classes specification defines, including the attributes and the `backup-thermostat` feature that outlets use;
- how messages are carried, which the Module Bus and Device Protocol specifications define;
- fail-safe behavior, which the Fail-Safe Behavior specification defines;
- the temperature probe port, which the Probe Interface specification defines;
- power checks and alarms, which the Alarms and Notifications specification defines;
- switched DC outputs; or
- equipment wired permanently into a building, three-phase equipment, and power modules rated above 250 V or 20 A, the limits of the North American standard for power strips [UL 1363].

4 References

4.1 Normative References

- **[RFC 2119]** Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997.
- **[RFC 8174]** Leiba, B., "Ambiguity of Uppercase vs Lowercase in RFC 2119 Key Words", BCP 14, RFC 8174, May 2017.
- **[RFC 8259]** Bray, T., Ed., "The JavaScript Object Notation (JSON) Data Interchange Format", STD 90, RFC 8259, December 2017.
- **[JSON Schema]** "JSON Schema: A Media Type for Describing JSON Documents" and "JSON Schema Validation", draft 2020-12, <https://json-schema.org/draft/2020-12>.
- **[ISO 3166-1]** ISO 3166-1, "Codes for the representation of names of countries and their subdivisions — Part 1: Country code", for the alpha-2 codes, which ISO publishes free of charge in its Online Browsing Platform.
- **[IEC 61000-4-11]** IEC 61000-4-11:2020, "Electromagnetic compatibility (EMC) — Part 4-11: Testing and measurement techniques — Voltage dips, short interruptions and voltage variations immunity tests for equipment with input current up to 16 A per phase".
- **[OAP-DM]** Open Aquarium Project, "Open Aquarium Data Model", Revision 0.4, [specs/data-model/spec.md](https://open-aquarium.org/specs/data-model/spec.md).
- **[OAP-DC]** Open Aquarium Project, "Open Aquarium Device Classes", Revision 0.5, [specs/device-classes/spec.md](https://open-aquarium.org/specs/device-classes/spec.md).
- **[OAP-FS]** Open Aquarium Project, "Open Aquarium Fail-Safe Behavior", Revision 0.4, [specs/fail-safe-behavior/spec.md](https://open-aquarium.org/specs/fail-safe-behavior/spec.md).

- **[OAP-MB]** Open Aquarium Project, “Open Aquarium Module Bus”, Revision 0.4, [specs/module-bus/spec.md](#).
- **[OAP-DP]** Open Aquarium Project, “Open Aquarium Device Protocol”, Revision 0.3, [specs/device-protocol/spec.md](#).
- **[OAP-PI]** Open Aquarium Project, “Open Aquarium Probe Interface”, Revision 0.4, [specs/probe-interface/spec.md](#).
- **[OAP-SA]** Open Aquarium Project, “Open Aquarium Security and Access”, Revision 0.3, [specs/security-and-access/spec.md](#).

IEC 61000-4-11 is available for purchase; every other normative reference is free.

4.2 Informative References

- **[P0001]** Open Aquarium Project, “Proposal 0001: Reference Controller Architecture”, [proposals/0001-reference-controller-architecture.md](#).
- **[OAP-AN]** Open Aquarium Project, “Open Aquarium Alarms and Notifications”, Revision 0.3, [specs/alarms-and-notifications/spec.md](#).
- **[OAP-FP]** Open Aquarium Project, “Open Aquarium Flow Programs”, Revision 0.3, [specs/flow-programs/spec.md](#).
- **[UL 1363]** UL 1363, “Relocatable Power Taps”, 6th edition, 2023.
- **[UL 1018]** UL 1018, “Electric Aquarium Equipment”, 6th edition, 2011.
- **[UL 60730-1]** UL 60730-1, “Automatic Electrical Controls — Part 1: General Requirements”, 6th edition, 2024.
- **[CSA C22.2 No. 308]** CSA C22.2 No. 308, “Cord reels and multi-outlet assemblies”, 2018.
- **[IEC 60335-1]** IEC 60335-1:2020, “Household and similar electrical appliances — Safety — Part 1: General requirements”.
- **[IEC 60335-2-55]** IEC 60335-2-55:2021, “Household and similar electrical appliances — Safety — Part 2-55: Particular requirements for electrical appliances for use with aquariums and garden ponds”.
- **[IEC 60730-1]** IEC 60730-1:2022, “Automatic electrical controls — Part 1: General requirements”.
- **[IEC 60730-2-9]** IEC 60730-2-9:2026, “Automatic electrical controls — Part 2-9: Particular requirements for temperature sensing controls”.
- **[IEC 60884-1]** IEC 60884-1:2022, “Plugs and socket-outlets for household and similar purposes — Part 1: General requirements”.
- **[IEC 60664-1]** IEC 60664-1, “Insulation coordination for equipment within low-voltage supply systems — Part 1: Principles, requirements and tests”.
- **[IEC 60664-3]** IEC 60664-3, “Insulation coordination for equipment within low-voltage supply systems — Part 3: Use of coating, potting or moulding for protection against pollution”.
- **[29 CFR 1910]** U.S. Occupational Safety and Health Administration, 29 CFR 1910.7, 1910.303, and 1910.399, <https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.7>, <https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.303>, and <https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.399>. Electrical equipment used in workplaces must be approved, that is, listed or labeled by a Nationally Recognized Testing Laboratory.
- **[O. Reg. 438/07]** Ontario Regulation 438/07, <https://www.ontario.ca/laws/regulation/070438>. Its section 5 forbids selling or using an electrical product that neither an accredited certification body nor a field evaluation has approved.
- **[B.C. Reg. 100/2004]** British Columbia Regulation 100/2004, https://www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/100_2004. Its section 21 sets the same rule in British Columbia.
- **[LVD 2014/35/EU]** Directive 2014/35/EU (Low Voltage Directive), <https://publications.europa.eu/resource/celex/32014L0035>.
- **[RED 2014/53/EU]** Directive 2014/53/EU (Radio Equipment Directive), <https://publications.europa.eu/resource/celex/32014L0053>; Delegated Regulation (EU) 2022/30, <https://publications.europa.eu/resource/celex/32022R0030>; and Decision (EU) 2025/138, which cites the EN 18031 standards for its cybersecurity requirements, <https://publications.europa.eu/resource/celex/32025D0138>.
- **[CRA]** Regulation (EU) 2024/2847 (Cyber Resilience Act), <https://publications.europa.eu/resource/celex/32024R2847>.

- **[EESR 2016]** The Electrical Equipment (Safety) Regulations 2016, SI 2016/1101, <https://www.legislation.gov.uk/uksi/2016/1101>.
- **[Plugs and Sockets 1994]** The Plugs and Sockets etc. (Safety) Regulations 1994, SI 1994/1768, <https://www.legislation.gov.uk/uksi/1994/1768/contents>.
- **[PSTI]** The Product Security and Telecommunications Infrastructure regulations for connectable products, SI 2023/1007, <https://www.legislation.gov.uk/uksi/2023/1007/made>.
- **[EESS]** Electrical Equipment Safety System, list of in-scope equipment and risk levels, version 4.3, July 2024, <https://www.eess.gov.au/wp-content/uploads/2024/07/EES-Inscope-Equipment-Definitions-and-Risk-Levels-v4.3-Approved.pdf>; and its requirements for Level 3 equipment, <https://www.eess.gov.au/registration/registration-in-scope-electrical-equipment/level-3/>.
- **[Smart Devices Rules 2025]** Cyber Security (Security Standards for Smart Devices) Rules 2025, <https://www.legislation.gov.au/F2025L00276/asmade/text>.
- **[BEAMA RCD]** BEAMA, guide to the selection and application of residual current devices (RCDs), <https://www.beama.org.uk/static/fbf52c82-78e8-4b89-8e7cf271aa9dd8bb/BEAMA-GUIDE-TO-THE-SELECTION-AND-APPLICATION-OF-RESIDUAL-CURRENT-DEVICES-4RCDs5.pdf>.

5 Terms, Definitions, and Conventions

5.1 Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC 2119] [RFC 8174] when, and only when, they appear in all capitals, as shown here.

5.2 Terms and Definitions

Terms defined in the Device Classes specification [OAP-DC], such as device, endpoint, feature, and controller, and in the Fail-Safe Behavior specification [OAP-FS], such as fail-safe behavior, unpowered state, and local control, have the same meaning here.

Power module: A device with one or more mains socket-outlets that a controller switches, which meets this Specification.

Outlet: A socket-outlet of a power module that the module switches, presented as one `switch` endpoint.

Mains: The public low-voltage alternating-current supply, from 100 V to 240 V nominal, at 50 Hz or 60 Hz.

Market: A country, or a group of countries such as the European Union, with one body of law on the safety of electrical products.

Switching device: The relay contact or semiconductor switch that connects an outlet to mains.

Cutoff contact: A second switching device in series with an outlet's switching device, which the module opens for its backup thermostat, or when the switching device is stuck (Section 11.6).

Electronics: The parts of a power module that run its firmware and drive its switching devices.

Backup thermostat: A function of a power module that holds an outlet off while the module's own temperature probe reads beyond a limit, and that can regulate the temperature while the outlet follows its fail-safe behavior (Section 11).

Protective function: A function that protects people and property from the electrical hazards of the power module itself: protection against overcurrent and short circuits, against overheating of the module, against electric shock through its insulation, and, where fitted, against residual current and surges.

Operating function: Any other function of a power module, including those that protect livestock, such as switching, fail-safe behavior, measurement, and a backup thermostat.

Safety certification: A certification body's approval of a product's electrical safety, or, where a market's law allows it, the manufacturer's own declaration of conformity, backed by a technical file.

Certification body: An organization accredited to certify products, such as a Nationally Recognized Testing Laboratory in the United States, or a recognised certifier in Australia.

Residual-current device (RCD): A device that disconnects a circuit when the currents through its conductors do not balance, because some current is flowing to earth, for example through water. In North America it is called a ground-fault circuit interrupter (GFCI).

SELV: Safety extra-low voltage: a voltage low enough, and separated well enough from mains, to be safe to touch. The module bus carries SELV [OAP-MB Section 7.3].

Reinforced insulation: A single insulation system that protects against electric shock as well as double insulation, which is two independent layers.

Pollution degree: How much contamination insulation must withstand, from 1, none, to 4, persistent conductive pollution, as IEC 60664-1 defines it [IEC 60664-1].

Stop-on-loss equipment: Equipment of a Data Model category whose recommended behavior on loss of contact is `stop` in Fail-Safe Behavior Table 3, such as a heater, a doser, or a CO2 system [OAP-DP Section 5.2].

5.3 Notation

Class, feature, attribute, command, event, and fault names are those of the Device Classes specification, and appear in `monospace`. Names beginning `org.openaquariumproject.` are extensions [OAP-DC Section 7.9] that this Specification defines: `org.openaquariumproject.power-module` and `org.openaquariumproject.outlet`, which declare what the Device Classes specification does not describe (Section 7.3). Voltages are in volts (V), currents in amperes (A), power in watts (W), and temperatures in degrees Celsius (°C), as the Data Model's units `V`, `A`, `W`, and `degC` [OAP-DM].

6 Introduction

6.1 Purpose

Four widely used commercial aquarium controllers switch mains equipment through power strips, and each maker builds its own: a strip from one maker works only with that maker's controller. The strips differ in what they do when something fails, and none of them names the safety standards it meets.

This Specification defines a power module once, for everyone: how a controller sees it; what each outlet does without power, without a controller, and when its relay welds; what it measures; and what its maker certifies and declares. A power module that meets it works with any conforming controller, and an owner can see from its declarations which outlet suits a return pump and which a heater, and which standards it was certified to.

The project's own reference designs stay at 24 V DC until a power module exists that a maker has certified [P0001]. This Specification is written so that such a module, from any maker, can conform.

6.2 Design Principles

1. **Certified by its maker.** Safety certification belongs to the company that makes and sells a power module, for its own product and its own factories. This Specification defines what any certified module does, so that any of them can conform.
2. **Protection in hardware.** What protects people and property works without firmware. Firmware operates the outlets; it never stands alone between a fault and a fire. An owner can therefore run their own firmware without removing protection.
3. **Off means off.** An outlet that is off passes no current that could keep equipment running, and an outlet that should be off but draws power is reported at once.
4. **Every state is defined.** Each outlet has an unpowered state, a fail-safe state, and a power-up behavior, and the owner can see all three.
5. **The heater has another layer.** A backup thermostat with its own probe holds a heater off when the water is too hot, whatever the controller does.
6. **Water is expected.** Insulation and spacing assume salt creep and condensation, and the instructions keep water away from the outlets.

6.3 Overview

Figure 1 shows one outlet of a power module.

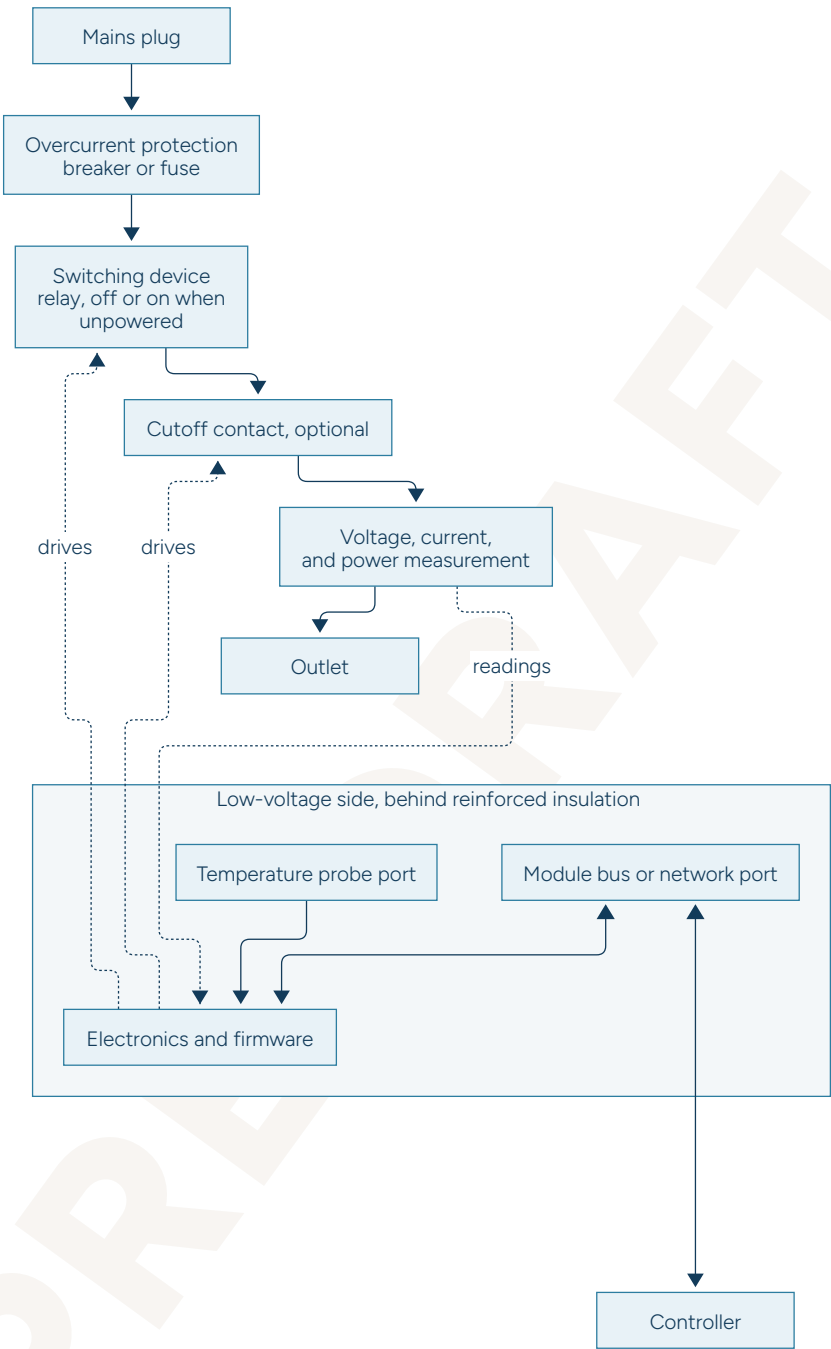


Figure 1 — One outlet of a power module

Table 1 shows what a power module uses, and where each element is defined.

Table 1 — What a power module uses

Element	Defined by	In this Specification
A switch endpoint for each outlet, with power-monitoring, identify, and powerOnDeLay	[OAP-DC] Section 9.1	7.1
The output attributes of fail-safe behavior	[OAP-FS]; [OAP-DC] Section 8.3	8.5

Element	Defined by	In this Specification
The faults <code>stuck-on</code> , <code>load-disconnected</code> , <code>overcurrent</code> , <code>expired</code> , <code>overtemperature</code> , <code>undervoltage</code> , <code>overvoltage</code> , and <code>cutoff</code>	[OAP-DC] Section 8.4	9, 10, and 11.4
A sensor endpoint for the temperature probe port	[OAP-DC] Section 11.1; [OAP-PI] Section 10	11.2
The Module Bus or the Device Protocol	[OAP-MB]; [OAP-DP]	7.2
Power checks and alarms	[OAP-AN] Sections 8 and 10	9.6
An outlet's <code>ratedCurrent</code> , <code>switchingDevice</code> , <code>unpoweredState</code> , <code>endurance</code> , and <code>switchCount</code> , and the device's <code>mainsPresent</code>	[OAP-DC] Sections 8.1 and 9.1	7.3, 9.5, and 10.3
The backup-thermostat feature of switch: <code>backupThermostat</code> , <code>cutoffContact</code> , <code>programRunning</code> , and <code>runProgram</code>	[OAP-DC] Sections 7.13 and 9.1	11
<code>org.openaquariumproject.power-module</code> and <code>org.openaquariumproject.outlet</code> : what a module and its outlets' sockets declare	This Specification	7.3

6.4 Example

A power module for 120 V has eight outlets, a 15 A circuit breaker, a temperature probe port, and a module bus port, and its electronics run from mains. Outlets 1 and 2 stay on without power, and are marked so. Outlets 7 and 8 have backup thermostats with cutoff contacts. The owner plugs the return pump into outlet 1, the skimmer into outlet 3, and the heater into outlet 7, puts the module's probe in the sump, and sets outlet 7's backup thermostat to a setpoint of 25.5 °C and a cutoff of 27.0 °C, with `failSafeAction continue`. The controller runs outlet 7 on its program, with `runProgram`, so that the backup thermostat regulates the heater.

- **The controller's firmware stops.** After 30 s, the outlets take their fail-safe behavior: outlet 1 keeps the return pump running, the skimmer keeps running, and outlet 7 keeps following its program, and holds the sump at 25.5 °C from its own probe.
- **The controller drives the heater itself, and its probe reads low.** To warm new water after a water change, the controller has taken outlet 7 off its program with `set`, and its probe, which has slipped out of the water, reads low, so it keeps the heater on, and the sump warms. At 27.0 °C on the module's probe, the backup thermostat holds outlet 7 off, opens its cutoff contact, and reports `cutoff`.
- **The sump runs low.** A low-water interlock stops outlet 7 with a latched stop, which takes it off its program, and then the controller fails. Outlet 7 keeps the stop, rather than heating a drained sump, until a controller ends it [OAP-FS Section 8.4].
- **Outlet 7's relay welds.** When the controller next switches the heater off, the heater keeps drawing 200 W. About 6 s later, the module opens the cutoff contact, the heater stops, and outlet 7 reports `stuck-on`, which raises a critical alarm, because a heater is hazardous equipment [OAP-AN Section 7.2].
- **The bus cable is pulled out.** The electronics run from mains, so nothing changes until the fail-safe timeout, and then the outlets behave as when the controller stopped.
- **Mains fails for an hour.** When it returns, the return pump starts at once, because outlet 1 is on without power; the heater's outlet, with `continue`, follows its program again 1 s later; and the skimmer waits its 600 s `powerOnDelay`, so that the sump settles first.
- **The owner wants to disable the backup thermostat.** The module refuses while outlet 7 uses `continue`, so the controller first sets outlet 7 to stop when it loses contact, and then disables the backup thermostat, in one change that the owner confirms (Sections 11.3 and 13.3).

The `examples` directory holds this module's device description (Appendix B).

7 The Device

7.1 Power Modules and Their Endpoints

1. A power module MUST present one `switch` endpoint for each outlet [OAP-DC Section 7.1].

2. The identifier of an outlet's endpoint MUST be `outlet_` followed by the outlet's number, counting from 1, as it is labeled on the module (Section 14.1).
3. Every outlet endpoint MUST declare the `power-monitoring` feature, and MUST implement `identify` and `powerOnDelay`, and list them in its `optional` [OAP-DC Section 12].
4. Outlet endpoints SHOULD implement `name`, `loadCategory`, `energy`, `resetEnergy`, and `operatingHours`. They MAY declare `overload-protection` (Section 9.3) and implement `pulse`.
5. A temperature probe port presents a `sensor` endpoint (Section 11.2).
6. A power module MUST name `power-module` in its `specRevisions`, with the revision it implements, "0.3" for this one, and MUST name `fail-safe-behavior` [OAP-DC Section 8.1]. It MUST implement Device Classes revision 0.5 or later, whose `switch` has the attributes and the feature that this revision uses (Section 7.3).
7. A socket-outlet that the module does not switch is not an endpoint, and MUST be marked as not switched (Section 14.1).
8. A device that has switched mains outlets as well as other functions, such as a controller with built-in outlets, MUST meet this Specification for those outlets.

7.2 Connecting to a Controller

1. A power module MUST connect to its controller through the Module Bus [OAP-MB], the Device Protocol [OAP-DP], or both, and MUST meet the specification of each that it implements.
2. A power module SHOULD connect by wire: through the module bus, or through the Device Protocol over Ethernet (Appendix E, issue 1). A wire keeps a safety function from depending on a radio link [OAP-FS Section 13.4], and a radio brings radio certification, and in the European Union the cybersecurity standard EN 18031, into the module's certification [RED 2014/53/EU].
3. A power module that connects only by radio conforms all the same, because its outlets can give the safety functions of their equipment a path that uses no radio link, as Fail-Safe Behavior Section 13.4 judges it [OAP-FS]. An outlet with an enabled backup thermostat holds a heater or a chiller off past its cutoff by itself, from the module's own probe (Section 11.4), which is protection inside the device [OAP-FS Section 13.4.2]. An outlet that stops by itself when it loses contact, with `failSafeAction` state, `failSafeState` `{"on": false}`, and a `failSafeTimeout` of at most 300 s, as outlets ship (Section 8.5), has a path whenever the function's inputs also allow one [OAP-FS Section 13.4.3]. An outlet that has neither, such as one whose fail-safe state runs its equipment, like a return pump that leak response stops, or one that keeps a heater on with `continue` when neither the heater has a thermostat of its own nor the outlet an enabled backup thermostat, has no such path while its module is on radio, and its controller warns its owners, as Fail-Safe Behavior Section 13.4.6 requires.
4. A power module on the module bus MAY supply power to the bus, as a node designed to supply it [OAP-MB Section 7.3], within the 4 A that the supplying nodes of a bus share [OAP-MB Section 7.6.7]; Section 10.1 says where its own electronics should draw their power.
5. A commercial power strip that an adapter presents [OAP-DP Section 16] is not a power module unless it meets this Specification itself (Appendix C).

7.3 What a Power Module Declares

A power module declares, in its device description [OAP-DC Section 12], what an owner and a controller need to know about its hardware.

1. The description's `device.extensions` MUST contain `org.openaquariumproject.power-module`, a JSON object [RFC 8259] with the members of Table 2, valid against `$defs/module` of `schema/power-module.schema.json` [JSON Schema].
2. The `extensions` of each outlet endpoint MUST contain `org.openaquariumproject.outlet`, an object with the members of Table 5, valid against `$defs/outlet`.
3. Each outlet endpoint MUST give the fixed attributes `ratedCurrent`, `switchingDevice`, `unpoweredState`, and `endurance` of `switch` in its description, and implements the other attributes of Table 6 as that table says [OAP-DC Section 9.1].
4. The extensions and the fixed attributes describe the hardware, and change only when it does.
5. What they declare MUST agree with the module, its labels, its instructions, and its certifications.

Table 2 — Members of `org.openaquariumproject.power-module`

Member	Type	Presence	Description
<code>ratedVoltage</code>	list of two numbers (V)	REQUIRED	The lowest and highest nominal mains voltage, such as [100, 127] or [220, 240].
<code>ratedFrequency</code>	list of numbers (Hz)	REQUIRED	[50], [60], or [50, 60].
<code>ratedCurrent</code>	number (A)	REQUIRED	The most current the module may draw in total (Section 8.1).
<code>plug</code>	string	REQUIRED	The plug or appliance inlet, by its standard designation, such as NEMA 5-15P, CEE 7/7, BS 1363, AS/NZS 3112, or IEC 60320 C14.
<code>overcurrentProtection</code>	object	REQUIRED	The module's own overcurrent protection: <code>device</code> , <code>circuit-breaker</code> or <code>fuse</code> ; <code>rating</code> , in A; and <code>resettable</code> , <code>true</code> for a breaker that the owner can reset (Section 9.3).
<code>electronicsSupply</code>	enum: <code>mains</code> , <code>bus</code> , <code>mains-and-bus</code>	REQUIRED	What powers the electronics and the switching devices (Section 10.1).
<code>connections</code>	list of enum: <code>module-bus</code> , <code>ethernet</code> , <code>wifi</code> , <code>thread</code>	REQUIRED	How the module can reach its controller (Section 7.2).
<code>radios</code>	list of strings	REQUIRED	Every radio fitted, such as <code>wifi</code> , <code>thread</code> , or <code>bluetooth</code> , including one used only for setup. Empty when none is.
<code>standbyPower</code>	number (W)	REQUIRED	The power the module draws with every outlet off, in contact with its controller.
<code>maxAmbientTemperature</code>	number (degC)	REQUIRED	The highest ambient temperature at which the module meets its ratings, at least 40 °C (Section 8.1).
<code>insulation</code>	object	REQUIRED	<code>pollutionDegree</code> , 2 or 3, which the creepage distances on the mains side meet; and <code>coating</code> , <code>true</code> if the circuit boards have a permanent coating (Section 12.4).
<code>surgeProtection</code>	boolean	REQUIRED	Whether surge protection is built in (Section 12.6).
<code>residualCurrent</code>	object	OPTIONAL	A built-in residual-current device: <code>type</code> , A, F, or B; <code>ratedResidualCurrent</code> , in A; <code>standard</code> ; and <code>reset</code> , which is <code>automatic</code> (Section 12.5). Absent when none is fitted.
<code>protections</code>	list of objects	REQUIRED	Each protective function, and whether it depends on firmware (Table 4; Section 12.3).
<code>certifications</code>	list of objects	REQUIRED	Each safety certification or declaration of conformity, one for each market (Table 3; Section 12.1).
<code>instructions</code>	string	REQUIRED	The HTTPS URL of the installation instructions (Section 14.3).

Table 3 — Members of a certification

Member	Type	Presence	Description
<code>market</code>	string	REQUIRED	The market: an ISO 3166-1 alpha-2 country code, such as US, CA, GB, AU, or NZ, or EU for the European Union [ISO 3166-1].
<code>kind</code>	enum: <code>certification</code> , <code>declaration</code>	REQUIRED	<code>certification</code> by a certification body, or the maker's own <code>declaration</code> of conformity.
<code>body</code>	string	REQUIRED for <code>certification</code>	The certification body.
<code>holder</code>	string	REQUIRED	The company that holds the certification, or makes the declaration.
<code>reference</code>	string	REQUIRED	The certificate or file number, or the declaration's identifier.
<code>standards</code>	list of strings	REQUIRED	Each standard, with its edition or year, such as UL 1363:2023. At least one.
<code>mark</code>	string	OPTIONAL	The mark the module carries for this market, such as a certification body's mark, CE, UKCA, or RCM.
<code>firmware</code>	list of strings	OPTIONAL	The firmware versions evaluated, where the certification covers firmware (Section 12.3).
<code>date</code>	date	OPTIONAL	When it was issued or signed.

Table 4 — Members of a protection

Member	Type	Presence	Description
function	enum: overcurrent, short-circuit, overtemperature, insulation, residual-current, surge, temperature-limit	REQUIRED	What the function protects against. <code>temperature-limit</code> is a backup thermostat that its maker has certified as a protective control (Section 11.7).
means	string	REQUIRED	How, such as “15 A thermal-magnetic circuit breaker”.
firmware	boolean	REQUIRED	Whether the function depends on firmware. It is <code>false</code> for every function except <code>temperature-limit</code> (Section 12.3).

Table 5 — Members of `org.openaquariumproject.outlet`

Member	Type	Presence	Description
socket	string	REQUIRED	The socket-outlet, by its standard designation, such as NEMA 5-15R, CEE 7/3, BS 1363, or AS/NZS 3112.
inrush	number (A)	OPTIONAL	The peak inrush current that the switching device is rated to make (Section 8.2).
fuse	number (A)	OPTIONAL	The rating of the outlet’s own fuse, if it has one (Section 9.3).

Table 6 gives the attributes, the feature, and the fault of the Device Classes specification that a power module uses for what earlier revisions of this Specification declared as provisional extensions [OAP-DC Sections 8.1, 8.4, and 9.1].

Table 6 — Device Classes elements of a power module

Name	Kind	Of	Presence for a power module	Section
<code>ratedCurrent</code>	Fixed attribute, a number (A)	Outlets	REQUIRED	8.1
<code>switchingDevice</code>	Fixed attribute, <code>relay</code> or <code>solid-state</code>	Outlets	REQUIRED	8.2
<code>unpoweredState</code>	Fixed attribute, <code>off</code> or <code>on</code>	Outlets	REQUIRED	8.3
<code>endurance</code>	Fixed attribute, an integer	Outlets	REQUIRED	8.2
<code>switchCount</code>	State attribute, an integer	Outlets	RECOMMENDED	9.5
<code>backup-thermostat</code>	Feature, with <code>backupThermostat</code> , <code>cutoffContact</code> , <code>programRunning</code> , and <code>runProgram</code>	Outlets with a backup thermostat	REQUIRED for them	11
<code>cutoff</code>	Fault code	Outlets with a backup thermostat	REQUIRED for them	11.4
<code>mainsPresent</code>	State attribute of the device, a boolean	The device, when its electronics can run without mains	REQUIRED for it	10.3

7.4 Checks

Table 7 — Device checks

Check	Presence	Applies to	What it requires	Section
Endpoints	REQUIRED	Power modules	Each outlet is a <code>switch</code> endpoint named <code>outlet_</code> and its number, with <code>power-monitoring</code> , <code>identify</code> , and <code>powerOnDelay</code> , and the description names <code>power-module</code> , <code>fail-safe-behavior</code> , and Device Classes revision 0.5 or later in <code>specRevisions</code> .	7.1
Bindings	REQUIRED	Power modules	The module connects through the Module Bus, the Device Protocol, or both, and meets each binding it implements.	7.2
A wired connection	RECOMMENDED	Power modules	The module connects by wire: through the module bus, or through the Device Protocol over Ethernet.	7.2
Declarations	REQUIRED	Power modules	The description carries <code>org.openaquariumproject.power-module</code> and, on each outlet, <code>org.openaquariumproject.outlet</code> and the fixed attributes <code>ratedCurrent</code> , <code>switchingDevice</code> , <code>unpoweredState</code> ,	7.3

Check	Presence	Applies to	What it requires	Section
			and endurance , and what they declare agrees with the module, its labels, its instructions, and its certifications.	

8 Outlets

8.1 Sockets and Ratings

1. Every outlet MUST be a standard socket-outlet of the market where the module is sold, with the shutters that market requires [IEC 60884-1].
2. An outlet's **ratedCurrent** MUST NOT exceed the rating of its socket, its switching device, its cutoff contact, its fuse, or the module's **ratedCurrent**. For an outlet whose unpowered state is **on**, the rating of the contact that is closed without power governs, and it is often much lower than the rating of the other.
3. The module's **ratedCurrent** MUST NOT exceed the rating of its plug, its cord, or its overcurrent protection. The outlets' ratings MAY add up to more than the module's.
4. A power module MUST meet its ratings with every outlet loaded, at ambient temperatures up to its **maxAmbientTemperature**, which MUST be at least 40 °C (provisional), the highest cabinet temperature that the Probe Interface also uses [OAP-PI Section 7.7].
5. This Specification does not cover power modules rated above 250 V or 20 A (Section 3).

8.2 Switching Devices

1. An outlet that is off MUST pass no more than 1 mA (provisional) to any load. Makers' data sheets give triacs and solid-state relays an off-state current of 1 mA to 14 mA, which can keep a small load running or hold a solenoid valve open. They can also fail on; one aquarium maker moved its power strips from triacs to relays for this reason.
2. Outlets SHOULD be switched by relays.
3. An outlet's switching device SHOULD be rated for at least 50,000 operations at the outlet's rated current (provisional), declared as **endurance**. A heater under a thermostat function can switch 10 to 30 times a day, so 50,000 operations last more than four years.
4. An outlet's switching device SHOULD be rated to make an inrush current of at least 80 A peak (provisional), declared as **inrush**. LED driver data sheets give an inrush of 60 A to 75 A, lasting under a millisecond, when a driver starts at 230 V, and motors draw 5 to 10 times their running current.
5. When its processor ceases to control an outlet, because it stops, restarts, or is held in reset, the outlet MUST be in its unpowered state within 1 s (provisional), changing state at most once, and MUST NOT change state otherwise until the processor controls it again [OAP-FS Section 8.3]. A restart that ends within the 1 s may leave the outlet as it was; one that lasts longer, such as a brown-out that holds the processor in reset, leaves a heater on an outlet whose unpowered state is **off** switched off. Its power-up behavior then follows (Section 10.2).
6. In a market whose plugs fit either way round, such as those of CEE 7/7 plugs, an outlet SHOULD switch both conductors, line and neutral, so that equipment on an outlet that is off is not left connected to the line conductor.

8.3 Unpowered States

1. Each outlet MUST have an unpowered state, **off** or **on**, declared as **unpoweredState**, which its switching device takes by itself, within 1 s (provisional), whenever the module's electronics cannot drive it, and holds for as long as mains is present (Section 8.2.5).
2. A latching relay, which keeps whatever state it was last set to, does not meet item 1, even with stored energy to return it to the unpowered state when the supply fails: an outlet's unpowered state comes from a switching device that returns to it by itself.
3. A power module SHOULD have at least one outlet whose unpowered state is **on**, for a return pump [OAP-FS Section 8.3].

4. An outlet whose unpowered state is `on`:
 - MUST be marked as such (Section 14.1);
 - MUST NOT have a backup thermostat, because its heater would run whenever the module's electronics fail; and
 - holds an overload trip only while the module's electronics are powered (Section 9.3). A controller never binds stop-on-loss equipment to it (Section 13.1).

Table 8 shows which state an outlet is in when something fails.

Table 8 — What an outlet does when something fails

Event	Electronics run from mains	Electronics run from the bus only
The controller stops, or the network fails	Fail-safe behavior, after <code>failSafeTimeout</code>	The same
The bus cable is unplugged, or the bus loses power	Fail-safe behavior, after <code>failSafeTimeout</code>	Unpowered state, at once
The module's own supply fails while mains is present	Unpowered state	—
The processor restarts, or installs new firmware	Its current state or its unpowered state, then its power-up behavior [OAP-FS Sections 11.1 and 11.2]	The same
Mains fails	No power at any outlet	No power at any outlet; the module reports it (Section 10.3)
Mains returns	Power-up behavior (Section 10.2)	Each outlet's <code>powerOnDelay</code> , then the state its controller commanded (Section 10.2)

A module whose electronics run from mains and the bus behaves as one that runs from mains, and also reports mains (Section 10.3).

8.4 Switching

1. Outlets carry out `set`, with `revertAfter`, and `pulse` where they implement it, as the Device Classes specification defines [OAP-DC Sections 7.4 and 9.1].
2. A power module MUST NOT close the switching devices of two outlets less than 0.2 s apart (provisional), so that the inrush of one has passed before the next begins. When several outlets are to switch on at once, it switches them in the order of the commands, or of their identifiers.
3. A power module MUST open an outlet within 0.1 s (provisional) of the command or event that switches it off, whatever else it is doing [OAP-FS Section 8.2].
4. An outlet MUST NOT switch on sooner than 5 s (provisional) after it last switched on. A switch-on that fails due sooner, from a command, a revert, a local control, or a backup thermostat, waits until then. The module MUST NOT refuse a command for this reason, and a later command replaces a switch-on that is waiting. This keeps a faulty or compromised controller from wearing out a relay in hours, and matches the shortest time that the Flow Programs specification lets a pump on a switch stay on or off [OAP-FP Section 10.5].
5. While a switch-on waits, `on` stays `false`, and the endpoint reports the change when it happens [OAP-DC Section 7.5].

8.5 Fail-Safe Configuration

1. Every outlet MUST implement the Fail-Safe Behavior specification [OAP-FS], with all of the output attributes [OAP-DC Section 8.3], including `powerOnDelay`.
2. An outlet whose unpowered state is `off` MUST ship with `failSafeAction` state, `failSafeState` `{"on": false}`, and `powerOnBehavior` `fail-safe` [OAP-FS Section 13.1].
3. An outlet whose unpowered state is `on` MUST ship with `failSafeAction` state, `failSafeState` `{"on": true}`, and `powerOnBehavior` `fail-safe`, so that it runs the return pump it is meant for, whether it has lost its controller or its power [OAP-FS Section 8.3].

4. Outlets MUST ship with `failSafeTimeout` at the recommended default of their binding, 30 s on the module bus and 120 s on the network [OAP-FS Section 7.2], with `powerOnDelay` 0, and without a `loadCategory`. A module that implements both bindings ships with the shorter, 30 s.
5. An outlet with a backup thermostat MAY use `failSafeAction continue`, with which it regulates the temperature by itself while it follows its program (Section 11.5), and its module then keeps the backup thermostat from being disabled (Section 11.3.1).

8.6 Identification, Indicators, and Local Controls

1. `identify` MUST show which socket an outlet is, for example by flashing a light beside it, and MUST NOT change any outlet [OAP-DC Section 8.2].
2. Each outlet SHOULD have a light beside it that shows whether the outlet is on.
3. A power module that has a status light or a display MUST show that it has lost contact with its controller while it reports `communication-lost` [OAP-FS Section 7.3]. Every power module SHOULD have one.
4. A power module MAY have local controls, such as a button for each outlet. If it has:
 - a local control MUST always be able to switch an outlet off;
 - a local control that switches an outlet on MUST end by itself within 2 hours [OAP-FS Section 12];
 - local controls MUST work without a controller or a network; and
 - a local control MUST NOT override a backup thermostat's cutoff (Section 11.4), or the time between switch-ons (Section 8.4).

8.7 Checks

Table 9 — Outlet checks

Check	Presence	Applies to	What it requires	Section
Sockets and ratings	REQUIRED	Power modules	Every outlet is a standard socket-outlet of its market, rated no higher than its socket, switching device, cutoff contact, fuse, or the module; the module is rated no higher than its plug, cord, or overcurrent protection, and meets its ratings up to its <code>maxAmbientTemperature</code> , at least 40 °C.	8.1
Off means off	REQUIRED	Power modules	An outlet that is off passes no more than 1 mA to any load.	8.2
Relays rated for the work	RECOMMENDED	Power modules	Outlets are switched by relays rated for at least 50,000 operations at the outlet's rated current, and for an inrush of at least 80 A peak.	8.2
Both conductors	RECOMMENDED	Power modules	In a market whose plugs fit either way round, each outlet switches both conductors, line and neutral.	8.2
Unpowered states	REQUIRED	Power modules	Each outlet takes its declared unpowered state, <code>off</code> or <code>on</code> , by itself within 1 s whenever the electronics cannot drive it, and holds it while mains is present; once the processor ceases to control it, an outlet is in its unpowered state within 1 s, having changed state at most once; latching relays do not qualify, even with stored energy, and no outlet whose unpowered state is <code>on</code> has a backup thermostat.	8.3
An outlet for a return pump	RECOMMENDED	Power modules	At least one outlet's unpowered state is <code>on</code> ; each such outlet is marked, is rated by the contact that is closed without power, and has no backup thermostat.	8.3
One at a time	REQUIRED	Power modules	Outlets close at least 0.2 s apart, in the order of the commands, and open within 0.1 s of any command or event that switches them off.	8.4
Time between switch-ons	REQUIRED	Power modules	An outlet switches on no sooner than 5 s after it last switched on; an earlier switch-on waits, and is never refused, and a later command replaces it.	8.4
Fail-safe configuration	REQUIRED	Power modules	Every outlet implements fail-safe behavior, and ships configured to stop, or to run if its unpowered state is <code>on</code> , with its binding's default timeout, the shorter on a module with both bindings, no power-on delay, and no <code>loadCategory</code> .	8.5

Check	Presence	Applies to	What it requires	Section
Identifying an outlet	REQUIRED	Power modules	<code>identify</code> shows which socket an outlet is, and changes no outlet.	8.6
Indicators	RECOMMENDED	Power modules	Each outlet has a light that shows whether it is on, and the module has a status light or a display.	8.6
Showing lost contact	REQUIRED	Power modules	A module with a status light or a display shows that it has lost contact with its controller while it reports <code>communication-lost</code> .	8.6
Local controls	REQUIRED	Power modules	On a module with local controls, a local control can always switch an outlet off, one that switches an outlet on ends within 2 hours, they work without a controller or a network, and they override neither a cutoff nor the time between switch-ons.	8.6

9 Measurement and Faults

9.1 Measurements

- Each outlet MUST measure and report the `voltage`, `current`, and `power` of its load [OAP-DC Section 9.1], and SHOULD report `energy`.
- `voltage` and `current` are RMS values, and `power` is real power, each over a whole number of mains cycles lasting at least 0.2 s (provisional). Each outlet MUST measure at least once a second (provisional). Real power leaves out the reactive current of filter capacitors, which is not a load.
- From no load to the outlet's rated current, across the module's rated voltages and frequencies, at ambient temperatures from 0 °C to 40 °C, readings MUST be within (provisional):
 - for voltage, $\pm 1\%$ of the reading;
 - for current, $\pm(2\%$ of the reading + 0.02 A); and
 - for power, $\pm(2\%$ of the reading + 1 W).
- The readings are for monitoring, not for billing, and the accuracy standards of electricity meters do not apply to them.
- Each outlet MUST report its readings at least once a second while they change (provisional), on every binding. On the module bus, it publishes its state at least once a second, which the bus allows [OAP-MB Section 11.1.3]; over the Device Protocol, it reports each change as often as the `minInterval` of its subscription allows, which is 1 s by default [OAP-DP Section 11.5].

9.2 Stuck and Disconnected Loads

- An outlet MUST report `stuck-on` while it is off and has drawn more than 2 W (provisional) for 5 s (provisional), and MUST remove it when that ends, except as Section 11.6 says.
- An outlet SHOULD report `load-disconnected` while it is on and has drawn no more than 2 W for 30 s (provisional). Equipment that switches itself, such as a heater with its own thermostat, draws nothing for a while, and an owner can lengthen the delay of the alarm [OAP-AN Section 10.4].
- An outlet MUST NOT report either fault in the first 5 s after it switches, while its load's power settles.
- `stuck-on` is the fault of a welded relay or a failed semiconductor switch. On an outlet that drives a heater, the Alarms and Notifications specification makes it critical [OAP-AN Section 8.4].

Controllers also check the power that outputs draw [OAP-AN Section 10], and a fault that both report raises one alarm [OAP-AN Section 8.3].

9.3 Overcurrent

- A power module MUST protect itself against overcurrent and short circuits with a circuit breaker or a fuse, in hardware (Section 12.3), declared as `overcurrentProtection`.
- It SHOULD be a circuit breaker that the owner can reset, so that an overload needs no spare part.
- A power module MUST report `overcurrent` among its device faults while the total current of its outlets has exceeded its `ratedCurrent` for 5 s (provisional), so that the owner hears of an overload before the breaker opens and every outlet stops.

4. An outlet MAY have a fuse of its own, declared as `fuse`. A fuse that opens before the module's breaker, on a short circuit at its outlet, keeps the other outlets, and the return pump, running.
5. An outlet that declares `overload-protection` MUST have a `currentLimit` no higher than its `ratedCurrent`, and MUST switch off, and report `tripped` and `overcurrent`, once its current has exceeded `currentLimit` for 5 s (provisional), and stay off until `resetTrip` [OAP-DC Section 9.1]. Makers differ: one aquarium strip only warns of overcurrent, and another switches the outlet off.

9.4 Temperature of the Module

1. A power module MUST report `overtemperature` among its device faults while its internal temperature exceeds the highest its maker allows, and SHOULD report `internalTemperature` [OAP-DC Section 8.1].
2. Protection against overheating that its safety standard requires is in hardware (Section 12.3).

9.5 Wear

1. Each outlet SHOULD count the operations of its switching device since manufacture, in the state attribute `switchCount` [OAP-DC Section 9.1], and keep the count across power loss and firmware updates.
2. An outlet that counts SHOULD report `expired` once the count exceeds its `endurance`, so that the owner can replace the module before a worn contact welds.

9.6 Faults and Alarms

Table 10 — Faults a power module reports

Fault	Reported by	While	Section
<code>stuck-on</code>	An outlet	It draws power while off	9.2
<code>load-disconnected</code>	An outlet	It draws nothing while on	9.2
<code>overcurrent</code>	An outlet with <code>overload-protection</code> ; the device	Its current exceeds <code>currentLimit</code> ; the total exceeds <code>ratedCurrent</code>	9.3
<code>expired</code>	An outlet	Its operations exceed its <code>endurance</code>	9.5
<code>hardware-failure</code>	An outlet	It cannot switch or measure [OAP-FS Section 11.3]	—
<code>cutoff</code>	An outlet with a backup thermostat	The backup thermostat holds it off	11.4
<code>overtemperature</code>	The device	It is too hot inside	9.4
<code>undervoltage, overvoltage</code>	The device	Mains is outside its rated range	10.4
<code>communication-lost</code>	The device	It has no contact with its controller [OAP-FS Section 7.3]	—
<code>sensor-disconnected, out-of-range</code>	The probe port's <code>sensor</code> endpoint	[OAP-PI Section 10]	11.2

1. These faults become alarms with the default severities of the Alarms and Notifications specification [OAP-AN Section 8.4].
2. `cutoff` has the default severity `warning` [OAP-AN Section 8.4]. The temperature that caused it raises range alarms of its own [OAP-AN Section 9].
3. Where this Section defines a fault, or a switch-off, by a delay, such as `stuck-on` once an outlet has drawn power for 5 s, the outlet or the module MUST report the fault, or switch the outlet off, no later than 2 s (provisional) after the delay has passed, and MUST remove the fault, except as Section 11.6.3 says, no later than 2 s after its condition ends. The 2 s allow for the measurement interval of Section 9.1.2 and for the report, so a welded relay is reported about 6 s, and no more than 7 s, after it begins to draw power.

9.7 Checks

Table 11 — Measurement checks

Check	Presence	Applies to	What it requires	Section
Accuracy	REQUIRED	Power modules	Each outlet measures its RMS voltage and current, and real power, at least once a second, within $\pm 1\%$, $\pm(2\% + 0.02\text{ A})$,	9.1

Check	Presence	Applies to	What it requires	Section
			and $\pm(2\% + 1\text{ W})$, from no load to its rated current, and reports them at least once a second while they change, on every binding.	
Stuck outlets	REQUIRED	Power modules	An outlet that draws more than 2 W while off for 5 s reports <code>stuck-on</code> no more than 2 s later, and removes it within 2 s of the end, and never reports it because of standing current or in the 5 s after it switches.	9.2
Disconnected loads	RECOMMENDED	Power modules	An outlet that is on but draws no more than 2 W for 30 s reports <code>load-disconnected</code> .	9.2
Overcurrent	REQUIRED	Power modules	The module protects itself with a circuit breaker or a fuse, and reports <code>overcurrent</code> among its device faults while its total current has exceeded its <code>ratedCurrent</code> for 5 s.	9.3
Overload protection	REQUIRED	Power modules	An outlet with <code>overload-protection</code> has a <code>currentLimit</code> no higher than its <code>ratedCurrent</code> , switches off and reports <code>tripped</code> and <code>overcurrent</code> once its current has exceeded <code>currentLimit</code> for 5 s, and stays off until <code>resetTrip</code> .	9.3
Temperature of the module	REQUIRED	Power modules	The module reports <code>overtemperature</code> among its device faults while its internal temperature exceeds the highest its maker allows.	9.4
Counting operations	RECOMMENDED	Power modules	Each outlet counts its switching operations in <code>switchCount</code> , keeps the count across power loss and firmware updates, and reports <code>expired</code> once it exceeds its <code>endurance</code> .	9.5
Faults after their delays	REQUIRED	Power modules	A fault defined by a delay is reported, or its outlet switched off, no more than 2 s after the delay has passed, and removed within 2 s of the end of its condition.	9.6

10 Mains Power

10.1 What Powers the Electronics

1. A power module **MUST** declare, as `electronicsSupply`, what powers its electronics and switching devices: `mains`, from a supply of its own; `bus`, from the module bus; or `mains-and-bus`, from either.
2. A power module **SHOULD** run its electronics from mains, or from mains and the bus (Appendix E, issue 4). A module that runs from the bus alone puts every outlet in its unpowered state the moment its bus cable is unplugged or its bus supply fails, which stops a return pump on an outlet whose unpowered state is `off` (Table 8).

10.2 Power-Up and the Return of Mains

1. After power-up, each outlet **MUST** follow the Fail-Safe Behavior specification [OAP-FS Section 9.1].
2. After power-up, a power module **MUST** switch outlets on at least 1 s apart (provisional), in the order of their `powerOnDelay` and then of their identifiers [OAP-FS Section 9.2]. Outlets whose unpowered state is `on` and whose `powerOnDelay` is 0 are on already, and do not wait. One whose `powerOnDelay` is longer keeps its output inactive for its `powerOnDelay`, as every output does [OAP-FS Section 9.1].
3. A power module whose electronics stay powered while mains is lost **MUST** open every outlet whose unpowered state is `off` when mains is lost, and, when mains returns, **MUST** keep each of them off for its `powerOnDelay` and then switch them on as item 2 says, each to the state its controller last commanded, or to its fail-safe behavior if it has lost contact. Its endpoints have not restarted, so their `controlSource` does not change.
4. A power module whose electronics lose power with mains restarts as item 1 says.

10.3 Reporting Mains Power

1. A power module whose `electronicsSupply` is `bus` or `mains-and-bus` **MUST** report whether mains is present at its plug, in the device state attribute `mainsPresent` [OAP-DC Section 8.1], and **MUST** report each change within 1 s (provisional).

2. A power module whose electronics run from mains alone stops when mains fails, and its controller loses it [OAP-FS Section 7.6].
3. A controller can use the report to detect the loss of mains power (Section 13.4).

10.4 Dips and Interruptions

1. Dips, short interruptions, and slow changes of the mains voltage MUST NOT make an outlet change state more than once as the voltage falls, and once as it recovers [OAP-FS Section 9.3]. They MUST NOT switch on an outlet that is off and whose unpowered state is `off`.
2. While its electronics are working, a power module MUST report `undervoltage` among its device faults while its mains voltage is more than 10 % (provisional) below the lowest of its `ratedVoltage`, and `overvoltage` while it is more than 10 % above the highest [OAP-FS Section 9.3].
3. The test procedures apply the voltage dips and short interruptions of IEC 61000-4-11 [IEC 61000-4-11], which the appliance safety standard also applies to protective electronics [IEC 60335-1].

10.5 Restarts and Firmware Updates

1. While its processor restarts, and while it installs new firmware, each outlet MUST be only in its current state, its unpowered state, or its power-up behavior, changing as Section 8.2.5 allows [OAP-FS Sections 11.1 and 11.2].
2. A firmware update MUST NOT change what a power module declares (Section 7.3), except to correct it or to add a certification.
3. Firmware is updated as the Security and Access specification requires [OAP-SA Section 15], and Section 12.3 says what an owner's own firmware means for certification.

10.6 Checks

Table 12 — Mains power checks

Check	Presence	Applies to	What it requires	Section
What powers the electronics	REQUIRED	Power modules	The module declares as <code>electronicsSupply</code> what powers its electronics and switching devices.	10.1
Electronics on mains	RECOMMENDED	Power modules	The electronics and switching devices run from mains, or from mains and the bus, so that losing the bus brings fail-safe behavior, not unpowered states.	10.1
Power-up	REQUIRED	Power modules	After power-up, outlets follow Fail-Safe Behavior Section 9.1, and switch on at least 1 s apart, in the order of their <code>powerOnDelay</code> and identifiers; outlets that are on without power, and whose <code>powerOnDelay</code> is 0, do not wait.	10.2
The return of mains	REQUIRED	Power modules	A module whose electronics stay powered opens its outlets when mains is lost, and when mains returns keeps each off for its <code>powerOnDelay</code> , then switches them on 1 s apart, to their commanded states, without changing <code>controlSource</code> .	10.2
Reporting mains	REQUIRED	Power modules	A module whose electronics can run without mains reports <code>mainsPresent</code> , and each change within 1 s.	10.3
Dips and interruptions	REQUIRED	Power modules	Dips, short interruptions, and slow changes of mains change no outlet's state more than once as the voltage falls and once as it recovers, never switch on an outlet that is off and whose unpowered state is <code>off</code> , and outside the rated range raise <code>undervoltage</code> or <code>overvoltage</code> .	10.4
Restarts and updates	REQUIRED	Power modules	During restarts and firmware updates, outlets are only in their current state, their unpowered state, or their power-up behavior, and an update changes no declaration except to correct it or add a certification.	10.5

11 Backup Thermostat

11.1 Purpose

A heater stuck on can kill livestock within hours, while a tank cools slowly [OAP-FS Section 13.2]. Controllers guard against it with two probes and a fail-safe state [OAP-FS Section 10.4], and owners set the heater's own thermostat just above the target as a backstop [P0001]. A backup thermostat adds a layer that shares none of the controller's failures: the module's own probe and logic hold a heater outlet off when the water is too hot, whatever the controller commands, and keep the water in range while the controller is gone. One aquarium power strip already runs a heater or chiller outlet from its own probe.

A backup thermostat is OPTIONAL. An outlet has one when its endpoint declares the `backup-thermostat` feature of `switch` [OAP-DC Section 9.1].

11.2 The Probe

1. A backup thermostat MUST read the water's temperature from a temperature probe port of the power module itself, not from a reading sent by its controller, so that it does not share its controller's failures.
2. The port MUST be a temperature port of the Probe Interface specification [OAP-PI Section 10], presented as a `sensor` endpoint for `temperature`, with its `port` [OAP-DC Section 11.1].
3. The port, whose probe is in the water, MUST be separated from mains by double or reinforced insulation (Section 12.4).
4. A controller MAY use the probe's readings like any other's, for example as the second probe of a heater function [OAP-FS Section 10.4].

11.3 Settings

An outlet with a backup thermostat has the config attribute `backupThermostat` of the `backup-thermostat` feature [OAP-DC Section 9.1], an object with the members of Table 13, valid against `$defs/backupThermostat` of `schema/power-module.schema.json`, which gives their ranges. It also has the fixed attribute `cutoffContact` (Section 11.6), and follows the backup thermostat as its program (Section 11.5).

Table 13 — Members of `backupThermostat`

Member	Type	Presence	Description
<code>enabled</code>	boolean	REQUIRED	Whether the backup thermostat acts. It ships <code>false</code> .
<code>probe</code>	string	REQUIRED	The identifier of the module's temperature <code>sensor</code> endpoint that it reads.
<code>mode</code>	enum: <code>heat</code> , <code>cool</code>	REQUIRED	<code>heat</code> for a heater on the outlet; <code>cool</code> for a chiller.
<code>cutoff</code>	number (degC)	REQUIRED	In <code>heat</code> mode, the outlet is held off while the probe reads at or above <code>cutoff</code> ; in <code>cool</code> mode, while it reads at or below. From 0 °C to 40 °C (provisional).
<code>setpoint</code>	number (degC)	OPTIONAL	The temperature the outlet regulates to by itself (Section 11.5). At least <code>hysteresis</code> below <code>cutoff</code> in <code>heat</code> mode, and above it in <code>cool</code> mode.
<code>hysteresis</code>	number (degC)	OPTIONAL	The difference between switching on and off, and how far the reading must return before the cutoff releases. From 0.1 °C to 5 °C. Default 0.5 °C (provisional).

1. A power module MUST reject a write of these settings, and keep the previous ones [OAP-DC Section 7.3], when:
 - `probe` is not a temperature `sensor` endpoint of the module;
 - `cutoff` is outside 0 °C to 40 °C;
 - `setpoint` is not at least `hysteresis` below `cutoff` in `heat` mode, or above it in `cool` mode;
 - the outlet has no backup thermostat; or
 - the write would set `enabled` `false`, or remove `setpoint`, from a backup thermostat that is `enabled` with a `setpoint`, while the outlet's `failSafeAction` is `continue`.
2. The settings are fail-safe settings: a controller changes them only with the owner's confirmation (Section 13.3).

3. The last case of item 1 keeps an outlet that uses `continue` from losing its backup thermostat, which is both its program and the cutoff that limits a heater left on when its controller is lost (Section 11.5); the owner first changes `failSafeAction` (Section 13.3.4).
4. A write that the module accepts, and that disables the backup thermostat or removes its `setpoint` while the outlet follows its program, takes the outlet off its program and switches it off [OAP-DC Section 7.13.9].

11.4 Cutoff

1. While its backup thermostat is `enabled`, an outlet in `heat` mode MUST be off while its probe reads at or above `cutoff`, and an outlet in `cool` mode MUST be off while its probe reads at or below `cutoff`. It MUST be off within 3 s (provisional) of the water reaching `cutoff`: the 2 s within which a temperature port measures [OAP-PI Section 7.3], the 0.1 s within which an outlet opens (Section 8.4.3), and a margin.
2. The cutoff releases once the reading is below `cutoff` minus `hysteresis` in `heat` mode, or above `cutoff` plus `hysteresis` in `cool` mode. The outlet then takes the state that its controller, a local control, its program, or its fail-safe behavior gives it.
3. While its backup thermostat is `enabled`, an outlet MUST also be off from no more than 10 s (provisional) after its probe becomes unavailable [OAP-FS Section 10.1], or reports `out-of-range`, until the probe gives a `good` reading within the limit of item 2. A lost probe leaves the heater off, as one aquarium strip does by default.
4. The cutoff is a limit that the device enforces [OAP-DC Section 7.8]: it applies whatever the controller, a local control, or the fail-safe behavior commands. A command to switch the outlet on while the cutoff holds it off is accepted, and waits, as a top-off unit at its daily limit waits [OAP-DC Section 7.8.3]; the outlet switches on when the cutoff releases, if no later command, and no fail-safe state, has replaced it. An outlet that follows its program goes on following it once the cutoff releases.
5. While the cutoff holds an outlet off, the outlet MUST report `cutoff` among its faults [OAP-DC Section 8.4].
6. The cutoff never switches an outlet on.

11.5 Regulating Without a Controller

1. An outlet whose backup thermostat is `enabled` and has a `setpoint` can follow it as its program [OAP-DC Section 7.13.9]: a controller returns the outlet to its program with `runProgram`, and the outlet reports `programRunning true` while it follows it.
2. While it follows its program, an outlet in `heat` mode MUST switch on when the probe reads at or below `setpoint` minus half the `hysteresis`, and off at or above `setpoint` plus half the `hysteresis`; in `cool` mode, it MUST do the reverse.
3. A `set`, such as an interlock's stop, takes the outlet off its program [OAP-DC Section 7.13.9]. With `failSafeAction continue`, an outlet that follows its program when it loses contact keeps following it, one that does not keeps the state last set [OAP-FS Section 7.3], and after power-up, with `powerOnBehavior fail-safe`, an outlet follows its program unless a latched stop holds it [OAP-FS Sections 8.4 and 9.1]. So a heater outlet that a low-water interlock stopped keeps the stop when its controller is lost, rather than heating a drained sump.
4. The cutoff, and the time between switch-ons (Section 8.4), still apply, whether or not the outlet follows its program.
5. With `continue`, an outlet that does not follow its program keeps the state last commanded [OAP-FS Section 7.3], which is not a safe state for a heater: only the cutoff limits a heater left on, and a controller does not propose `continue` unless the backup thermostat is `enabled` with a `setpoint` (Section 13.3).
6. The Fail-Safe Behavior specification recommends `stop` for heaters and chillers, and allows `continue` for an outlet that its backup thermostat regulates as its program [OAP-FS Section 13.2] (Appendix E, issue 5). A heater that keeps the water warm through a long outage of the controller, rather than switching off, matters most in a cold room.
7. Once configured, and running its program, a power module keeps regulating with no controller at all, through any number of power cuts.

11.6 Cutoff Contacts

1. An outlet with a backup thermostat SHOULD have a cutoff contact, declared as `cutoffContact`, so that a welded contact cannot defeat the cutoff.
2. A cutoff contact MUST be open when unpowered, and SHOULD be opened whenever the cutoff holds its outlet off.
3. While an outlet with a cutoff contact is off and draws power as `stuck-on` requires (Section 9.2), the module MUST open the cutoff contact, and MUST keep reporting `stuck-on` until the outlet is next commanded on, although the outlet then draws nothing. When the outlet is next commanded on, the module closes the cutoff contact, and if its switching device is still stuck, the next switch-off repeats this. A welded heater relay then costs about 6 s of heating, and no more than 7 s (Section 9.6.3), each time the heater should stop, and the owner knows it is welded.

11.7 An Operating Control

1. This Specification treats a backup thermostat as an operating control that protects livestock, not as a protective control that protects people and property (Appendix E, issue 3). A heater's own safety standard already requires it to be safe with its thermostat short-circuited [IEC 60335-1] [IEC 60335-2-55]; what a backup thermostat adds protects the water. Claiming it as a protective control would need tolerance of single faults, software of class B in the terms of IEC 60730-1, and immunity tests [IEC 60335-1] [IEC 60730-1], and would make its firmware part of the certified product.
2. A maker MAY nevertheless certify a backup thermostat as a protective control, and then declares it in `protections` as a `temperature-limit`, with `firmware true` (Table 4).

11.8 Checks

Table 14 — Backup thermostat checks

Check	Presence	Applies to	What it requires	Section
The probe	REQUIRED	Power modules	A backup thermostat reads the module's own temperature probe port, a Probe Interface temperature port presented as a <code>sensor</code> endpoint, separated from mains by double or reinforced insulation.	11.2
Settings	REQUIRED	Power modules	The module rejects backup thermostat settings that name a probe that is not a temperature sensor of the module, a cutoff outside 0 °C to 40 °C, or a setpoint less than <code>hysteresis</code> from the cutoff on its side, or that are for an outlet without a backup thermostat, or that disable an enabled backup thermostat, or remove its setpoint, while the outlet uses <code>continue</code> ; it ships disabled, and keeps its settings across power loss.	11.3
Cutoff	REQUIRED	Power modules	While enabled, the outlet is off within 3 s of the water reaching <code>cutoff</code> , and while its probe reads at or beyond it, whatever is commanded, reports <code>cutoff</code> , accepts commands to switch on and carries them out when the reading has returned by <code>hysteresis</code> , and never switches on by itself.	11.4
A lost probe	REQUIRED	Power modules	While enabled, the outlet is off from no more than 10 s after its probe becomes unavailable, until a good reading within the release limit.	11.4
Regulating as a program	REQUIRED	Power modules	An outlet that follows its program, after <code>runProgram</code> , switches on at the setpoint minus half the hysteresis, and off at the setpoint plus half; with <code>failSafeAction continue</code> , it goes on following it after loss of contact and after power-up, while an outlet that a <code>set</code> took off its program keeps the state set, and one that a latched stop holds stays off after power-up.	11.5
Cutoff contacts	RECOMMENDED	Power modules	An outlet with a backup thermostat has a cutoff contact, which opens whenever the cutoff holds the outlet off.	11.6
Cutoff contacts that act	REQUIRED	Power modules	On an outlet with a cutoff contact, the contact is open when unpowered, and opens when the outlet is off but its switching device is stuck, with <code>stuck-on</code> reported until the outlet is next commanded on.	11.6

12 Electrical Safety

12.1 Safety Certification

1. A power module **MUST** hold, for each market where it is sold, the safety certification that the market's law requires, and **MUST** meet the standards on which that certification rests. Table 15 summarizes what the law required in five markets in October 2026; a maker checks the law itself.
2. A power module **SHOULD** be certified by a certification body even where the law accepts the maker's own declaration (Appendix E, issue 2). A certification body tests the product, and inspects each factory that makes it, usually four times a year.
3. Each certification and declaration **MUST** be declared in **certifications** (Table 3), naming the standards with their editions, the holder, the certification body of a certification, and the certificate or file number, or the declaration's identifier. None of the power strips of four widely used commercial aquarium controllers names the standard it is certified to, and owners need it to compare products.
4. A power module, its packaging, and its documentation **MUST NOT** say or suggest that it is certified, listed, or approved for a market where it is not.
5. Conforming to this Specification is not safety certification, and does not replace it.
6. A certification belongs to its holder, for the product it names, made at the factories it names. Another maker that builds the same design needs a certification of its own, or must have the module made at a factory that the holder's certification covers.

Table 15 — What the law requires, by market, in October 2026

Market	Safety certification before sale	Route	Also
United States	Not required by federal law for household products. Required for equipment used in workplaces [29 CFR 1910], and expected by retailers and inspectors.	A listing by a Nationally Recognized Testing Laboratory.	FCC Part 15 for emissions; FCC certification for a radio.
Canada	Required, by provincial law [O. Reg. 438/07] [B.C. Reg. 100/2004].	Certification by a body accredited by the Standards Council of Canada. One investigation can give both US and Canadian marks.	ICES-003; markings in English and French.
European Union	Not required.	The maker's declaration of conformity and technical file, kept for 10 years [LVD 2014/35/EU].	EMC Directive; Radio Equipment Directive and EN 18031 for a radio [RED 2014/53/EU]; the Cyber Resilience Act from 11 December 2027 [CRA].
United Kingdom	Not required, except approval of the plug's type to BS 1363 [Plugs and Sockets 1994].	A declaration [EESR 2016]; the CE marking is accepted.	The Product Security and Telecommunications Infrastructure regulations [PSTI].
Australia	Required: a power module is a "control or conditioning device", Level 3 equipment [EESS].	A certificate from a recognised certifier, the RCM, and registration by a responsible supplier in Australia or New Zealand.	Rules on the security of smart devices [Smart Devices Rules 2025].

12.2 Standards by Market (Informative)

No standard names an aquarium power module, so a certification body decides which standards apply to a product. Table 16 lists those most likely to apply.

Table 16 — Standards most likely to apply

Part	United States	Canada	European Union and United Kingdom	Australia and New Zealand
The power module	UL 1363 [UL 1363]	CSA C22.2 No. 308 [CSA C22.2 No. 308]	No harmonised standard: a national socket-outlet standard based on IEC 60884-1 [IEC 60884-1], such as DIN VDE 0620-2-1 or BS 1363-2; or IEC 60335-1 [IEC 60335-1], if the module is treated as an appliance	AS/NZS 3105, as a "control or conditioning device"

Part	United States	Canada	European Union and United Kingdom	Australia and New Zealand
Its control functions	UL 60730-1 [UL 60730-1]	CSA E60730-1	EN 60730-1 [IEC 60730-1]; some smart strips use EN 60669-2-1 or EN 61058-1 instead	Not checked
A backup thermostat	UL 60730-2-9	CSA C22.2 No. 24	EN 60730-2-9 [IEC 60730-2-9]	Not checked
Electromagnetic compatibility	FCC Part 15, Subpart B	ICES-003	EMC Directive	ACMA rules

- IEC 60335-2-55, the standard for electrical appliances for aquariums, names aerators, heaters, food dispensers, and sludge-suction appliances, excludes pumps and luminaires, and is not known to have been applied to a power strip [IEC 60335-2-55]. UL 1018, its counterpart in the United States, does not name controllers or power strips [UL 1018].
- Smart power strips listed in North America follow one pattern: UL 1363 for the strip and UL 60730-1 for its control.
- A heater controller with outlets has been listed as a control, to UL 60730-1 and UL 60730-2-9, rather than as a power strip.

12.3 Protection Does Not Depend on Firmware

1. Every protective function of a power module **MUST** work without its firmware, and with any firmware: protection against overcurrent and short circuits, against overheating of the module, against electric shock through its insulation, and, where fitted, against residual current and surges.
2. Each **MUST** be declared in `protections`, with `firmware false`.
3. Firmware **MAY** add to a protective function, for example by reporting `overcurrent` before a breaker opens (Section 9.3), but **MUST NOT** be the only means.
4. An owner can therefore install firmware of their own [OAP-SA Section 15.8] without removing the module's protection. A certification covers only the firmware that was evaluated, so owner firmware leaves the certified configuration, but not the protection of the hardware. A module reports who signed its firmware as `firmwareSigner` [OAP-DC Section 8.1], and a controller shows it (Section 13.5).
5. A maker **MAY** list in a certification the firmware versions it covers (Table 3).

12.4 Insulation from Low-Voltage Parts

1. Insulation between mains and every part an owner can touch or connect to, such as the module bus, Ethernet, probe ports, and buttons, **MUST** be double or reinforced [IEC 60335-1]. This includes the insulation between relay coils and contacts, and across current sensors and isolators, wherever they bridge the two sides.
2. The module's low-voltage ports carry SELV, as the module bus does [OAP-MB Section 7.3].
3. Creepage distances on the mains side **SHOULD** meet pollution degree 3, or the circuit boards **SHOULD** have a permanent coating that the module's certification accepts [IEC 60664-3], because salt creep from aquarium water conducts, and an enclosure does not keep out condensation [IEC 60664-1]. Both are declared as `insulation`.

12.5 Residual-Current Protection

1. A power module **MUST NOT** be presented as a replacement for residual-current protection of its supply, which its instructions require (Section 14.2).
2. A power module **MAY** have a built-in residual-current device. If it has, the device:
 - **MUST** be covered by the module's certification, under its own standard, such as UL 943, IEC 61540, BS 7071, or AS/NZS 3190;
 - **MUST** be of Type A, F, or B, because DC pumps and LED drivers can cause residual currents that a Type AC device does not detect [BEAMA RCD];
 - **MUST NOT** need a manual reset after a power cut that it did not trip on, so that a return pump restarts when power returns; and
 - **MUST** be declared as `residualCurrent`.

3. A trip of a residual-current device switches off every outlet it protects, a return pump with the rest. This revision does not define monitoring residual current outlet by outlet, which would find a leaking appliance before it trips anything.

12.6 Functions That Bring In Other Standards (Informative)

Each function in Table 17 adds a standard to a power module's certification, and its cost.

Table 17 — Functions that bring in other standards

Function	Standards it brings in
Ground-fault or residual-current protection	US: UL 943, through UL 1363. IEC markets: IEC 61540; UK: BS 7071; Australia: AS/NZS 3190.
Surge protection	US: UL 1449 Type 3, for more than two outlets. EU: EN 61643-11.
A radio, such as Wi-Fi or Bluetooth	US and Canada: radio certification. EU: the Radio Equipment Directive, with EN 18031.
Fixing to furniture with tools	US: UL 962A instead of UL 1363.
A battery in the mains circuit	US: UL 1778.
Four or fewer controlled outlets	US: UL 244B, as an alternative to UL 1363.
A backup thermostat	UL 60730-2-9 and IEC 60730-2-9.
A timer function	UL 60730-2-7 and IEC 60730-2-7.

12.7 Checks

Table 18 — Electrical safety checks

Check	Presence	Applies to	What it requires	Section
Safety certification	REQUIRED	Power modules	The module holds the safety certification that each market where it is sold requires, and never claims one it does not hold.	12.1
Certifications declared	REQUIRED	Power modules	Each certification and declaration is declared in certifications , with its standards and editions, its holder, its body for a certification, and its reference.	12.1
Third-party certification	RECOMMENDED	Power modules	The module is certified by a certification body in every market, even where the law accepts a declaration.	12.1
Protection in hardware	REQUIRED	Power modules	Every protective function works without firmware, and with any firmware, and is declared with firmware false .	12.3
Insulation from low-voltage parts	REQUIRED	Power modules	Insulation between mains and every part an owner can touch or connect to, including the module bus, Ethernet, and probe ports, is double or reinforced.	12.4
Spacing for salt	RECOMMENDED	Power modules	Creepage distances on the mains side meet pollution degree 3, or the circuit boards have a permanent coating that the certification accepts.	12.4
Built-in residual-current devices	REQUIRED	Power modules	The module is never presented as a replacement for residual-current protection of its supply, and a built-in residual-current device is covered by the certification under its own standard, is of Type A, F, or B, and needs no manual reset after a power cut it did not trip on.	12.5

13 Controllers

13.1 Binding Equipment to Outlets

1. A controller **MUST NOT** bind an output whose equipment is stop-on-loss equipment to an outlet whose unpowered state is [on](#), because the equipment would run whenever the module's electronics fail. For example, it refuses a heater, a doser, or a CO2 system on such an outlet, and says why.
2. A controller **SHOULD** propose an outlet whose unpowered state is [on](#) for a return pump, and an outlet with a backup thermostat for a heater or a chiller.

3. These rules also apply when a controller binds a replacement device [OAP-DC Section 7.12].

13.2 Ratings and the Power Budget

1. A controller SHOULD warn the owner when the equipment on an outlet draws more than the outlet's `ratedCurrent`.
2. A controller SHOULD warn the owner when the outlets of one power module together draw more than 80 % (provisional) of the module's `ratedCurrent`, so that there is room for inrush, and for a heater and a chiller that start together.

13.3 Backup Thermostat Settings

1. A controller MUST treat backup thermostat settings as fail-safe settings: it changes them only with the owner's confirmation [OAP-FS Section 13.1], and only for a user allowed the operation `change-fail-safe-settings` [OAP-SA Section 11.3], and MUST record each change in its audit log, with the old and new settings, as it records changes to other fail-safe settings [OAP-SA Section 12.1].
2. When an owner binds the output of a heater or chiller function to an outlet with a backup thermostat, a controller SHOULD propose settings: the `mode` of the equipment, the function's setpoint as `setpoint`, and a `cutoff` 1.5 °C (provisional) beyond it; and SHOULD propose the module's probe as the function's second input [OAP-FS Section 10.4]. The owner confirms them. Once the owner has enabled the backup thermostat with a `setpoint`, a controller MAY also propose `failSafeAction continue` for the outlet, and then runs the outlet on its program with `runProgram`, so that it keeps the water in range through an outage of the controller (Section 11.5); the owner confirms it as any fail-safe setting. An interlock's stop then takes the outlet off its program, so that it stays off if the controller fails [OAP-DC Section 7.13.9].
3. A controller MUST NOT propose `failSafeAction continue` for an outlet that drives a heater or a chiller unless its backup thermostat is `enabled` and has a `setpoint`.
4. When an owner disables the backup thermostat of an outlet whose `failSafeAction` is `continue`, or removes its `setpoint`, a controller MUST first set the outlet's `failSafeAction` to `state`, with `failSafeState {"on": false}`, as part of the same confirmed change, because the module refuses the change otherwise (Section 11.3.1).

13.4 Detecting Power Loss

1. A controller that keeps running on a battery when mains fails MAY use the `mainsPresent` of a power module to detect the loss of mains power [OAP-FS Section 9.5]. It then enters power-loss mode, and raises `mains-power-lost`, as the Alarms and Notifications specification says [OAP-AN Section 8.5].
2. Only a module whose electronics stay powered without mains reports it (Section 10.3).

13.5 What a Controller Shows

1. A controller MUST show the owner, for each outlet, its `ratedCurrent`, its `unpoweredState`, its fail-safe configuration [OAP-FS Section 13.3], and its backup thermostat settings; and, for each power module, its `ratedCurrent` and its `certifications`, with the standards they name.
2. A controller MUST show when a power module runs firmware that its maker did not sign, and that the module's certification does not cover that firmware, while the protection in its hardware is unchanged (Section 12.3).
3. The wording of item 2 is the controller's, in the owner's language, as long as it says all three; for example:

This power module runs firmware that its maker did not sign. Its safety certification covers only firmware that its maker evaluated, so it does not cover this firmware. Its protection against overcurrent, overheating, and electric shock is in its hardware, and still works.

13.6 Checks

Table 19 — Controller checks

Check	Presence	Applies to	What it requires	Section
Stop-on-loss equipment	REQUIRED	Controllers	A controller does not bind stop-on-loss equipment to an outlet whose unpowered state is on , and says why.	13.1
Proposing outlets	RECOMMENDED	Controllers	A controller proposes an outlet whose unpowered state is on for a return pump, and an outlet with a backup thermostat for a heater or a chiller.	13.1
Power budget	RECOMMENDED	Controllers	A controller warns when equipment draws more than its outlet's rating, and when a module's outlets together draw more than 80 % of its rating.	13.2
Backup thermostat settings	REQUIRED	Controllers	A controller changes backup thermostat settings only with the owner's confirmation and change-fail-safe-settings , records each change in its audit log, does not propose continue for a heater or chiller outlet without an enabled backup thermostat with a setpoint, and sets an outlet on continue to stop before it disables the outlet's backup thermostat.	13.3
Power loss from a power module	OPTIONAL	Controllers	A controller on a battery that uses a power module's report of mains enters power-loss mode, and raises mains-power-lost , when the module reports that mains is absent.	13.4
What a controller shows	REQUIRED	Controllers	A controller shows each outlet's rating, unpowered state, fail-safe configuration, and backup thermostat settings, and each module's rating and certifications with their standards.	13.5
Owner firmware	REQUIRED	Controllers	A controller shows when a power module runs firmware its maker did not sign, and that the certification does not cover it, while the protection of its hardware is unchanged.	13.5

14 Labels, Instructions, and Documentation

14.1 Labels

1. Each outlet **MUST** be labeled with its number, the number in its endpoint's identifier (Section 7.1).
2. Each outlet's rated current **MUST** be marked on the module, beside the outlet or in a table on the module, where it differs from the module's.
3. Each outlet whose unpowered state is **on** **MUST** be marked beside it, in words or with a symbol that the instructions explain, so that an owner does not plug a heater into it by mistake.
4. Each outlet with a backup thermostat **SHOULD** be marked, and so **SHOULD** the probe port.
5. A socket-outlet that the module does not switch **MUST** be marked as not switched.
6. These labels are in addition to the markings that the module's safety certification requires.

14.2 Installation Instructions

A power module's installation instructions **MUST** say, in the languages that each market requires:

1. to connect the module only to a circuit protected by a GFCI, or by a residual-current device of at most 30 mA, of Type A or better where the market distinguishes types;
2. to mount it above the highest level the water can reach, and never above an open tank or sump;
3. to give every cord a drip loop;
4. to keep it in a dry, ventilated place where it cannot be splashed, and to cover unused outlets where covers are supplied;
5. which outlets suit a return pump, and which suit a heater or a chiller, and why: their unpowered states, and any backup thermostats;
6. the rated current of the module and of each outlet, and that chillers and motors draw several times their rated current when they start;
7. that a heater's own thermostat should still be set just above the target temperature [P0001]; and
8. what installing other firmware means for the module's certification (Section 12.3).

14.3 Published Documentation

1. A maker **MUST** publish, for each model and market, before the module is sold:
 - its device description, with the declarations of Section 7.3;
 - its installation instructions, at the URL it declares; and
 - for each certification, the certificate, or the declaration of conformity.
2. A maker **SHOULD** publish the results of the test procedures of Section 16.4.

14.4 Checks

Table 20 — Documentation checks

Check	Presence	Applies to	What it requires	Section
Labels	REQUIRED	Power modules	Each outlet is labeled with its number, and with its rating where it differs from the module's; outlets that are on without power, and outlets that are not switched, are marked beside them.	14.1
Installation instructions	REQUIRED	Power modules	The instructions require a GFCI or a 30 mA residual-current device, mounting above the water and not over it, and drip loops, and explain the unpowered states, backup thermostats, ratings, a heater's own thermostat, and owner firmware.	14.2
Published documentation	REQUIRED	Power modules	Before sale, the maker publishes each model's description, its installation instructions at the declared URL, and each certificate or declaration of conformity.	14.3

15 Provisional Values

Table 21 gives the values of this Specification's limits and defaults. Every one is provisional, and they are published in machine-readable form in `checks.json`.

Table 21 — Provisional values

Area	Value	Provisional value	Kind	Why
Outlets	Highest ambient temperature, at least	40 °C	Limit	The highest cabinet temperature the Probe Interface uses (its Section 7.7); a cabinet with pumps and lights can reach it in a warm room.
Outlets	Off-state current	1 mA	Limit	Below what holds small solenoid valves and loads on; triacs and solid-state relays pass 1 mA to 14 mA when off, and a relay passes none.
Outlets	Rated endurance	50,000 operations	Limit	A heater under a thermostat function can switch 10 to 30 times a day, so 50,000 operations last more than four years; relays are rated for 6,000 to 100,000.
Outlets	Inrush rating	80 A	Limit	LED drivers draw 60 A to 75 A for under a millisecond when they start at 230 V.
Outlets	Closing interval	0.2 s	Limit	Longer than the inrush of an LED driver, and most of a small motor's; eight outlets switched together take under 2 s.
Outlets	Opening time	0.1 s	Limit	A relay releases in about 10 ms; the bindings report a change within 100 ms.
Outlets	Unpowered state time	1 s	Limit	A relay releases in about 10 ms once its coil loses power; 1 s allows for the electronics' supply to decay after it fails, and matches the bindings' reporting of a change.
Outlets	Time between switch-ons	5 s	Limit	The shortest time the Flow Programs specification lets a pump on a switch stay on or off; at one switch-on every 5 s, a relay rated for 50,000 operations lasts about three days of constant cycling, rather than 14 hours at one a second.
Measurement and faults	Measurement interval	1 s	Limit	Fast enough to report stuck-on within 2 s of its 5 s delay, and as often as outlets report their readings.

Area	Value	Provisional value	Kind	Why
Measurement and faults	Reporting interval	1 s	Limit	As often as an outlet measures, so that the readings a controller sees are no older than the stuck-on detection needs.
Measurement and faults	Averaging time	0.2 s	Limit	10 cycles at 50 Hz and 12 at 60 Hz: a whole number of cycles at both.
Measurement and faults	Voltage accuracy	1 %	Limit	Enough to see a sagging supply, and within reach of any metering method.
Measurement and faults	Current accuracy, of the reading	2 %	Limit	Enough for the power checks of the Alarms and Notifications specification, which work in tens of percent.
Measurement and faults	Current accuracy, fixed	0.02 A	Limit	A 5 W load draws about 0.04 A at 120 V and 0.02 A at 230 V.
Measurement and faults	Power accuracy, of the reading	2 %	Limit	As for current.
Measurement and faults	Power accuracy, fixed	1 W	Limit	Half the stuck-on threshold, so that an empty outlet never looks stuck, and a 3 W load always does.
Measurement and faults	Stuck-on threshold	2 W	Limit	The Alarms and Notifications default for an outlet that is off (its Section 10.3); filters and switching devices draw milliamperes, but almost no real power.
Measurement and faults	Stuck-on delay	5 s	Limit	Long enough for a load's power to settle after it switches off; short enough that a welded heater relay is known at once.
Measurement and faults	Reporting margin	2 s	Limit	One measurement interval of 1 s, and time for the report: a fault defined by a delay of 5 s is reported within 7 s.
Measurement and faults	Disconnected delay	30 s	Default	The Alarms and Notifications default delay of a power check (its Section 10.2).
Measurement and faults	Overcurrent delay	5 s	Limit	Longer than the start of a motor or a chiller's compressor, which draws about 5 times its rated power for a moment; much shorter than a breaker takes at a small overload.
Mains power	Restart interval	1 s	Limit	Fail-Safe Behavior Section 9.2.2 requires it for every device with several outputs that switch mains.
Mains power	Mains report time	1 s	Limit	Soon enough for a controller to enter power-loss mode before a battery has done much work.
Mains power	Supply tolerance	10 %	Limit	The usual tolerance of public supplies around their nominal voltage.
Backup thermostat	Lowest cutoff	0 °C	Limit	The lowest water temperature the Probe Interface requires ports to measure (its Section 7.7).
Backup thermostat	Highest cutoff	40 °C	Limit	The highest water temperature the Probe Interface requires ports to measure; no aquarium needs a cutoff above it.
Backup thermostat	Hysteresis	0.5 °C	Default	Holds a heater within about 0.25 °C of its setpoint without switching it often.
Backup thermostat	Cutoff time	3 s	Limit	A temperature port measures at least every 2 s (Probe Interface Section 7.3), and an outlet opens within 0.1 s; 3 s leaves a margin.
Backup thermostat	Probe loss time	10 s	Limit	A temperature port reports a missing probe within 5 s (Probe Interface Section 10.2); 10 s allows for the reading to be judged unavailable.
Controllers	Budget warning	80 %	Default	Leaves room for inrush, and for a heater and a chiller that start together.
Controllers	Proposed cutoff margin	1.5 °C	Default	Above the overshoot of a heater function with a dead band of 1 °C, and below temperatures that harm most livestock.

16 Conformance

16.1 Power Modules

A conforming power module:

1. presents its outlets, and declares its hardware, as Section 7 says;
2. meets Sections 8, 9, and 10;
3. meets Section 11, if any outlet has a backup thermostat;
4. meets Section 12;
5. is labeled, documented, and published as Section 14 says; and
6. passes the test procedures of Section 16.4 that apply to power modules.

A conforming power module is also a conforming device of the Device Classes and Fail-Safe Behavior specifications [OAP-DC Section 13.1], and of each binding it implements.

16.2 Controllers

A conforming controller:

1. binds equipment to outlets as Section 13.1 says;
2. treats backup thermostat settings as Section 13.3 says;
3. shows the owner what Section 13.5 says; and
4. passes the test procedures of Section 16.4 that apply to controllers.

16.3 Schema and Tools

- `checks.json` is normative for the checks, their test procedures, and the provisional values. The check tables, Table 21, and Table 22 are generated from it by `tools/render_spec_tables.py`, which also checks that every check has a test procedure and a section that exists.
- `schema/power-module.schema.json` is normative for the structure of the extensions, `$defs/module` and `$defs/outlet`, and for the structure and ranges of `backupThermostat`, `$defs/backupThermostat`. Where it and this document differ, this document governs.
- `tools/validate_power_module.py` checks device descriptions of power modules: first with the Device Classes validator, then against the schema and the rules of Sections 7 to 12 that a description shows, such as outlet identifiers, ratings, unpowered states, shipped fail-safe configurations, backup thermostat settings, protections, and certifications. It warns about choices this Specification advises against. It checks descriptions of revision 0.3 only. It is informative.

```
python tools/validate_power_module.py specs/power-module/examples/*.json
```

16.4 Test Procedures

Tests of power modules use the module, a mains supply that can be switched and varied, loads, and a calibrated power analyzer. Some tests need a sample that its maker has prepared, so that an outlet's switching device can be bridged, or the supply of its electronics interrupted while mains stays connected. Tests of controllers use a controller and a simulated power module whose declarations, readings, and faults the tester can set. Every check of Tables 7, 9, 11, 12, 14, 18, 19, and 20 has a test in Table 22. A pass criterion that checks what a SHOULD asks applies to a product that does it.

The tests of power modules work at mains voltage, and are for people trained and equipped to work with it.

Table 22 — Test procedures

Check	Applies to	Method	Pass criteria
Endpoints (7.1)	Power modules	Read the module's description and check it with the validator. Then send <code>identify</code> to each outlet in turn, with a lamp plugged into every outlet.	The validator reports no errors. Each <code>identify</code> shows the socket whose label matches the endpoint's number, and no lamp changes.
Bindings (7.2)	Power modules	Run the test procedures of each binding the module implements (Module Bus Section 14.3,	The module passes every test that applies to it.

Check	Applies to	Method	Pass criteria
		Device Protocol Section 17.7), and those of Fail-Safe Behavior Section 14.3 on every outlet.	
A wired connection (7.2)	Power modules	Inspect the module and its declared <code>connections</code> . Then turn off every radio it has, and operate every outlet from its controller.	<code>connections</code> includes <code>module-bus</code> or <code>ethernet</code> , and every outlet works with the radios off.
Declarations (7.3)	Power modules	Check the description with the validator. Compare each declared rating, socket, plug, unpowered state, protection, and certification with the module's labels, its instructions, the data sheets of its switching devices and overcurrent protection, and each certificate or declaration.	The validator reports no errors, and every declaration matches.
Sockets and ratings (8.1)	Power modules	Inspect each socket, the plug, and the cord, and compare the data sheets of the parts with the declared ratings. Then, at the declared <code>maxAmbientTemperature</code> , load the module to its <code>ratedCurrent</code> , spread across its outlets with no outlet above its own <code>ratedCurrent</code> , until temperatures are steady, and measure the temperatures of the sockets, switching devices, and enclosure.	Each socket is its market's standard type, with the shutters the market requires. No rating exceeds a part's. <code>maxAmbientTemperature</code> is at least 40 °C, and no temperature exceeds the limits of the module's safety standard.
Off means off (8.2)	Power modules	With each outlet off, at the highest of its rated voltages, measure the RMS current into a 10 kΩ resistor, into a 1 μF capacitor, and into a small solenoid valve.	Each current is at most 1 mA, and the valve stays closed.
Relays rated for the work (8.2)	Power modules	Compare each outlet's declared <code>switchingDevice</code> , <code>endurance</code> , and <code>inrush</code> with the data sheet of its switching device. Then switch on a 150 W LED driver on each outlet 1,000 times, 10 s on and 10 s off.	Each outlet is switched by a relay rated for at least 50,000 operations at its rated current and 80 A of inrush. No contact welds during the switching, and every outlet then passes the stuck-on test.
Both conductors (8.2)	Power modules	On a module sold in such a market, switch every outlet off, and measure the voltage between each contact of each outlet's socket and protective earth, with the module's plug inserted one way round and then the other.	With the plug either way round, no contact of a socket that is off is at mains voltage.
Unpowered states (8.3)	Power modules	With a lamp on every outlet and mains connected, interrupt the supply of the module's electronics: disconnect the bus from a module whose electronics run from the bus; otherwise, use a sample prepared by its maker. Do this with every outlet on, and again with every outlet off. Then hold the processor in reset for 10 minutes, and repeat the tests 20 times. Check the data sheet of each outlet's switching device, and the declarations of each outlet whose unpowered state is <code>on</code> .	Within 1 s, each outlet is in its declared unpowered state, whatever its state before, having changed state at most once, and it stays in that state for as long as the supply is interrupted or the processor is held in reset, in every repetition. No outlet is switched by a latching relay, and no outlet whose unpowered state is <code>on</code> declares <code>backup-thermostat</code> .
An outlet for a return pump (8.3)	Power modules	Inspect the module, its labels, its declarations, and the data sheet of each switching device of an outlet whose unpowered state is <code>on</code> .	At least one outlet's unpowered state is <code>on</code> . Each such outlet is marked beside it, its <code>ratedCurrent</code> is no higher than the rating of its closed-without-power contact, and it does not declare <code>backup-thermostat</code> .
One at a time (8.4)	Power modules	With a resistive load on every outlet, record the current of each outlet with a multi-channel recorder. Send <code>set</code> with <code>on true</code> to every outlet in one burst, in a shuffled order. Then send <code>set</code> with <code>on false</code> to every outlet in one burst. Then switch one outlet off with a local control, and one with a revert.	The outlets close at least 0.2 s apart, in the order of the commands. Each opens within 0.1 s of its command, local control, or revert.
Time between switch-ons (8.4)	Power modules	At 0 s, send <code>set on</code> ; at 1 s, off; at 2 s, on. Then, after a pause, at 0 s send on; at 1 s, off; at 2 s, on; and at 3 s, off. Then, after a pause, at 0 s send on, and at 1 s send off with <code>revertAfter 2</code> .	No command is refused. In the first case, the outlet switches on again at 5 s, and <code>on</code> is <code>false</code> from 1 s until then. In the second, it stays off from 1 s. In the

Check	Applies to	Method	Pass criteria
			third, the revert falls due at 3 s, and the outlet switches on at 5 s.
Fail-safe configuration (8.5)	Power modules	Factory reset the module, and read each outlet's fail-safe configuration, <code>powerOnDelay</code> , and <code>loadCategory</code> . Then run the loss of contact, power-up, and restart tests of Fail-Safe Behavior Section 14.3 on every outlet.	Outlets whose unpowered state is off have <code>failSafeState {"on": false}</code> , and the others <code>{"on": true}</code> ; all have <code>failSafeAction</code> state, <code>powerOnBehavior</code> fail-safe, the binding's default <code>failSafeTimeout</code> , 30 s on a module with both bindings, <code>powerOnDelay</code> 0, and no <code>loadCategory</code> . Every outlet passes the tests.
Identifying an outlet (8.6)	Power modules	With a load on every outlet, send <code>identify</code> to each outlet, with and without a <code>duration</code> .	Each time, the module shows the socket whose label matches the endpoint, for the duration, 10 s by default, and no outlet changes state.
Indicators (8.6)	Power modules	Inspect the module. Switch each outlet on and off.	The module has a status light or a display, and the light beside each outlet follows it.
Showing lost contact (8.6)	Power modules	On a module with a status light or a display, stop all messages from the controller until the fail-safe timeout has passed, then send messages again.	While the module reports <code>communication-lost</code> , its status light or display shows lost contact, and stops showing it when contact returns.
Local controls (8.6)	Power modules	With the controller and the network disconnected, switch each outlet off and on with its local control, and leave it on. Switch an outlet off with its local control while the controller holds it on. Try to switch on an outlet held off by its backup thermostat's cutoff, and to switch an outlet on again 2 s after it last switched on.	Every outlet switches off at once. An outlet switched on locally ends its local control within 2 hours. The cutoff holds its outlet off, and the second switch-on waits until 5 s after the first.
Accuracy (9.1)	Power modules	With a calibrated power analyzer between an outlet and its load, at the lowest and highest of the module's rated voltages and at each rated frequency, and at ambient temperatures of 0 °C and 40 °C, apply in turn: no load; a 5 W LED driver; a 60 W resistive load; an aquarium pump with a motor; a load with a capacitor of 1 µF across it; and a resistive load at the outlet's rated current. Record <code>voltage</code> , <code>current</code> , <code>power</code> , and their times of report, on each binding the module implements, with the default <code>minInterval</code> on the Device Protocol. Repeat for every outlet.	Every reading is within the limits of Section 9.1 of the analyzer's, each reading is reported at least once a second while it changes, and with no load, or the capacitor alone, <code>power</code> is at most 1 W.
Stuck outlets (9.2)	Power modules	On a sample prepared by its maker, bridge the switching device of an outlet without a cutoff contact through a test switch, with a 60 W resistive load plugged in. With the outlet off, close the test switch; after 30 s, open it. Then, without the bridge, plug in a load with a capacitor of 1 µF across it, and switch the outlet on and off 10 times, 6 s apart.	<code>stuck-on</code> is reported no sooner than 5 s and within 7 s of closing the test switch, and removed within 2 s of opening it. It is never reported with the capacitor, or in the 5 s after a switch.
Disconnected loads (9.2)	Power modules	Switch an outlet on with nothing plugged in. After 60 s, plug in a 60 W resistive load.	<code>load-disconnected</code> is reported between 30 s and 32 s after the outlet switched on, and removed within 2 s of plugging in the load.
Overcurrent (9.3)	Power modules	Load the module to 110 % of its <code>ratedCurrent</code> , spread across outlets so that no outlet exceeds its own <code>ratedCurrent</code> , for 60 s, then reduce the load to 90 %. Then, with the processor held in reset, short an outlet through a current-limited test circuit of the size the module's safety standard uses.	<code>overcurrent</code> is reported among the device faults no sooner than 5 s and within 7 s of the overload, and removed within 2 s of the load falling. The breaker or fuse opens on the short with the processor in reset.
Overload protection (9.3)	Power modules	On an outlet that declares <code>overload-protection</code> , raise the load to 120 % of <code>currentLimit</code> for 10 s.	<code>currentLimit</code> is no higher than <code>ratedCurrent</code> . The outlet switches off

Check	Applies to	Method	Pass criteria
		Then send <code>set on</code> , then <code>resetTrip</code> , then <code>set on</code> , with the load back at 50 %.	within 7 s, and reports <code>tripped</code> and <code>overcurrent</code> . It stays off after the first <code>set</code> , and switches on after <code>resetTrip</code> and the second <code>set</code> .
Temperature of the module (9.4)	Power modules	With every outlet loaded to its rated current, raise the ambient temperature from the declared <code>maxAmbientTemperature</code> in steps of 5 °C until the module reports <code>overtemperature</code> or its thermal protection acts, then let it cool.	The module reports <code>overtemperature</code> above <code>maxAmbientTemperature</code> , before any thermal protection acts, and removes it when it has cooled. It reports no fault at <code>maxAmbientTemperature</code> .
Counting operations (9.5)	Power modules	Read an outlet's count, switch it on and off 100 times, remove the module's power, restore it, and install a firmware update. Then, on a sample whose maker has set the count just below <code>endurance</code> , switch the outlet until it passes it.	The count rises by 100, and is the same after the power cut and the update. The outlet reports <code>expired</code> once the count exceeds <code>endurance</code> .
Faults after their delays (9.6)	Power modules	Run the tests of stuck outlets, overcurrent, and overload protection, and of disconnected loads on a module that reports <code>load-disconnected</code> , recording when each condition begins and ends.	Each fault is reported, or its outlet switched off, no sooner than its delay and no more than 2 s after it, and removed within 2 s of the end of its condition, except <code>stuck-on</code> on an outlet with a cutoff contact, which stays until the outlet is next commanded on.
What powers the electronics (10.1)	Power modules	Compare the declared <code>electronicsSupply</code> with the module's circuit. Then, with the module running, interrupt mains, and then the module bus, while watching whether the electronics keep running.	The declaration matches: electronics declared to run from mains stop only when mains is interrupted, from the bus only when the bus is, and from mains and the bus only when both are.
Electronics on mains (10.1)	Power modules	On a module on the module bus, with some outlets on and some off, unplug the bus cable, and wait for longer than the outlets' <code>failSafeTimeout</code> .	<code>electronicsSupply</code> is <code>mains</code> or <code>mains-and-bus</code> . Every outlet keeps its state until its <code>failSafeTimeout</code> , and then applies its fail-safe behavior.
Power-up (10.2)	Power modules	Configure one outlet for each <code>powerOnDelay</code> of 0 s, 0 s, 10 s, and 30 s, with <code>failSafeState {"on": true}</code> , and include an outlet whose unpowered state is <code>on</code> , with <code>powerOnDelay</code> 0. With a recorder on every outlet and no controller, remove mains for 10 s and restore it.	The outlet whose unpowered state is <code>on</code> is on as soon as mains returns. The others switch on at least 1 s apart, each no sooner than its <code>powerOnDelay</code> , in the order of their delays and identifiers.
The return of mains (10.2)	Power modules	On a module whose <code>electronicsSupply</code> is <code>bus</code> or <code>mains-and-bus</code> , with its controller in contact and outlets on, with <code>powerOnDelay</code> of 0 s, 0 s, and 20 s, remove mains for 60 s and restore it.	Every outlet whose unpowered state is <code>off</code> opens when mains is lost. When mains returns, outlets switch on at least 1 s apart, each no sooner than its <code>powerOnDelay</code> , to the states the controller commanded; <code>controlSource</code> stays <code>controller</code> .
Reporting mains (10.3)	Power modules	On a module whose <code>electronicsSupply</code> is <code>bus</code> or <code>mains-and-bus</code> , remove and restore mains 10 times, for 5 s each time, and record the module's state reports.	<code>mainsPresent</code> becomes <code>false</code> within 1 s of each loss, and <code>true</code> within 1 s of each return.
Dips and interruptions (10.4)	Power modules	With a recorder on every outlet, half of them on and half off, apply the voltage dips and short interruptions of IEC 61000-4-11 for the module's class: 0 % for 0.5, 1, 5, 10, 25, and 50 cycles, 40 % for 10 cycles, and 70 % for 25 cycles, ten times each. Then lower mains from its lowest rated voltage to 0 V over 60 s and raise it again over 60 s; then raise it to 15 % above its highest rated voltage for 60 s.	No outlet changes state more than once as the voltage falls and once as it recovers, and none whose unpowered state is <code>off</code> switches on while it is commanded off. <code>undervoltage</code> is reported below 90 % of the lowest rated voltage while the electronics work, and <code>overvoltage</code> above 110 % of the highest.
Restarts and updates (10.5)	Power modules	With a recorder on every outlet, force a watchdog restart 10 times; then install a firmware update, and an update that fails; then compare the description before and after.	Every outlet is only ever in its state before, its unpowered state, or its power-up behavior. The failed update returns to the previous firmware. The declarations of Section 7.3 are unchanged.

Check	Applies to	Method	Pass criteria
The probe (11.2)	Power modules	Run the temperature port checks of the Probe Interface on the port. Check the module's certification report for the insulation between mains and the port. Then stop the controller from sending anything but supervision messages, and change the probe's temperature.	The port passes the Probe Interface checks, the report shows double or reinforced insulation, and the backup thermostat acts on the probe's readings alone.
Settings (11.3)	Power modules	After a factory reset, read the settings. Then write settings with each of these in turn: the probe of another device; a cutoff of 45 °C; in <code>heat</code> mode, a setpoint of 26.8 °C with a cutoff of 27.0 °C and a hysteresis of 0.5 °C; and any settings to an outlet without <code>backup-thermostat</code> . Then write valid settings and remove the module's power. Then enable the backup thermostat with a setpoint, set <code>failSafeAction</code> <code>continue</code> , and write settings with <code>enabled</code> <code>false</code> , and settings without a setpoint; then set <code>failSafeAction</code> <code>state</code> , send <code>runProgram</code> , and write them again.	The settings ship with <code>enabled</code> <code>false</code> . Each invalid write is rejected, and the previous settings stay. The valid settings remain after power returns. With <code>continue</code> , both writes are rejected; with <code>state</code> , both are accepted, and the first takes the outlet off its program and switches it off.
Cutoff (11.4)	Power modules	In place of the probe, connect a simulator of the probe's kind. In <code>heat</code> mode with a cutoff of 27.0 °C and a hysteresis of 0.5 °C, with the outlet commanded on, raise the simulated temperature from 26.0 °C to 27.5 °C. Send <code>set</code> on; press the outlet's local control; let the controller time out with <code>failSafeState</code> <code>{"on": true}</code> . Then lower the temperature to 26.7 °C, and then to 26.4 °C. Repeat in <code>cool</code> mode with a cutoff of 18.0 °C.	The outlet is off within 3 s of the simulated temperature reaching 27.0 °C, reports <code>cutoff</code> , and accepts the command. It stays off through the command, the local control, and the fail-safe behavior, and at 26.7 °C. At 26.4 °C it switches on, as the standing command and its fail-safe state say, and the fault clears. The <code>cool</code> mode mirrors this.
A lost probe (11.4)	Power modules	With a heating outlet commanded on and its probe reading 25.0 °C, unplug the probe. Plug it back in. Then short the probe's port, and remove the short.	The outlet is off within 10 s of the probe being unplugged and of the short, and reports <code>cutoff</code> . It switches on again once the probe gives a good reading.
Regulating as a program (11.5)	Power modules	With a probe simulator, a setpoint of 25.5 °C, a hysteresis of 0.5 °C, and <code>failSafeAction</code> <code>continue</code> , send <code>runProgram</code> , disconnect the controller, and wait for the fail-safe timeout. Sweep the simulated temperature from 24.5 °C to 26.5 °C and back, in steps of 0.05 °C every 10 s. Then remove mains for 10 s, restore it with the simulated temperature at 24.5 °C, and wait. Then reconnect the controller, send <code>set</code> with <code>on</code> <code>false</code> and <code>latch</code> <code>true</code> , as a low-water interlock does, disconnect the controller, wait for the fail-safe timeout, and lower the simulated temperature to 24.0 °C; then remove mains for 10 s, and restore it.	<code>programRunning</code> is <code>true</code> after <code>runProgram</code> . In <code>heat</code> mode, the outlet switches on at 25.25 °C and off at 25.75 °C, within the accuracy of the port, with switch-ons at least 5 s apart. After power-up, it switches on once its <code>powerOnDelay</code> has passed, and regulates the same way. After the latched stop, <code>programRunning</code> is <code>false</code> , and the outlet stays off after the timeout and after the power cut.
Cutoff contacts (11.6)	Power modules	Inspect the declarations of each outlet with a backup thermostat, and its circuit. Then raise the probe's reading above <code>cutoff</code> , and measure across the cutoff contact.	<code>cutoffContact</code> is <code>true</code> , and the cutoff contact is open while the reading is above <code>cutoff</code> .
Cutoff contacts that act (11.6)	Power modules	On a sample prepared by its maker, bridge the outlet's switching device through a test switch, with a 200 W heater or resistive load plugged in. With the test switch closed, switch the outlet off. After 30 s, switch it on, then off again. Then interrupt the electronics' supply.	Within 7 s of each switch-off, the load stops drawing current, and <code>stuck-on</code> is reported until the next command to switch on. The outlet works when commanded on. With the electronics unpowered, the load draws nothing.
Safety certification (12.1)	Power modules	For each market where the module is sold, check its certificate in the certification body's directory, or its declaration of conformity and the test reports it rests on, against the law of Table 15. Inspect the module, its packaging, and its documentation for claims.	Each market has the certification its law requires, naming this model. No claim of certification, listing, or approval is made for a market where the module has none.

Check	Applies to	Method	Pass criteria
Certifications declared (12.1)	Power modules	Compare each entry of <code>certifications</code> with its certificate or declaration.	Every certification and declaration the module holds is listed, and each entry's standards, holder, body, and reference match it.
Third-party certification (12.1)	Power modules	Inspect <code>certifications</code> .	Every entry has <code>kind</code> <code>certification</code> .
Protection in hardware (12.3)	Power modules	Check <code>protections</code> against the certification report. Then, with the processor held in reset, load the module to 150 % of its <code>ratedCurrent</code> ; and, on a module that allows owner firmware, install firmware that commands every outlet on and reports nothing, and repeat.	Every protective function other than <code>temperature-limit</code> has <code>firmware</code> <code>false</code> , and includes overcurrent protection. The breaker or fuse opens within its rated time in both cases.
Insulation from low-voltage parts (12.4)	Power modules	Join the line and neutral contacts of the plug, and, separately, every contact of the low-voltage ports and every accessible metal part. Apply the test voltage for reinforced insulation of the module's safety standard between the two for 60 s, and then measure the insulation resistance at 500 V DC.	No breakdown occurs, the insulation resistance meets the module's safety standard, and the module then passes its other checks.
Spacing for salt (12.4)	Power modules	Check the declared <code>insulation</code> against the certification report. Then spray the module's outside with artificial seawater of salinity 35 until a film forms, let it dry, repeat on 5 days, and test the insulation as the insulation check does.	<code>pollutionDegree</code> is 3, or <code>coating</code> is <code>true</code> , as the report confirms, and the insulation passes after the salt.
Built-in residual-current devices (12.5)	Power modules	Inspect the module, its packaging, and its documentation. On a module with a built-in residual-current device, check the certification report and the declared <code>residualCurrent</code> . With a pump on an outlet, remove and restore mains 10 times, for 1 s and for 60 s. Then make it trip with a test residual current.	Nothing presents the module as a replacement for residual-current protection of its supply. The report covers the device under its standard, and its type is A, F, or B. After every power cut, the outlets return without a reset. It trips on the test current.
Stop-on-loss equipment (13.1)	Controllers	With a simulated power module that has outlets whose unpowered states are <code>on</code> and <code>off</code> , try to bind to an outlet whose unpowered state is <code>on</code> an output for a heater, a doser, a CO2 system, and a return pump. Then bind a heater to an outlet whose unpowered state is <code>off</code> , and replace the module with another whose only free outlet is <code>on</code> .	The heater, doser, and CO2 system are refused with an explanation; the return pump is accepted. The controller does not move the heater to the replacement's outlet.
Proposing outlets (13.1)	Controllers	Add a return pump and a heater with a simulated power module that has an outlet of each kind and plain outlets.	The controller proposes the outlet whose unpowered state is <code>on</code> for the return pump, and the outlet with a backup thermostat for the heater.
Power budget (13.2)	Controllers	Have the simulated module report a current on one outlet of 110 % of its <code>ratedCurrent</code> , and then currents on several outlets that add up to 85 % of the module's.	The controller warns the owner each time, naming the outlet or the module.
Backup thermostat settings (13.3)	Controllers	As a user with the <code>override</code> role, try to change an outlet's backup thermostat settings; then as the owner, change them, declining and then accepting the confirmation. Bind a heater to an outlet with a backup thermostat that has no setpoint, and look at the configuration proposed. Then, as the owner, disable the backup thermostat of an outlet whose <code>failSafeAction</code> is <code>continue</code> .	The <code>override</code> user is refused. The settings change only after the owner confirms, and the change is in the audit log, with the old and new settings. <code>continue</code> is not proposed for the outlet until its backup thermostat is enabled with a setpoint. Before it disables the backup thermostat, the controller sets the outlet's <code>failSafeAction</code> to <code>state</code> with <code>failSafeState {"on": false}</code> , in the same confirmed change.
Power loss from a power module (13.4)	Controllers	With the controller on a battery and a power module whose electronics run from the bus, remove mains for 5 minutes.	The controller enters power-loss mode once the module reports that mains is absent, raises <code>mains-power-lost</code> after its delay, and leaves power-loss mode when mains returns.

Check	Applies to	Method	Pass criteria
What a controller shows (13.5)	Controllers	Add a simulated power module with outlets of both unpowered states, a backup thermostat, and two certifications, and look at what the controller shows.	Every item is shown, for every outlet and for the module.
Owner firmware (13.5)	Controllers	Have the simulated power module report <code>firmwareSigner owner</code> .	The controller shows that the module runs owner firmware, that the certification does not cover that firmware, and that its hardware protection is unchanged.
Labels (14.1)	Power modules	Inspect the module's labels, and compare them with its description.	Every outlet's label matches its endpoint's number. Every rating that differs from the module's is marked. Every outlet whose unpowered state is <code>on</code> , and every socket that is not switched, is marked beside it.
Installation instructions (14.2)	Power modules	Read the instructions, in each language that each market requires.	They say every item of Section 14.2, in every required language.
Published documentation (14.3)	Power modules	Retrieve the description, the instructions from <code>instructions</code> , and each certificate or declaration, from the maker's published documentation, without buying the module.	Each is published, and the published description is the one the module serves.

17 Security Considerations

1. **Mains is a physical hazard.** A compromised controller can switch every outlet as it pleases. What limits the harm is in the module, and no command overrides it: protection in hardware (Section 12.3), outlets that switch on one at a time and no more often than every 5 s (Section 8.4), and a backup thermostat's cutoff (Section 11.4). The Security and Access specification left the security of mains equipment to this Specification [OAP-SA Section 7.3], and this item is its answer.
2. **Rapid switching.** A flood of commands cannot wear out a relay quickly, or make outlets chatter, because the time between switch-ons is enforced on the module (Section 8.4).
3. **Firmware.** Updates are signed and approved as the Security and Access specification requires [OAP-SA Section 15]. An owner may install their own firmware, with the operation `allow-owner-firmware` [OAP-SA Section 15.8]; protection stays in hardware, and the controller says that the certification no longer covers the firmware (Section 13.5).
4. **Settings that protect.** Backup thermostat settings are fail-safe settings, and changing them needs `change-fail-safe-settings`, which is audited (Section 13.3). A module refuses to disable a backup thermostat that keeps a heater safe without its controller (Section 11.3.1).
5. **Radios.** A module without a radio offers no radio to attack. A module with one meets the Security and Access specification, and, in the European Union, EN 18031 [RED 2014/53/EU].
6. **Physical access.** Anyone at the module can unplug equipment, and its local controls can switch outlets off, by design; a local control that switches an outlet on ends within 2 hours (Section 8.6).
7. **Rules for connected products.** The United Kingdom's rules on connectable products, the European Union's Cyber Resilience Act, and Australia's rules on smart devices apply to power modules that connect to a network, with requirements on passwords, the reporting of security issues, and periods of support [PSTI] [CRA] [Smart Devices Rules 2025].
8. **Privacy.** The energy that outlets use shows when people are at home and what they do. It is the owner's data, and leaves the owner's network only as the Security and Access specification allows [OAP-SA Section 16].

Appendix A — Approval Checklist

Complete this checklist before requesting Working Group approval. Link each item to the evidence.

Item	Status	Details
Section 2 describes compliance with all five tenets.	Done	
A public review period of at least 30 days has been announced and completed.	Not started	
At least two independent implementations exist, at least one from an organization not represented among the Authors.	Not started	
The implementations have passed the test procedures in Section 16.4, including a power module and a controller.	Not started	
At least one conforming power module holds safety certification in at least one market.	Not started	
A certification body has reviewed Sections 8 to 12 for conflicts with the standards of Table 16.	Not started	
The provisional values have been confirmed with measurements on real power modules.	Not started	
Every normative reference is publicly available.	Done	IEC 61000-4-11 is available for purchase; all others are free.
The checks file, schema, and examples are published, and the examples pass the validator.	Done	
The Open Issues appendix is empty, or each open issue is explicitly deferred.	Not started	
No unresolved Exclusion Notices for this Specification are recorded in <code>Notices.md</code> .	Done	
The Maintainer has recorded consensus to approve.	Not started	

Appendix B — Examples (Informative)

The `examples` directory contains the device descriptions of two power modules:

- `power-module-us.json`: the module of Section 6.4, for 120 V and 15 A, on the module bus, with eight outlets, two of which stay on without power, and two with backup thermostats and cutoff contacts; its temperature probe port; and its certification for the United States and Canada.
- `power-module-eu.json`: a module for 230 V and 16 A, on the network by Ethernet, with six outlets, one of which stays on without power, a resettable breaker, a built-in Type A residual-current device, and its maker's declaration of conformity for the European Union.

The certification bodies, holders, and references in the examples are invented.

Appendix C — Using Smart Power Strips Today (Informative)

Until power modules exist, controllers switch mains through smart power strips that are already safety-certified and have a local interface [P0001]. Such strips are a sound choice when they:

1. carry each market's certification, with the standards named: in the United States, a listing to UL 1363 and UL 60730-1; in Canada, a mark to CSA C22.2 No. 308 and CSA E60730-1; in the European Union and the United Kingdom, a declaration that names its standards; and in Australia, the RCM with a certificate;
2. offer a local interface, with no cloud;
3. let the state of each outlet after a power failure be set;
4. report the current of each outlet; and
5. come from a maker whose instructions do not exclude critical equipment, as some do.

An adapter presents such a strip as a bridged device [OAP-DP Section 16]. Most strips know nothing of their controller, so they cannot apply fail-safe behavior by themselves: their adapter states `failSafe adapter` or `none`, and a controller does not bind heaters, dosers, or other stop-on-loss equipment to them [OAP-DP Section 16.4]. They suit return pumps, circulation pumps, lights, and other equipment that may keep running.

Each outlet's state after a power failure should match its fail-safe state: a return pump's outlet always on [P0001].

Table 23 — A smart power strip and a power module

	A typical certified smart strip	A power module
Safety certification	Yes	Yes, with its standards declared
Fail-safe behavior when its controller is lost	No	On every outlet
State without power	Undeclared	Declared for every outlet; one or more stay on, for a return pump
Measurement	On some, for each outlet	On every outlet, with stuck relays reported
Backup thermostat	No; one aquarium strip has one	Optional
Interface	Its maker's, through an adapter	The Module Bus or the Device Protocol

Appendix D — Designing for Certification (Informative)

This appendix gives any maker advice on designing a power module for certification. It is not a design, and a certification body has the last word on every point.

Scope the certification first. Before the first schematic, ask a laboratory that is both a Nationally Recognized Testing Laboratory and a certification body of the IECEE CB Scheme for a review of the concept. It can confirm which standards apply (Table 16), the pollution degree it will apply, and whether it will treat a backup thermostat as a protective function. One investigation can give marks for the United States and Canada, and a CB test certificate and report can support declarations in the European Union and the United Kingdom, and a certificate in Australia.

One design for every market. A single circuit board for 100 V to 240 V, with the spacings of 240 V, and regional panels of outlets and cords, needs one design and one set of tests.

Spacing. Table 24 gives minimum distances from the tables of IEC 60335-1, read in older editions; the current editions must be checked before they are used.

Table 24 — Minimum distances under IEC 60335-1, up to 2000 m altitude

Supply	Basic clearance	Reinforced clearance	Reinforced creepage, pollution degree 2, material group I / II / III	Reinforced creepage, pollution degree 3, material group I / II / IIIa
120 V	0.5 mm, or 0.8 mm at pollution degree 3	1.5 mm	1.6 / 2.2 / 3.0 mm	3.8 / 4.2 / 4.8 mm
230 V to 240 V	1.5 mm	3.0 mm	2.6 / 3.6 / 5.0 mm	6.4 / 7.2 / 8.0 mm

Clearances grow by 0.5 mm where parts can move, such as at soldered or screw terminals. A slot in a circuit board counts toward creepage only if it is at least 1.0 mm wide at pollution degree 2, or 1.5 mm at pollution degree 3 [IEC 60664-1]. Under a permanent coating, pollution degree 1 applies, but only to assemblies that have not been repaired [IEC 60664-3].

Relays. Choose relays whose coil-to-contact insulation is reinforced, because the coils sit on the low-voltage side; several common power relays state reinforced insulation with about 8 mm to 10 mm between coil and contacts, while some smaller relays state basic insulation only. Choose relays rated for inrush, such as a TV-8 rating or 100 A peak, for every outlet. A contact that is closed without power is usually rated 5 A to 12 A, against 16 A for the other; a few changeover relays rate both at 16 A. Avoid latching relays (Section 8.3). Switching near a zero crossing of the voltage reduces inrush, but switching always at the same point of the cycle can wear contacts unevenly. Drive relays through drivers whose inputs read off when they float, because some microcontroller pins glitch high for tens of microseconds at power-up.

Measuring current. Use current sensors with reinforced insulation, shunts with isolated converters, or an energy-metering chip on the mains side behind a reinforced digital isolator. A Hall-effect sensor whose offset is ± 40 mA reads ± 4.8 W at 120 V with no load, more than Section 9.1 allows, so shunts and metering chips are the likelier choice.

Leave out of a first design a built-in residual-current device, surge protection, USB ports, fixing to furniture, and radios; each adds a standard (Table 17).

Fire. In appliances that run unattended, and remote control makes an appliance unattended, insulating parts that hold connections carrying more than 0.2 A need a glow-wire flammability index of at least 850 °C, or must pass a glow-wire test. Circuit boards need a needle-flame test unless they are rated V-0.

Heat. Relay ratings are often given at 85 °C, and two-pole relays derate. A 16 A track needs about 9 mm of 1 oz copper, or 4.5 mm of 2 oz copper, for a rise of 20 °C by the formula of IPC-2221; check it against IPC-2152.

Leakage. IEC 60335-1 limits leakage current to 0.75 mA for a portable appliance with protective earth, and to 0.25 mA for one without. A GFCI in North America must not trip below 4 mA, and that allowance is shared by everything on its circuit, so keep filter capacitors to earth small.

Test before certifying. Run temperature-rise, dielectric-strength, and EMC tests in-house before submitting a module, and publish the results with the design.

Treat the certified configuration as a release. Critical components, their named alternatives, and the firmware that was evaluated change only through the holder of the certification.

Budget. Expect a first certification to cost tens of thousands of US dollars and to take two to six months from a finished design, and follow-up inspections to cost about USD 5,000 to 8,000 a year for each factory.

Appendix E — Open Issues (Informative)

Issues 1 to 19 were open in revision 0.1. The Project Lead decided issue 1 on 15 October 2026, the question of Device Classes that issue 8 raised, and issues 2 to 6 and 20 on 16 October 2026, accepting the recommendation in each. Each issue says how a revision resolves it, which specification is to apply it, or what it waits for. On 17 October 2026 the Project Lead froze the scope of revision 1.0, and decided issues 5, 13, 16, and 17; revision 0.3 applies the decisions. Device Classes revision 0.5 makes the change that issue 8 asked for, and the scope note of that day assigns those of issues 10 and 11 to the final revisions of Security and Access and of Alarms and Notifications. Issues 13, 14, 15, and 18 are deferred beyond revision 1.0, and are tracked outside this Specification; revision 0.3 applies the decision on issue 13 itself (Section 8.3.2). Only issue 12 stays open: it waits on measurements of real power modules. Issue numbers do not change, because other specifications refer to them.

Questions for the Project Lead

1. **A wired connection.** *Resolved in revision 0.2: recommended, as before.* Section 7.2 recommends that a power module connect by wire, because a wire keeps a safety function off radio links, and a radio adds certification. The alternatives were to recommend it, to require it, or to say nothing; requiring it would exclude every smart strip that might grow into a power module. The Project Lead decided to keep the recommendation, as proposed, and Section 7.2.3 now says why a module on radio conforms: it fails safe by itself when it loses contact, so a radio link is not the only path for its safety functions (Fail-Safe Behavior Section 13.4; its Appendix C, issue 14). An outlet on [continue](#) for a heater that nothing regulates without the controller has no such path, and its controller warns its owners.
2. **Third-party certification everywhere.** *Resolved in revision 0.2, as the Project Lead decided on 16 October 2026: recommended; whether to require it is for the approval of this Specification.* Section 12.1 recommends certification by a certification body even where the law accepts a declaration, as in the European Union and the United Kingdom. Requiring it would exclude small makers who declare conformity themselves, but a power module carries mains beside water, and only a certification body inspects factories. The Project Lead decided to recommend it now, as Section 12.1.2 does, and to decide whether to require it before this Specification is approved.

3. **A backup thermostat as an operating control.** *Resolved in revision 0.2: an operating control.* Section 11.7 treats a backup thermostat as an operating control that protects livestock. Claiming it as a protective control would need single-fault tolerance, class B software, and immunity tests, and would tie its firmware to the certification. The Project Lead decided that it is an operating control, with a cutoff contact for welded relays (Section 11.6), as recommended; a maker may still certify one as a protective control (Section 11.7.2).
4. **What powers the electronics.** *Resolved in revision 0.2: mains, or mains and the bus, recommended.* Section 10.1 recommends that the electronics run from mains, or from mains and the bus, so that losing the bus does not drop outlets into their unpowered states. A module powered from the bus alone is cheaper, and can report the loss of mains. The Project Lead decided to keep the recommendation, as proposed.
5. **Heater outlets with a backup thermostat.** *Resolved in revision 0.2: the recommended defaults are unchanged, and a controller may propose continue; resolved further in revision 0.3, as the Project Lead decided on 17 October 2026: the backup thermostat is the outlet's program (Section 11.5).* Fail-Safe Behavior Table 3 recommends stop for heaters, and allows continue for heaters that regulate themselves (Section 11.5). Recommending continue for an outlet that its backup thermostat regulates would keep the water warm through a long outage of the controller, but an outlet ships with its backup thermostat disabled, and only the owner knows where its probe is. The recommendation was to keep stop as the default, and to let a controller propose continue once the owner has enabled the backup thermostat with a setpoint, which the owner confirms; the module then refuses to disable the backup thermostat while the outlet uses continue (Section 11.3.1). The Project Lead decided so: Section 13.3.2 lets a controller propose it, and the notes for heaters and chillers in Fail-Safe Behavior Table 3 now name such outlets, with the defaults unchanged. The second review then found that an outlet on continue regulated whenever its controller was lost, so that a heater outlet that a low-water interlock had stopped switched on in a drained sump. The Project Lead decided on 17 October 2026 that such an outlet gets a program state, as lights and pumps have, which an interlock's stop takes away. Device Classes revision 0.5 defines it, with runProgram and programRunning (its Section 7.13.9), and revision 0.3 regulates only while the outlet follows its program (Section 11.5), so a controller may propose continue for an outlet that a low-water interlock protects.
6. **Explaining owner firmware.** *Resolved in revision 0.2: three facts required, with example wording.* Section 13.5 has a controller say that the certification does not cover firmware that the maker did not sign, while protection in hardware is unchanged. The recommendation was to require those facts, not words, so that each controller can say them in its owner's language, and to give example wording. The Project Lead decided so, and Section 13.5.3 gives the example.

For other specifications

7. **Module Bus.** *Resolved in Module Bus revision 0.2.* A power module may also supply the bus (Section 7.2.4), which bears on the power budget. Module Bus revision 0.2 records it with the budget (its Appendix C, issue 3), and defines the protection that every node that supplies the bus needs (its Section 7.6).
8. **Device Classes.** *Resolved in revision 0.3: Device Classes revision 0.5 makes the extensions attributes, a feature, and a fault, and this revision uses them (Section 7.3, Table 6).* The switch class was to take over the provisional extensions of revision 0.2's Table 6, and of its Tables 2 and 5 where they describe outlets: fixed attributes for an outlet's rated current, switching device, unpowered state, and endurance; a backup-thermostat feature, with its settings and a fault for its cutoff; a state attribute for the count of operations; and a device attribute for the presence of mains. The Project Lead decided that the extensions stay provisional in this revision, which settles them, and that a later revision of Device Classes then makes them attributes and a backup-thermostat feature of switch, so that they are not defined twice while they change (Device Classes Appendix D, issue 33). Revision 0.2 settles them as Tables 2 to 6 and the schema define them, with one new rule: a module refuses to disable a backup thermostat while the outlet uses continue (Section 11.3.1). Device Classes revision 0.3 already says that a condition that holds an output off, such as a cutoff, accepts commands and carries them out when it ends (its Section 7.8.3), and Section 11.4.4 cites it. Device Classes revision 0.5 makes them the fixed attributes ratedCurrent, switchingDevice, unpoweredState, and endurance, the state attribute switchCount, the device attribute mainsPresent, the fault cutoff, and the feature backup-thermostat, with backupThermostat,

`cutoffContact`, and a program (its Appendix D, issue 33). Revision 0.3 uses them, and keeps as its own extensions only what describes the module as a whole, and each outlet's socket, inrush rating, and fuse.

9. **Fail-Safe Behavior.** *Resolved in Fail-Safe Behavior revision 0.2 (its Appendix C, issue 1).* A backup thermostat is a rule that a device runs as its local program (Section 11.5), and protection inside the device for a safety function (Fail-Safe Behavior Section 13.4.2). Fail-Safe Behavior Section 8.3.4 now says that a latching relay has no unpowered state, and its Section 9.2.2 requires outputs that switch mains to start 1 s apart, as Section 10.2 does here.
10. **Security and Access.** *Resolved for this Specification: the scope note of 17 October 2026 assigns the change to Security and Access revision 0.3.* The operation `change-fail-safe-settings` in its Table 6 should name backup thermostat settings (Section 13.3).
11. **Alarms and Notifications.** *Resolved for this Specification: the scope note of 17 October 2026 assigns the change to Alarms and Notifications revision 0.3.* It could list the fault `cutoff` with its default severity (Section 9.6), and name a power module's report of mains as a way to detect `mains-power-lost` (Section 13.4). Alarms and Notifications already lists `cutoff` as a `warning` (its Section 8.4), since Device Classes revision 0.5 made it a fault code.

Details of this Specification

12. **Numbers.** *Open: waits on measurements of real power modules.* Every value of Table 21 needs confirming with measurements on real power modules, especially the accuracy of Section 9.1, the thresholds and delays of Section 9.2, and the time between switch-ons of Section 8.4. Revision 0.2 adds four: the time to the unpowered state (Section 8.2.5), the reporting interval of readings (Section 9.1.5), the 2 s within which a delayed fault is reported (Section 9.6.3), and the time to the cutoff (Section 11.4.1). The ± 1 W of the accuracy of power stays, as the Project Lead decided on 17 October 2026, until these measurements show what it costs (issue 17).
13. **Switching both conductors.** *Resolved in revision 0.3, as the Project Lead decided on 17 October 2026: recommended (Section 8.2.6).* In markets whose plugs fit either way round, such as those with CEE 7/7 plugs, an outlet that switches one conductor may leave equipment connected to the line conductor while it is off. Revision 0.3 recommends that outlets sold there switch both.
14. **Accuracy and cost.** *Resolved in revision 0.3, as the Project Lead decided on 17 October 2026: ± 1 W stays, provisional, with the other numbers of issue 12.* The accuracy of Section 9.1 favors shunts and metering chips over Hall-effect sensors (Appendix D). The limit is confirmed or changed with the measurements of real power modules that issue 12 waits for.
15. **Certification.** *Resolved: yes.* The project's governance says that a compatibility program, if created, will require conformance testing (its Section 5), and the test procedures of Section 16.4 are those of this Specification. Which products may carry a mark, and how their results are checked, belong to the program, not to this Specification.

The following issue arose in revision 0.2:

20. **The time to the cutoff.** *Resolved in revision 0.2: 3 s, provisional, with no faster port required.* The test procedure of revision 0.1 had an outlet off within 2 s of the water reaching `cutoff`, which no requirement said. Revision 0.2 requires 3 s (Section 11.4.1), because a temperature port need measure only every 2 s [OAP-PI Section 7.3]. A module whose port measures every second could meet 2 s, but a second makes no difference to a heater, so the Project Lead decided to keep 3 s and the ports of the Probe Interface, as recommended. The value stays provisional, with the others of issue 12.