

Quasar BMS Advanced Logic Functions

Safiery have filed 5 patents that cover many of these features.

There is little prior inventive art using EIS in active running batteries in parallel banks.

Core Technology

Hardware Protection against Electrical Abuse

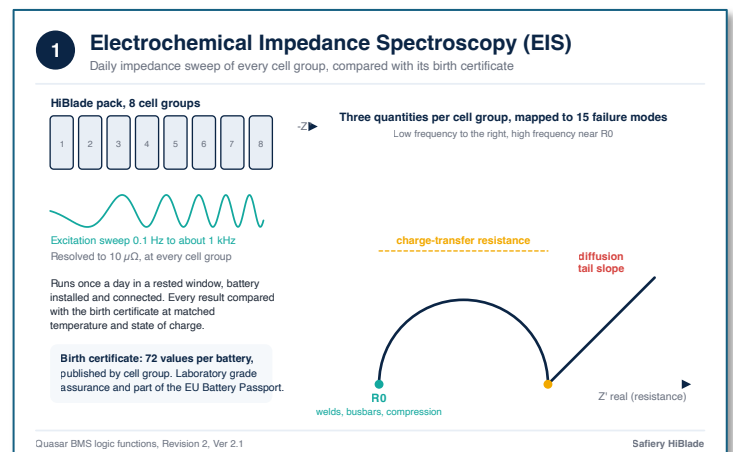
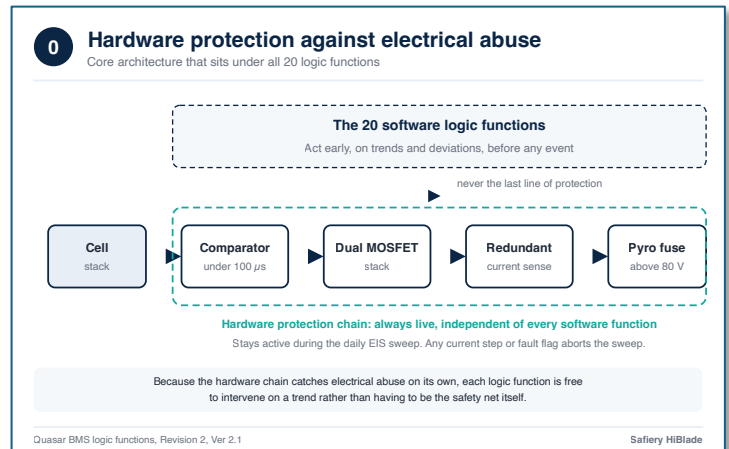
Independent to any of the software functions listed below sits the hardware protection chain. It includes a sub-100 μs comparator, dual MOSFET stack, redundant current sense, and pyrotechnic fuse for unsafe voltages above 80 V. This is a core BMS architecture rather than logic but is what lets the functions below act without each being the last line of protection.

Electrochemical Impedance Spectroscopy

Inside the BMS is Electrochemical Impedance Spectroscopy on every cell group, resolving to 10 $\mu\Omega$. An excitation signal sweeps each cell group from 0.1 Hz to 976 Hz and the response is fitted to a ladder model and read as four quantities: the series resistance R_0 (welds, busbar joints, current collectors, contacts and the bulk electrolyte), the width of the interphase arc where it falls inside the sweep, the width of the charge-transfer arc, and the slope of the low-frequency diffusion tail. Changes in these quantities, their rate and the pattern of which move together are mapped to 15 failure modes. The sweep runs once a day in a rested window with the battery installed and in service, and every result is compared with the signed factory birth certificate of that cell group at matched temperature and state of charge, and with the other groups in the pack. A result outside its expected band is not acted on alone: validity checks come first, then a targeted repeat at the frequency of the deviation while the pack is still rested; a repeat that agrees confirms the reading, a repeat that disagrees is logged as instability, which is itself an early sign of a loose joint or a micro-short: scatter in the series resistance that follows the enclosure temperature is a contact opening and closing at a weld, busbar or terminal; random dips that recover within a day are micro-shorts forming and fusing, the precursor of dendrite growth, corroborated by rising balancing demand on that group. An unstable group is left out of the operating-window map of item 21 until it settles again. The hardware protection chain stays live during the sweep, and the sweep aborts on any current step or fault flag. Advance warning is the purpose; the lead time under normal service is being established by the accelerated ageing programme.

On every EIS AC sine wave pass from 0.1Hz to 1kHz:

Region	Frequency band	Half-period	Processes able to respond within a half-cycle
R_0	Around 1 kHz	$\leq 500 \mu\text{s}$	Electronic conduction in metal only. Laser tab welds, busbar interconnects, current collectors, terminations, solid–solid interface contact.
R_{SEI}	100 Hz – 1 kHz	0.5 – 5 Ms	Charging and discharging of the interphase passivation film.
Recto	1 Hz – 100 Hz	5 – 500 Ms	Charge transfer across the electrode interface and double-layer capacitance.
W	below 1 Hz	> 500 Ms	Solid-state lithium diffusion within the active-material particles.

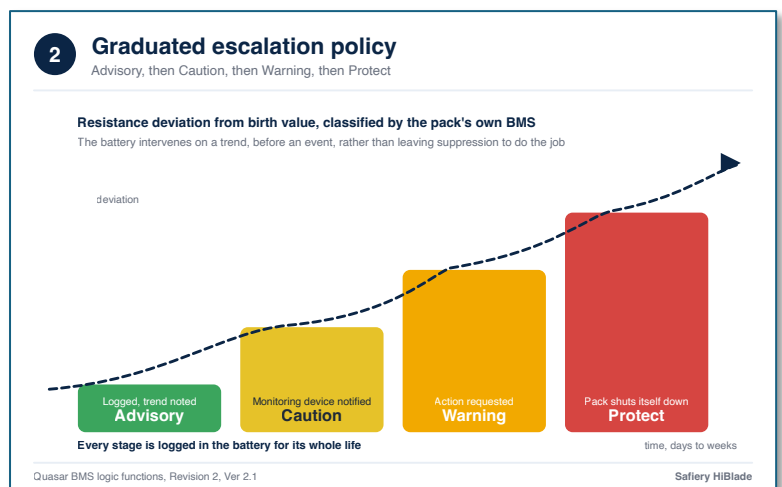


Advance Warning Period by Failure Mode

Failure mode	Region	Advance warning
Mechanical and contact		
Electrolyte dryout / depletion	R ₀ , W	8 – 24 weeks
Contact, weld and busbar degradation	R ₀	4 – 12 weeks *
Loss of stack compression (interface separation)	R ₀ , R_SEI	2 – 8 weeks
Current-collector corrosion	R ₀	12 – 24 weeks
Interphase and chemical ageing		
SEI layer growth (lithium inventory loss)	R_SEI	4 – 12 weeks
High-temperature calendar ageing	R_SEI, R_ct	12 – 26 weeks
Cathode CEI growth / surface reconstruction	R_SEI, R_ct	4 – 12 weeks
Transition-metal dissolution (Ni/Mn crosstalk)	R_SEI, R_ct	4 – 8 weeks
Kinetic and safety-critical		
Lithium plating (low-temperature or high-rate charge)	R_ct, W	4 – 8 weeks
Dendrite growth / internal soft-short precursor	R ₀ , R_ct	4 – 8 weeks
Power fade (interfacial kinetic ageing)	R_SEI, R_ct	12 – 26 weeks
Structural and transport		
NCM particle microcracking	R_ct, W	6 – 16 weeks
Electrode delamination	R ₀ , W	4 – 12 weeks
Pore blockage / gas generation	R_ct, W	2 – 8 weeks
Active-material loss (binder / conductive network)	R_ct, W	12 – 26 weeks

Graduated escalation policy (Advisory → Caution → Warning → Protect)

Deviations are classified and acted on by the pack on its own authority, from logging through trimmed charge limits and derating to self-restriction. Only a reading confirmed by the repeat scan of item 1 escalates: fast modes, such as the drop in charge-transfer resistance that follows a cold or high-rate charge, are acted on at once with one corroborating signal from the charge or temperature log; slow modes must persist for several consecutive valid days before an advisory is raised. The battery intervenes on the trend, before an event, rather than leaving suppression to do the job.



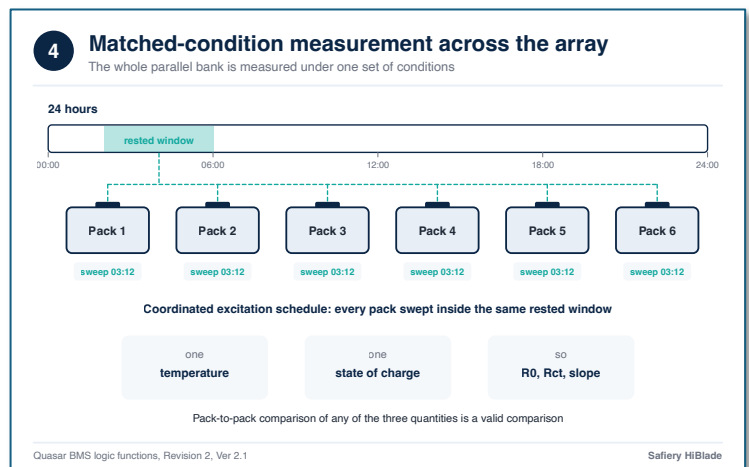
Low-current measurement (about 10 mA floor, 0.5 mA resolution)

10 Batteries together with a conventional BMS measure 0.1A each. So 10 batteries will not record a drop in SOC until the load exceeds 1A which is around 50W. Experience is that hubs and screens are around 10-15W and inverters in standby another 10W. Combined these would draw down the pack while SOC is still showing 100%. Not with HiBlade: 10 batteries at 10mA is 100mA = 5W. Coulomb counting shows an honest SOC% above this value. It is also important for other logic functions.



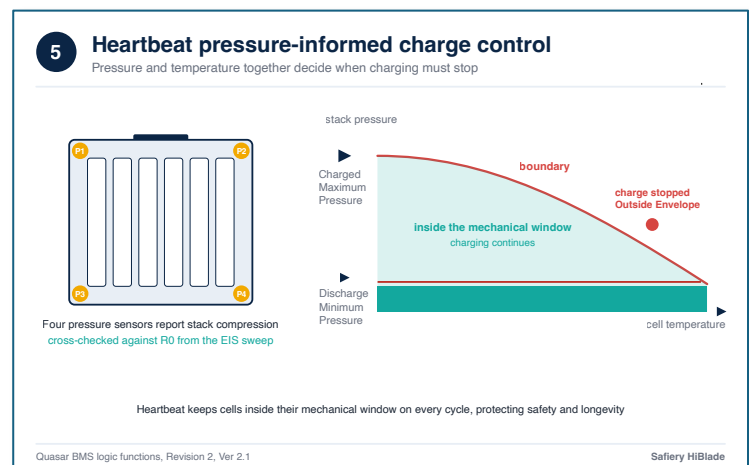
Matched-condition measurement across the array

Every pack in the bank is swept within one rested window on a coordinated excitation schedule, so the whole population is measured under one set of temperature and state-of-charge conditions, and pack-to-pack comparison of any of the four quantities is valid. Sweep frequencies are kept clear of multiples of the mains frequency whenever a mains-fed charger is running, because inverter ripple at 100 or 120 Hz on the DC bus would otherwise be read as cell impedance. More generally, the spectral monitor of item 23 reports which frequency bins the equipment on the bus is occupying, the sweep scheduler places each sweep frequency on a clear bin and shifts a planned frequency by a few hertz where a line sits on it, and the monitor in turn excludes the sweep tone, so the two functions do not read each other. Concurrent excitation of all packs at once is a later firmware step that needs a frequency plan so that harmonics from different packs do not collide; the same plan lets the packs be excited orthogonally for the bus-side measurement of item 24.



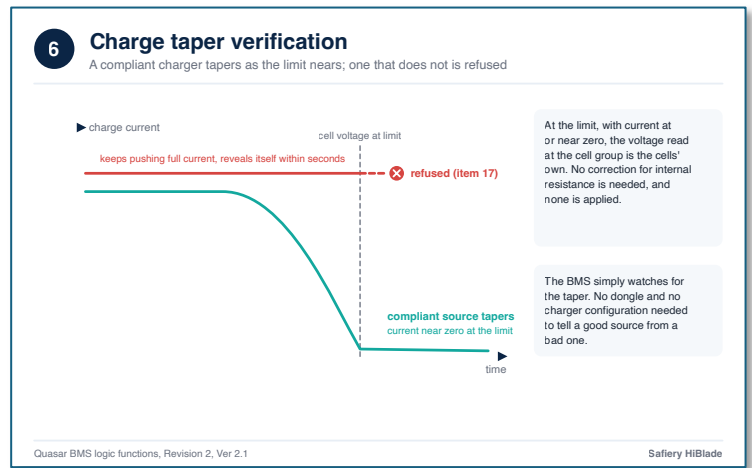
Heartbeat™ pressure-informed charge control

Four pressure sensors report stack compression, cross-checked against R_0 and the interphase arc, and charging can be stopped when the combination of pressure and cell temperature exceeds the boundary. Cells are kept inside their mechanical window on every cycle, protecting both safety and longevity.



Charge taper verification

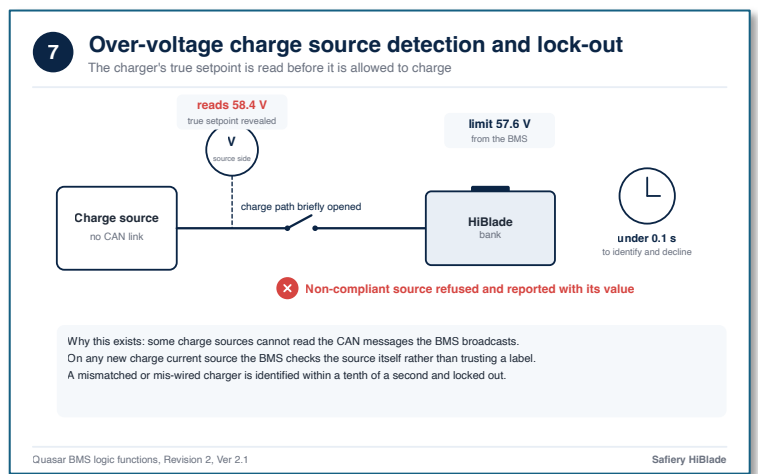
A compliant charge source tapers its current as the cells approach the charge voltage limit. The BMS watches for the taper; a source that keeps pushing full current as the limit approaches reveals itself within seconds and is refused under item 17. With current at or near zero at the limit, the voltage read at the cell group is the cells' own, so no correction for internal resistance is needed and none is applied.



Charge Protection Against Excessive Voltage

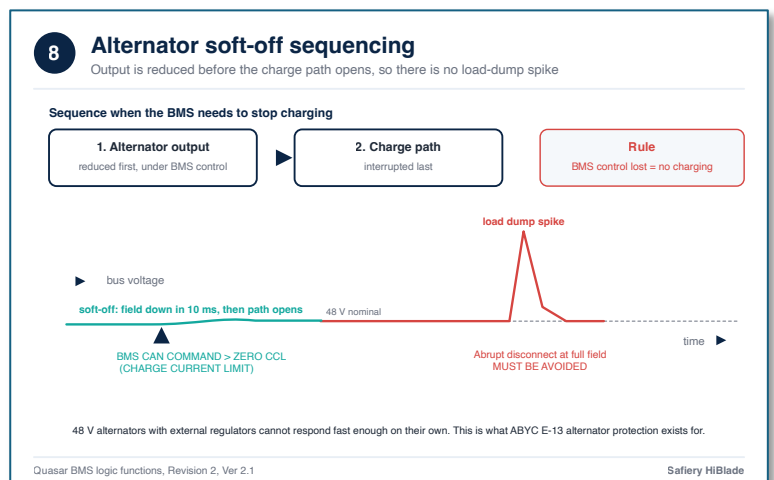
Over-voltage charge source detection and lock-out

There may be circumstances when charge sources cannot read the CAN messages broadcast by the BMS. On any new charge current source, the charge path is briefly opened and the source-side voltage read, revealing the charger's true setpoint; a non-compliant source is refused and reported with the value. A mismatched or mis-wired charger with no CAN link is identified and declined within a tenth of a second.



Alternator soft-off sequencing

This charge protection will briefly in 10ms stop charging sources from charging. 48V alternators with external regulators can't respond fast enough to this. These alternators must always be under BMS control, and their logic stipulates a no charging is the BMS control is lost for any reason. Where the alternator is under BMS control, its output is reduced first and the charge path interrupted last. This avoids the load-dump voltage spike that ABYC E-13 alternator protection exists to guard against.

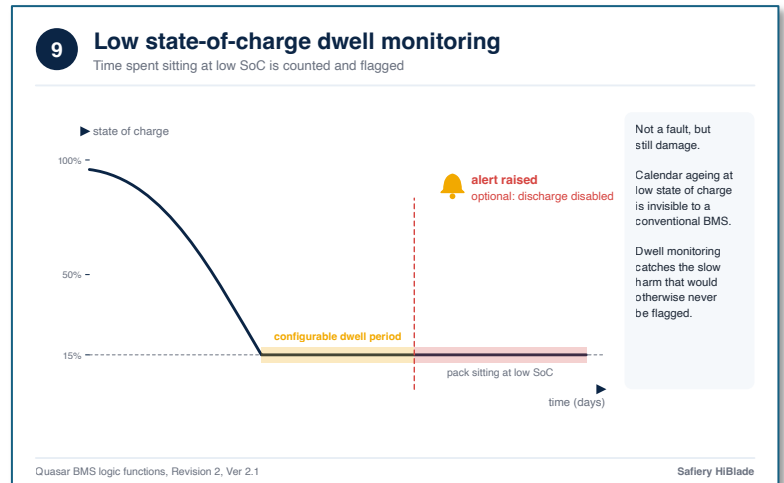


Protection Against Low Voltage in Each Battery

At all times, unless safety protection is urgently required, a parallel array of HiBlade batteries is designed to provide power even if selected batteries may have their discharge circuit turned off.

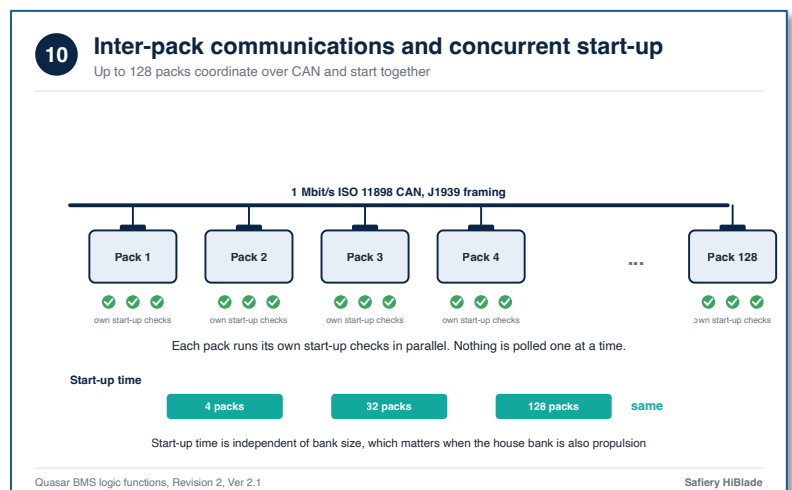
Low state-of-charge dwell monitoring

An alert is raised, and optionally discharge is disabled, when a pack sits at low SoC beyond a configurable period. This catches calendar-ageing damage that is not a fault and would otherwise never be flagged.



Inter-pack communications and concurrent start-up

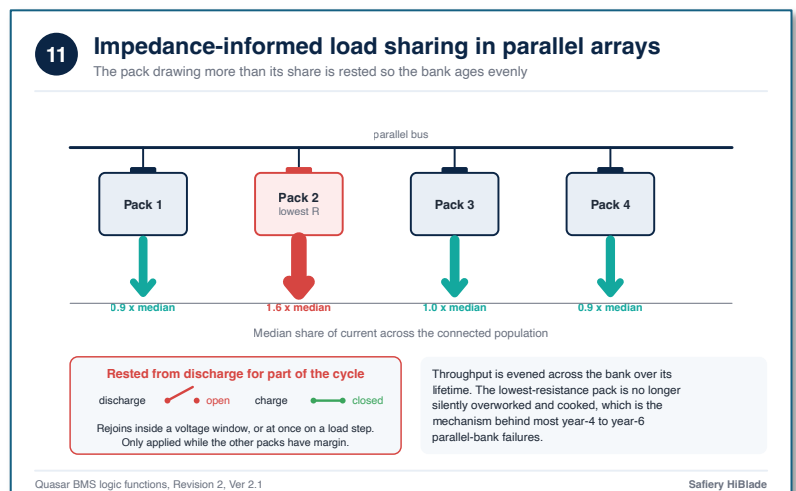
Up to 128 packs coordinate over 1 Mbit/s ISO 11898 with J1939 framing, each running its own start-up checks in parallel rather than being polled. Start-up time is independent of bank size, which matters when the house bank is also propulsion.



Healing Low Voltage Cells in a Parallel Bank

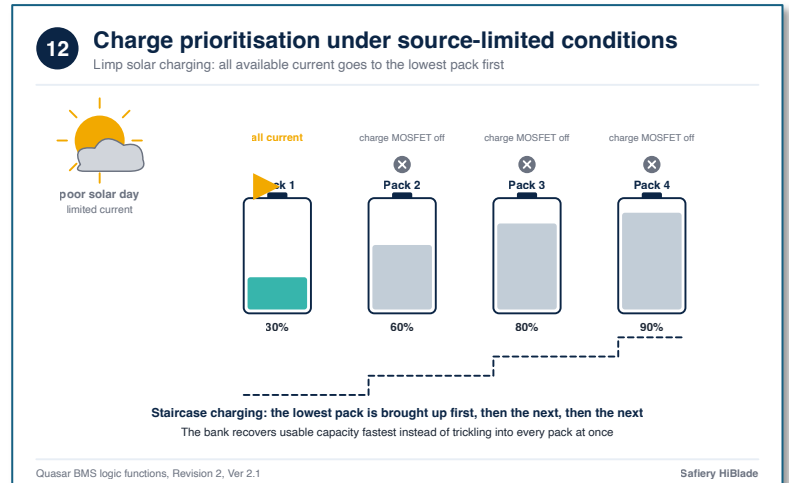
Impedance-informed load sharing in parallel arrays

Each pack's resistance and share of current is compared with the median of the connected population. A pack drawing more than its share is rested from discharge for part of the cycle: its discharge path is opened while it continues to accept charge, and it is rejoined within a voltage window or immediately on a load step. Its charge path can also be closed a little early so it starts the next discharge slightly below the others and takes a smaller share. Lifetime throughput is evened across the bank, so the lowest-resistance pack is no longer silently overworked and cooked, which is the mechanism behind most year-4 to year-6 parallel-bank failures. A rest is only applied while the remaining packs have margin to carry the load.



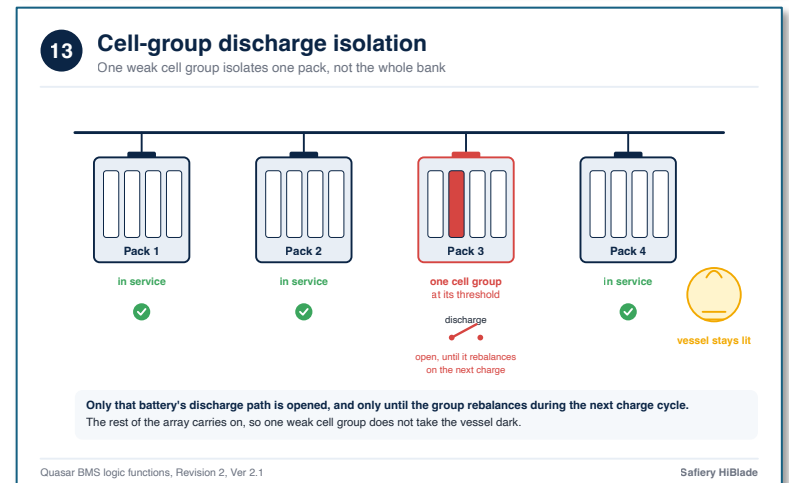
Charge prioritisation under source-limited conditions ("limp solar charging")

On a poor solar day, charge MOSFETs on the higher-SoC packs are turned off so all available current goes to the lowest pack first. The bank recovers usable capacity fastest instead of trickling into every pack at once. This charging process is called "staircase charging".



Cell-group discharge isolation

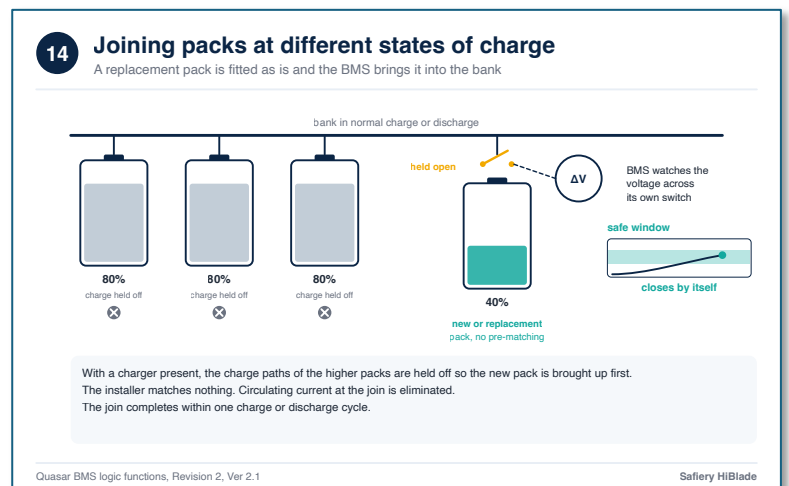
If any cell group hits its protection threshold, only that individual battery's discharge path is opened, and only until the group rebalances during the next charge cycle. The rest of the array stays in service, so one weak cell group does not take the vessel dark.



Batteries added to a Parallel Bank

Joining packs at different states of charge

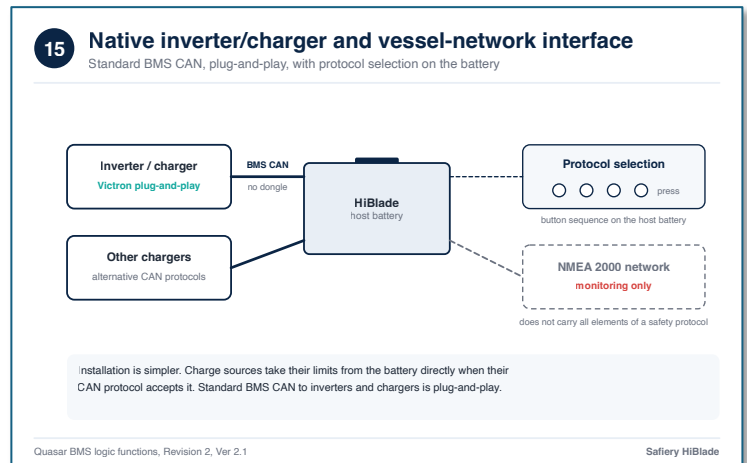
When a pack at a different state of charge is added, it is held open and the BMS watches the voltage difference across its own switch. It closes by itself when the bank drifts into a safe window during normal charging or discharging, and where a charger is present the charge paths of the higher packs are held off so the new pack is brought up first. A replacement pack is fitted without pre-matching its state of charge, the installer matches nothing, and circulating current at the join is eliminated. The join completes within one charge or discharge cycle.



Compliant CAN BMS Protocols

Native inverter/charger and vessel-network interface

Standard BMS CAN to inverters and chargers with no dongle are Victron plug-and-play. Alternative protocols are selected using a button press sequence on the host battery. Note that NMEA 2000 does not support all the elements of a safety protocol and is for monitoring only. Installation is simpler and the charge sources take their limits from the battery directly if their CAN protocol accepts it.



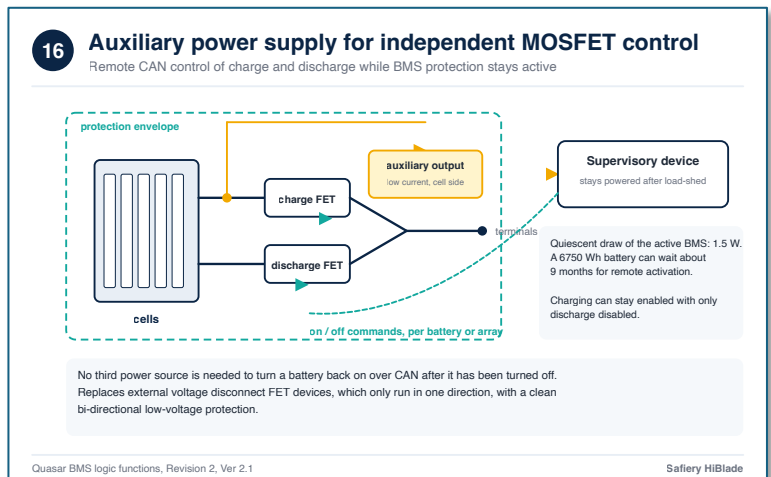
Remote CAN Control of Battery Charge and Discharge whilst BMS Protection is still Active.

In a conventional installation of a battery or banks of batteries, using a third device to remotely turn on a battery (s) over CAN that has been turned off over CAN would require another power source. With HiBlade this problem is solved in the BMS design.

Auxiliary power supply for independent MOSFET control

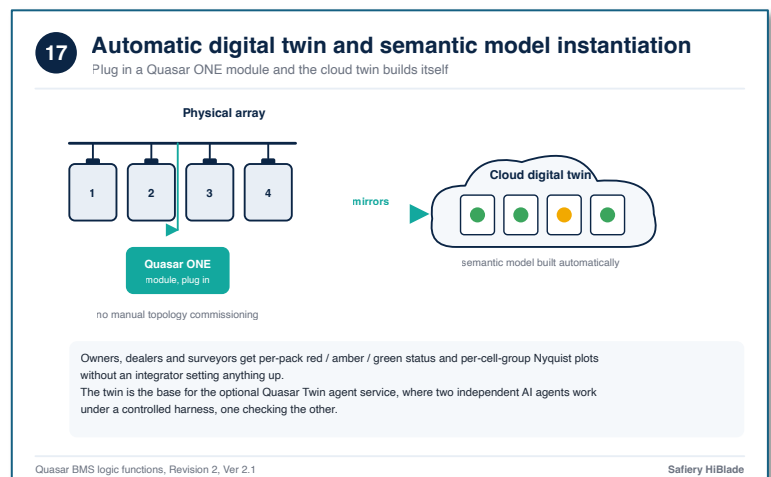
A dedicated low-current output sits on the cell side of the main MOSFETs but inside the protection envelope, so a supervisory device stays powered after load-shed and can command charge or discharge on or off per battery or array of batteries. This replaces external voltage disconnect FET devices which only run in one direction, giving a clean bi-directional simplicity for low voltage protection.

The battery's discharge MOSFETs can be turned off remotely with the optional accessories. The remain active BMS has a quiescent discharge of 1.5W meaning a 6750Wh battery can have a standby period of 9 months awaiting remote activation. During this time, charging can be enabled and only discharging disabled.



Optional Harness to Digital Twin with Agent Notification.

In conventional monitoring or remote management software, alarms and alerts are notified to listed parties within that service. Those parties must perform the judgement of the battery(s) condition and/or the requirement to urgently charge. With HiBlade, the optional Quasar Twin service is performed by two independent AI agents under a controlled AI harness. One agent checks the other and the choice of LLM may be



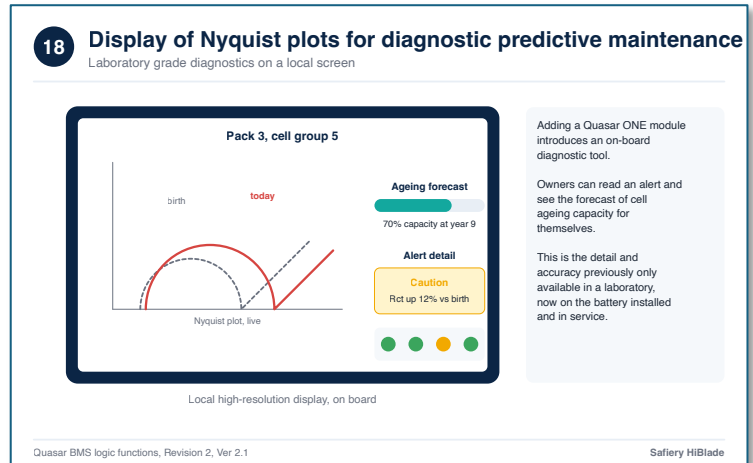
changed at any time should a better LLM become available.

Automatic digital twin and semantic model instantiation

Adding a Quasar ONE module builds the cloud twin mirroring automatically on plug-and-play. The physical array has no manual topology commissioning. Owners, dealers and surveyors get per-pack red/amber/green status and per-cell-group Nyquist plots without an integrator setting anything up.

Display of Nyquist plots for diagnostic predictive maintenance

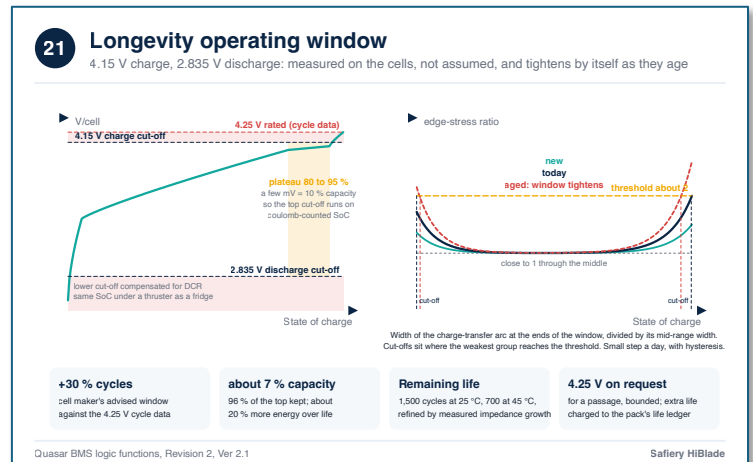
Adding a Quasar ONE module introduces a local high-resolution display as an on-board diagnostic tool to understand alerts and the forecast cell ageing capacity. This is the detail and accuracy previously only available in the laboratory, now available with the battery installed and in service. Owners get per-pack red/amber/green status and per-cell-group Nyquist plots without setting anything up.



Prolonging Life of Battery

Longevity operating window (4.15 V charge, 2.835 V discharge)

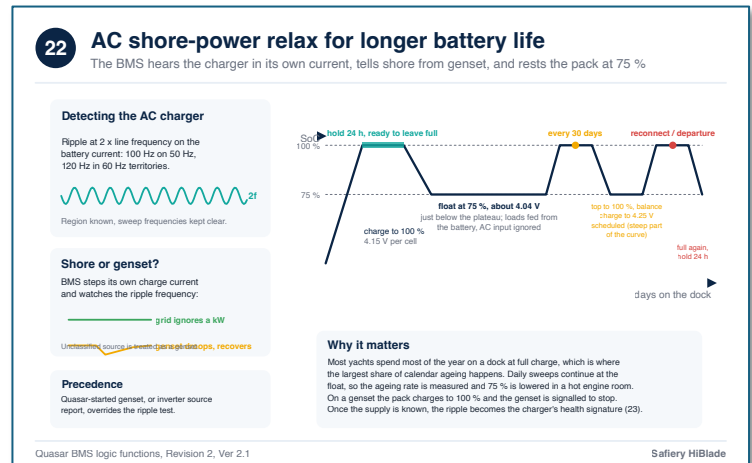
The cell maker's cycle data are taken at a 4.25 V charge; their advised longevity window is a 4.15 V charge cut-off and a 2.835 V discharge cut-off, for about 30 % more cycles. On their measured 25 °C open-circuit curve that window keeps 96 % of the cell at the top and costs about 7 % of capacity in all, so the pack delivers about 20 % more energy over its life as well as lasting longer. The BMS applies this window by default. The cell's open-circuit curve has a plateau from 80 to 95 % SoC (4.075 to 4.112 V), where a few millivolts are ten percent of capacity, so the upper cut-off is enforced on coulomb-counted SoC, reset at each full charge, with voltage as the guard. The lower cut-off is compensated for internal resistance from the cell maker's DCR map, so it means the same state of charge under a thruster as under a fridge, and is never set below their temperature-stepped minimum. The default is also measured rather than assumed. The daily sweeps, taken at whatever state of charge the day provides and supplemented by edge sweeps near the top and bottom of the window, give the width of the charge-transfer arc against state of charge; its ratio to the mid-range width, the edge-stress ratio, is a direct reading of how hard the ends of the window are pushing the cells, close to one through the middle and rising steeply at both ends. The cut-offs are the states of charge at which the ratio of the weakest cell group reaches a threshold, set at about 2, so the window tightens by itself as the ratio steepens with age, without a cycle count or a capacity estimate, moving by no more than a small step a day with hysteresis, and never widening beyond the rated limits. The wider 4.25 V window is available on request for a passage, for a bounded period, with the extra life consumed entered in the pack's life ledger. Remaining life is reported against the cell maker's reference, 1,500 cycles at 25 °C and 700 at 45 °C, held



per window setting and refined by the measured impedance growth. The ratio of impedance growth per unit of throughput between the wide and the narrow window is measured on the pack itself, and across the fleet, and replaces the cell maker's multiplier once enough throughput has been logged under both settings, so the life consumed on a passage is charged to the ledger at a rate the battery has demonstrated.

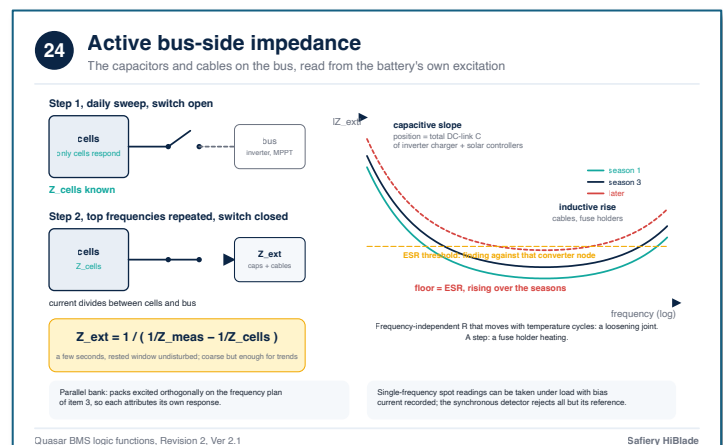
AC shore-power relax for longer battery life

A mains-fed charger puts ripple on the battery current at twice the line frequency: 100 Hz on 50 Hz supplies, 120 Hz in 60 Hz territories. The EIS current channel listens for it, so the BMS knows when an AC charger is running without any external signal, which region it is in, and which sweep frequencies to keep clear of. It then tells shore power from a genset by stepping its own charge current and watching the ripple frequency: the grid does not notice a kilowatt, a genset droops and recovers. Ripple-frequency variance and the amplitude envelope are checked as well, and if Quasar started the genset or the inverter reports its source, that takes precedence; an unclassified source is treated as a genset. On shore power the pack charges to 100 % of the longevity window (4.15 V per cell), holds there for 24 hours so a boat that has just come in can leave full, then relaxes to 75 % (about 4.04 V per cell, just below the plateau) by feeding the boat's loads from the battery with the AC input ignored, and floats there. If shore power is lost and reconnected, or a departure is requested from the app or the energy plan, the pack charges to 100 % and holds 24 hours again before relaxing. Every 30 days on the dock the pack is topped to 100 %, and a balance charge to the rated 4.25 V is scheduled, because balancing needs the steep part of the curve above the plateau. On a genset the pack charges to 100 % and the genset is signalled to stop. Daily sweeps continue at the float, so the calendar-ageing rate is measured and the 75 % is lowered in a hot engine room if the trend says so. Most yachts spend most of the year on a dock at full charge, which is where the largest share of calendar ageing happens and where this function buys the most life. Once the supply is known, the same ripple is trended as the charger's own health signature under item 23.



Active bus-side impedance: the capacitors and cables on the bus read from the battery's own excitation

The cell sweep is taken with the battery's switch open, so only the cells respond and Z_{cells} is known. At the end of the daily sweep the top frequencies are repeated with the switch closed, so the injected current divides between the cells and everything else on the bus, and the external network follows by subtraction: $Z_{\text{ext}} = 1 / (1/Z_{\text{meas}} - 1/Z_{\text{cells}})$. It costs a few seconds and does not disturb the rested window. The subtraction is coarse, because the bank is low in impedance and the capacitors carry only a



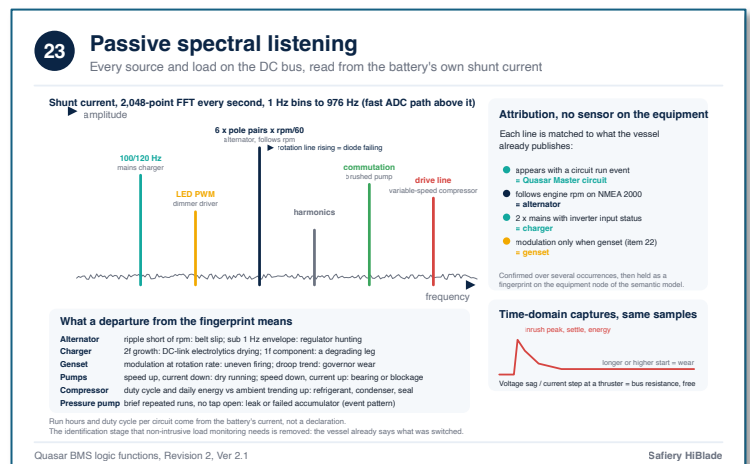
fraction of the current, but it is enough for trends. The magnitude of Z_{ext} against frequency shows a capacitive slope whose position is the total DC-link capacitance of the inverter charger and the solar controllers, and a floor whose height is their equivalent series resistance; the floor rising over the seasons is the electrolytics drying out, the commonest converter failure, and ESR against a threshold is the finding against that converter's node. The conduction path of cables, fuse holders, switches and contacts appears as a frequency-independent resistance and a rising inductive term at the top of the band: a resistance that moves with temperature cycles is a loosening joint, a step is a fuse holder heating. In a parallel bank the packs are excited orthogonally, on the frequency plan of item 3, so each attributes its own response. Single-frequency spot readings can also be taken under load with the bias current recorded, since the synchronous detector rejects everything except its reference.

Passive spectral listening: the equipment on the DC bus read from the battery's own current

The shunt and sampling chain that measure the cells are also the one instrument that sees every source and load on the DC bus. The BMS transforms its shunt current into a spectrum every second (a 2,048-point FFT in 1 Hz bins up to the 976 Hz ceiling of the EIS channel, with a fast ADC path on the shunt at tens of kilosamples per second for lines above it, such as an alternator's six-pulse ripple at high rpm) and tracks each line, its harmonics and its envelope from frame to frame. Each line is attributed to a piece of equipment by correlation with what the vessel already publishes: a line that appears with a circuit's run event from Quasar Master and disappears with it belongs to that circuit; a line whose frequency follows engine rpm on NMEA 2000 is the alternator's; a line at twice mains frequency that appears with the inverter's input status is the charger's; a modulation present only when the supply is classified as a genset under item 22 is the genset's. Once attribution has been confirmed over several occurrences, a fingerprint is held against that equipment's node in the semantic model: frequency and its relation to speed, amplitude at a reference load, harmonic content, envelope, and for events the inrush profile and duty cycle at reference conditions. A departure beyond the node's own scatter is qualified by repeat, as in item 1, before a finding is raised against the node, carrying the spectrum snippet, the event record and the corroborating operating signal as evidence.

The signatures. Alternator: ripple frequency is $6 \times \text{pole pairs} \times \text{rpm}/60$, and a shortfall against rpm is belt slip; the electrical fundamental and the rotation-frequency line rising from the noise floor is a rectifier diode failing, months before it delivers AC into the bank; envelope modulation below 1 Hz is regulator hunting. Mains charger: growth of the twice-line-frequency ripple at a given charge current is the DC-link electrolytics drying out; a component at once the line frequency, which a symmetric bridge never produces, is a degrading leg. Genset: cyclic modulation of the ripple at the rotation rate, or half of it on a four-stroke, is uneven firing; slow amplitude modulation is regulator hunting; the droop and recovery on a load step, trended over months, is governor wear. Brushed pumps: commutation frequency is speed and amplitude is torque, so rising speed with falling current is dry running or cavitation, and falling speed with rising current is a blocked impeller or a failing bearing. Variable-speed compressor: speed from the drive line, and duty cycle and daily energy against ambient temperature trend upward with refrigerant loss, a fouled condenser or a failed door seal. LED dimmer drivers: growth of the PWM line.

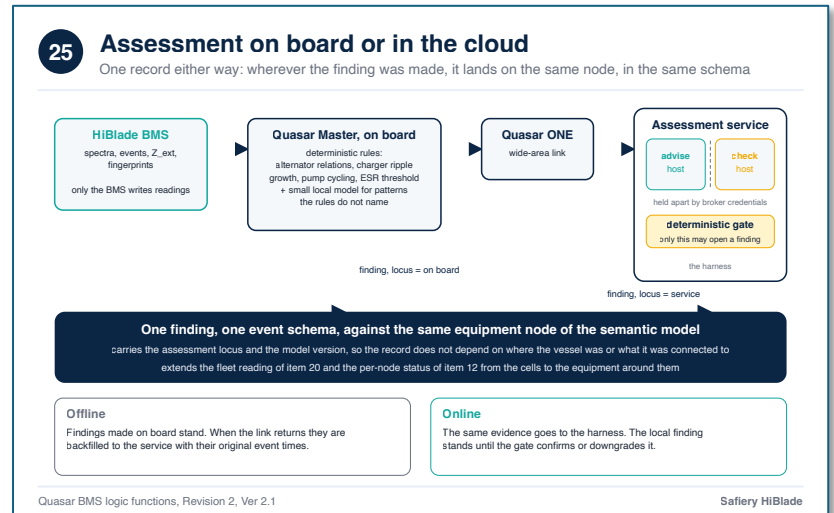
Time-domain captures from the same samples. The step detector records the peak, settle time and energy of every motor and compressor inrush, and a start that grows longer or higher is a mechanism wearing. At every large load step, such as a thruster, the ratio of terminal-voltage sag to current step, less the cells'



known series resistance, is the resistance of the bus and its connections at that moment, obtained many times a season without a test. A fresh-water pressure pump that runs briefly and repeatedly with no tap open has a leak or a failed accumulator; the event pattern, not the spectrum, is the detector. Run hours and duty cycle per circuit are derived from the battery's own current rather than declared. None of the equipment carries a sensor, and the identification stage that non-intrusive load monitoring otherwise needs is removed because the vessel already says what was switched.

Assessment on board or in the cloud, with one record either way

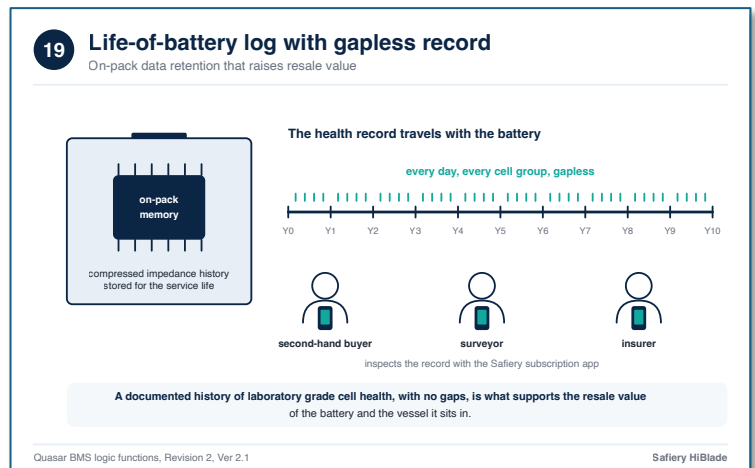
Spectra, events, Z_ext and fingerprints go from the BMS to Quasar Master, which applies deterministic rules (the alternator relations, the charger ripple growth rule, the pump cycling rule, the ESR threshold) and may run a small local model for patterns the rules do not name; and through Quasar ONE over the wide-area link to the assessment service, where an advise host and a check host are held apart by broker credentials and only a deterministic gate may open a finding. Whichever locus assessed it, the finding is published against the same equipment node of the semantic model in one event schema, carrying the locus and the model version, so the record does not depend on where the vessel was or what it was connected to. Offline, findings made on board stand and are backfilled to the service with their original event times when the link returns; online, the same evidence goes to the harness and the local finding stands until the gate confirms or downgrades it. Only the BMS writes readings, so no assessment locus can alter what was measured. This is the mechanism behind the fleet reading of item 20 and the per-node status of item 12, now extended from the cells to the equipment around them.



Battery Log with Gapless Record.

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Resale value increases with on-pack data retention

Compressed impedance history is stored on the pack itself for its service life. The health record travels with the battery, so a second-hand buyer, surveyor or insurer can inspect it with the Safiery subscription app.

1,000 vessels reporting every 15 minutes: 95 million values to read a month

This cannot be done by people in a control room. With the Safiery subscription app, AI agents read the cell-group values across the fleet, trend them and route issues for engineer approval, with the first year's subscription included with the Quasar module.

