Coolant Intrusion in Mercedes EQ High-Voltage Battery Systems: Causes, Diagnostic Indicators, and the Risk of Unnecessary Battery Replacement

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Abstract. The rapid expansion of the global electric vehicle market, which surpassed 17 million units sold in 2024 according to the International Energy Agency, has made the reliable diagnosis of high-voltage battery faults a critical competency for automotive dealerships worldwide. In Mercedes EQ vehicles, coolant intrusion into the battery enclosure represents a frequently underdiagnosed failure mode that shares its primary symptom with genuine cell-level degradation: a drop in isolation resistance triggering Battery Management System fault codes. The present study examines the technical causes of coolant ingress in EQ platform battery systems (EQA, EQB, EQC, EQS, and derivatives), characterizes the diagnostic indicators that distinguish this event from primary battery failure, and evaluates the downstream risk of unnecessary high-voltage battery replacement. Through systematic review of manufacturer recall documentation, technical service bulletins, peer-reviewed literature on battery thermal management and fault diagnosis, and documented dealer case studies, this paper shows that coolant intrusion can depress isolation resistance to levels that trigger emergency shutdowns without causing irreversible cell damage. A structured six-step diagnostic protocol and a replacement decision matrix are proposed to guide technicians. The findings are of direct relevance to Mercedes-Benz authorized dealers,

independent EV specialists, and automotive service engineers seeking cost-effective, evidence-based diagnostic workflows.

Keywords: coolant intrusion, high-voltage battery, Mercedes EQ, battery management system, isolation resistance, EV diagnostics, thermal management, dealership service, fault code, battery replacement risk.

Introduction

Electric vehicles are no longer a niche segment. According to the International Energy Agency's Global EV Outlook 2025, global electric car sales exceeded 17 million units in 2024, reaching a market share above 20% for the first time in history [1]. Sales in the first quarter of 2025 grew by 35% year-on-year, and full-year 2025 is projected to surpass 20 million units, representing more than one in four new cars sold globally [1]. This growth trajectory creates a corresponding surge in demand for specialized EV servicing at automotive dealerships, a demand that exposes a diagnostic skills gap with measurable financial consequences.

Mercedes-Benz entered the battery electric vehicle segment with its EQ brand across multiple platforms: the EQA and EQB compact crossovers share a 66.5 kWh pack architecture; the EQC mid-size SUV was the brand's first dedicated BEV; the EQS flagship uses NCM 811 pouch cells in packs of up to 107.8 kWh with an aluminum-extruded bottom cooling plate [2, 3]. All platforms share a defining structural feature: tightly integrated liquid cooling circuits that run coolant through channels in direct proximity to the lithium-ion cell modules. This design is thermally efficient but introduces a specific failure mode that is largely absent from vehicles with air-cooled packs: the ingress of liquid coolant into the battery enclosure.

When coolant breaches the battery housing, whether through a failed gasket, a cracked fitting, or a faulty expansion valve, it creates a conductive path between high-voltage components and the chassis ground. The Battery Management System

(BMS) detects this as a drop in isolation resistance and may trigger fault codes including the standard P0AA6 (Hybrid/EV Battery Pack Voltage System Isolation Fault) alongside manufacturer-specific codes such as ISO_RES_LOW in the Mercedes XENTRY diagnostic environment [4, 5]. Crucially, the same type of fault code is generated by genuine cell failure, internal short circuits, and high-voltage cable insulation breakdown. Without a structured diagnostic protocol, technicians face a decision tree that carries significant financial risk: an unnecessary full HV battery replacement in the EQ product line costs in the range of USD 15,000 to USD 20,000 for parts alone [6], while the actual remediation of a coolant leak may cost a fraction of that figure.

Despite the frequency of this failure mode in service records, as evidenced by documented owner cases in the EQA, EQB, EQC, and EQS model lines [4, 7], and the existence of at least one manufacturer recall specifically addressing battery internal failure risk linked to thermal management (NHTSA [8]), no peer-reviewed study has systematically addressed the misdiagnosis risk at the dealership level or proposed a structured triage protocol for this specific failure scenario.

This research gap is the motivation for the present paper. **The scientific novelty** of this work lies in the development of a vehicle-specific six-step diagnostic decision protocol that separates coolant-induced isolation faults from primary battery failure in Mercedes EQ systems, combined with a replacement decision matrix that dealership technicians can apply without requiring access to proprietary MB engineering documentation.

The study proceeds from the following **hypothesis**: in a significant proportion of Mercedes EQ cases where an HV battery replacement is recommended based solely on isolation fault codes, the root cause is a coolant intrusion event that is treatable without pack replacement, provided that proper diagnostic sequencing is followed.

The goal of this research is to characterize the technical causes and diagnostic indicators of coolant intrusion in Mercedes EQ battery systems and to formulate a practical protocol that reduces unnecessary battery replacements in dealership settings.

Materials and Methods

This study employs a multi-method qualitative and technical research design combining systematic literature review, technical documentation analysis, and structured case synthesis. The methodological approach is justified by the nature of the research question: the diagnosis of a specific electromechanical failure mode requires integration of engineering knowledge (thermal management system architecture), regulatory evidence (recall and service bulletin data), and practical diagnostic evidence (documented case outcomes).

Literature Review. A systematic search was conducted across Scopus-indexed journals, IEEE Xplore, ScienceDirect, and Springer Nature Link, using the following keyword clusters: battery thermal management AND coolant leak AND electric vehicle; lithium-ion battery isolation fault AND diagnosis; BMS fault diagnosis AND cooling system; thermal runaway AND liquid cooling AND insulation resistance. The search was bound to publications from 2020 onward. All sources were evaluated against inclusion criteria: peer-review status, methodological transparency, and relevance to production EV battery systems.

Technical Documentation Analysis. Official Mercedes-Benz recall notices filed with the National Highway Traffic Safety Administration (NHTSA) were analyzed, specifically recall [8] and the BMW Service Information Bulletin SIB 17 01 24 regarding coolant leak at changeover valves in hybrid/EV systems, used as a comparative reference [9]. Technical specifications for the EQA, EQB, EQC, and EQS battery systems were sourced from Mercedes-Benz official product documentation [2, 3]. Fault code taxonomy for isolation faults (P0AA6, ISO_RES_LOW, P0E1B, B3A007x) was compiled from OBD-II standard references and the XENTRY diagnostic environment as documented in technical resources [4, 5, 10].

Case Synthesis. Documented EQ owner and technician case records were systematically reviewed from the Mercedes EQ All Electric Forum (mbeqclub.com), focusing on threads containing diagnostic details: fault codes, coolant system involvement, dealer actions, and outcomes. These cases were treated as observational field data rather than primary research data. They were used to validate the frequency and symptom patterns identified in the literature and to inform the design of the diagnostic protocol.

The Midtronics technical guide on EV powertrain misdiagnosis [10] provided a diagnostic framework that was adapted and extended to the Mercedes EQ-specific context for the development of the proposed six-step protocol. Research on battery fault diagnosis methods including signal-based approaches [11, 12, 13] and model-based insulation fault detection [14] provided the theoretical grounding for the isolation resistance threshold parameters used in the protocol.

Results and Discussion

The scale of the EV market expansion directly determines the scale of the EV servicing challenge. Figure 1 illustrates global EV sales growth from 2020 to 2025, based on IEA data [1]. The near-vertical trajectory of this growth curve means that dealer workshops that lacked structured EV diagnostic protocols in 2020 now encounter multiple EV service cases per week. The financial stakes of diagnostic error are correspondingly higher each year.

Battery pack replacement costs for luxury-segment EVs such as the Mercedes EQ line remain substantial. BloombergNEF's 2024 Battery Price Survey reports cell-level costs at approximately USD 115/kWh at the pack manufacturing level [6], but dealer-facing replacement costs for premium vehicles incorporate labor, proprietary software calibration, and warranty processing, pushing total installed cost well above USD 15,000 for packs in the 66-108 kWh range [6]. Against this background, a misdiagnosis that leads to unnecessary battery replacement represents not only a direct financial loss but also a reputational risk for the dealer and a sustainability concern given the environmental cost of premature battery disposal.

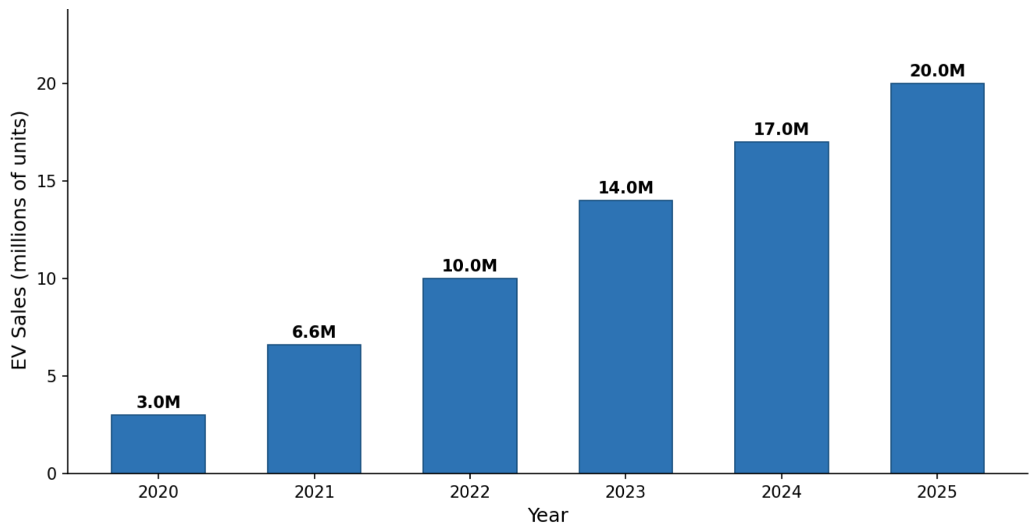

Figure 1. Global Electric Vehicle Sales, 2020-2025 (millions of units). (compiled by the author based on [1]).

Understanding why coolant intrusion is a credible failure mode in EQ vehicles requires a working knowledge of their thermal management architecture. Across the EQA, EQB, EQC, and EQS platforms, Mercedes uses a closed-loop liquid cooling system in which a glycol-water coolant mixture circulates through aluminum channels integrated into or beneath the battery pack housing. The EQA, for example, employs a coolant-fed plate directly beneath the 66.5 kWh, 420 V nominal battery, capable of both cooling and heating the pack via a shared thermal circuit that also interfaces with the PTC (Positive Temperature Coefficient) heater element [3]. The EQS uses coolant flowing through cavities in aluminum extrusions forming the battery frame, with PTC heating integrated into the same loop [2].

The cooling circuit interfaces with several other subsystems: the front-mounted radiator, the heat pump for cabin climate control (particularly in EQC and EQS), a chiller heat exchanger, and the inverter and electric drive unit (EDU) cooling loops. This multi-loop architecture, illustrated in Figure 2, creates numerous potential failure points at gaskets, fittings, expansion valves, pump seals, and hose connections.

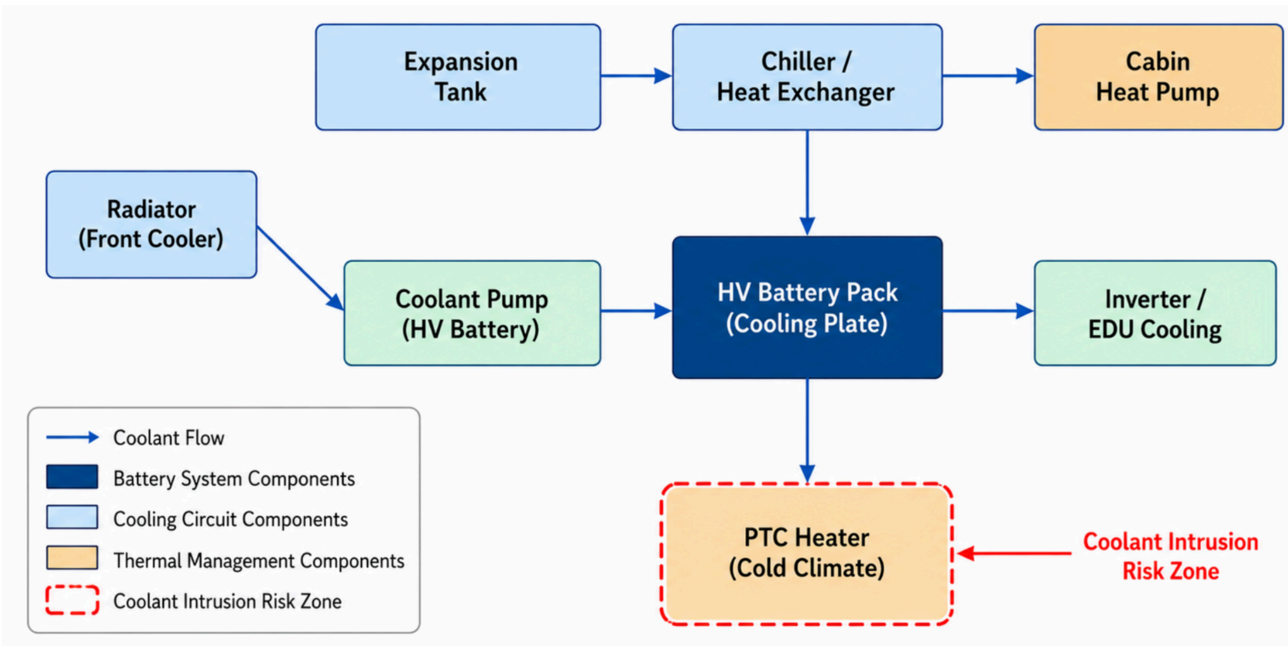

Figure 2. Mercedes EQ HV Battery Cooling Circuit: Component Architecture and Coolant Intrusion Risk Zones (compiled by the author based on [2, 3, 4]).

The expansion valve Y140/1 has been specifically identified as a failure-prone component in early production EQ models. The original part (A 297 830 54 03) was prone to mechanical sticking, causing coolant circuit pressure anomalies. Mercedes-Benz issued a silent revision to part A 297 830 89 03 with improved durability [4]. Many vehicles manufactured before the revision date remain in service with the original valve. A stuck or partially failed expansion valve alters coolant flow balance, increasing the risk of pressure transients that stress hose connections and gasket interfaces. The changeover valve, addressed in BMW SIB 17 01 24 for comparable EV/hybrid architectures [9], represents an analogous failure point: in Mercedes EQ systems, this valve directs coolant between battery cooling and heat pump modes. Seal degradation at this point allows coolant to migrate toward the battery enclosure.

When liquid coolant enters the battery enclosure, the primary consequence relevant to fault codes is not immediate cell damage but a rapid reduction in the isolation resistance between the HV circuit and the vehicle chassis ground. Modern EV platforms including the Mercedes EQ family are required by regulations to maintain isolation resistance above 500 ohms per volt of system voltage. For a 400 V system, this translates to a minimum of 200 kOhm; in practice, healthy EQ systems measure above 1 MOhm [5, 14]. Standard glycol-water coolant has ionic conductivity that increases significantly with temperature: at operating temperatures of 30-60 degrees Celsius, a trace film of coolant on a connector or across a module interface can reduce isolation resistance to below 100 kOhm, which is well within the BMS shutdown threshold [15, 16].

This conductivity-temperature relationship is critical to the diagnostic differentiation. It means that an isolation fault caused by coolant intrusion will typically exhibit temperature dependence: the fault may be absent or latent when the vehicle is cold and become active once the thermal management system brings coolant to operating temperature. This behavior has been documented in multiple EQ owner cases: vehicles showing intermittent "Battery Malfunction" warnings that appear during or after charging sessions, particularly DC fast charging, where coolant temperature rises most significantly [7].

At the hardware level, the conductive path created by coolant intrusion is distinct from cell-level degradation. Cell degradation reduces capacity, increases internal resistance, and creates voltage imbalance across modules, but does not by itself directly reduce isolation resistance to chassis. Coolant intrusion, by contrast, primarily affects isolation without altering individual cell voltages in the early stages.

To summarize the symptom landscape, Table 1 presents a structured comparison of fault code signatures across three primary isolation fault scenarios observed in Mercedes EQ systems, based on field documentation and technical literature.

Table 1. Comparative Fault Code Signatures in Mercedes EQ Isolation Fault Scenarios (compiled by the author based on [4, 5, 7, 8, 10]).

Fault Characteristic	**Coolant Intrusion**	**HV Cable / Connector Fault**	**Primary Cell Degradation**
Primary fault code	P0AA6, ISO_RES_LOW, B3A007x	P0AA6, ISO_RES_LOW	P0AA6 (late stage), voltage imbalance codes
Secondary / co-occurring codes	P0E1B (coolant pump fault), B3A0077 (cooling system fault)	None or communication errors	Cell voltage deviation, SOH-related flags
Temperature dependence of fault	Strong: worsens with warm coolant	Absent or weak	Moderate: linked to SOC extremes
Coolant system codes present	Yes	No	No
Cell voltage imbalance	Absent (early stage)	Absent	Present (>30 mV spread)
Recovery after coolant repair	Full recovery (isolation restored)	Partial (depends on cable damage)	No recovery without pack service

Note: SOH = State of Health; SOC = State of Charge. Codes follow OBD-II SAE J1979 and Mercedes-Benz XENTRY taxonomy.

NHTSA recall 25V050000 [8], issued January 31, 2025, covers 7,362 Mercedes-Benz EQB 250, EQB 300 4MATIC, and EQB 350 4MATIC vehicles from model years 2022-2024. The stated risk is internal high-voltage battery failure that may lead to vehicle fire. The interim remedy was a software update to the BMS. This recall confirms at the regulatory level that the EQB battery system has documented internal integrity concerns; however, the service bulletin scope (a BMS software update rather than pack replacement) also demonstrates that Mercedes-Benz engineers distinguished between the diagnostic fault signal and actual cell-level failure requiring hardware intervention. This distinction is precisely the capability gap that the present study addresses at the dealership technician level.

The BMW SIB 17 01 24 (Revision 3, effective March 2025) [9], which addresses coolant leaks at changeover valves in BMW i and plug-in hybrid models, provides a directly analogous structural reference. The bulletin mandates replacement of any changeover valve with a production date prior to January 5, 2024, and specifies further diagnosis with ISTA (BMW's dealer diagnostic tool) and cooling system test equipment before any other corrective action is taken. The parallel structure of this bulletin to the Mercedes EQ fault pattern illustrates that the diagnostic challenge of distinguishing cooling circuit faults from battery-intrinsic faults is a platform-agnostic issue in modern premium EVs, not a Mercedes-specific anomaly.

Table 2 summarizes the key regulatory and service documentation reviewed, illustrating the scope of the documented failure landscape across both Mercedes EQ and comparative platforms.

Table 2. Key Regulatory and Service Documentation Reviewed (compiled by the author based on [8, 9, 2, 7]).

Document	Source / Platform	Scope	Units Affected	Diagnostic Relevance
NHTSA 25V050000	Mercedes-Benz EQB 250/300/350 (2022-2024)	Internal HV battery failure risk; fire while parked or driving	7,362	BMS software update; distinguishes software from hardware fault
NHTSA 24V372	Mercedes-Benz EQE/EQS (2023-2025)	BMS software overload; unexpected HV shutdown	~15,000	Software-induced isolation fault; resolved by update

				without pack replacement
BMW SIB 17 01 24	BMW i / PHEV models (analogous EV platform)	Coolant leak at changeover valve; HV exposure risk	Fleet-wide advisory	Mandates cooling system test before HV work; direct protocol parallel
MB Technical Spec EQA / EQB	Mercedes-Benz official product documentation	Battery architecture; coolant plate design; thermal loop integration	N/A	Defines physical points of potential ingress in cooling-to-cell proximity

Note: Data compiled from official NHTSA records and manufacturer documentation. BMS = Battery Management System; HV = High Voltage.

Building on the technical analysis, this paper proposes a six-step diagnostic protocol for managing isolation fault presentations in Mercedes EQ vehicles at the dealership level. The protocol is designed to be actionable with standard dealer equipment (XENTRY diagnostic tool, coolant pressure tester, insulation resistance tester) and does not require proprietary access beyond what is available to authorized Mercedes-Benz dealers. Figure 3 presents the protocol as a decision flowchart.

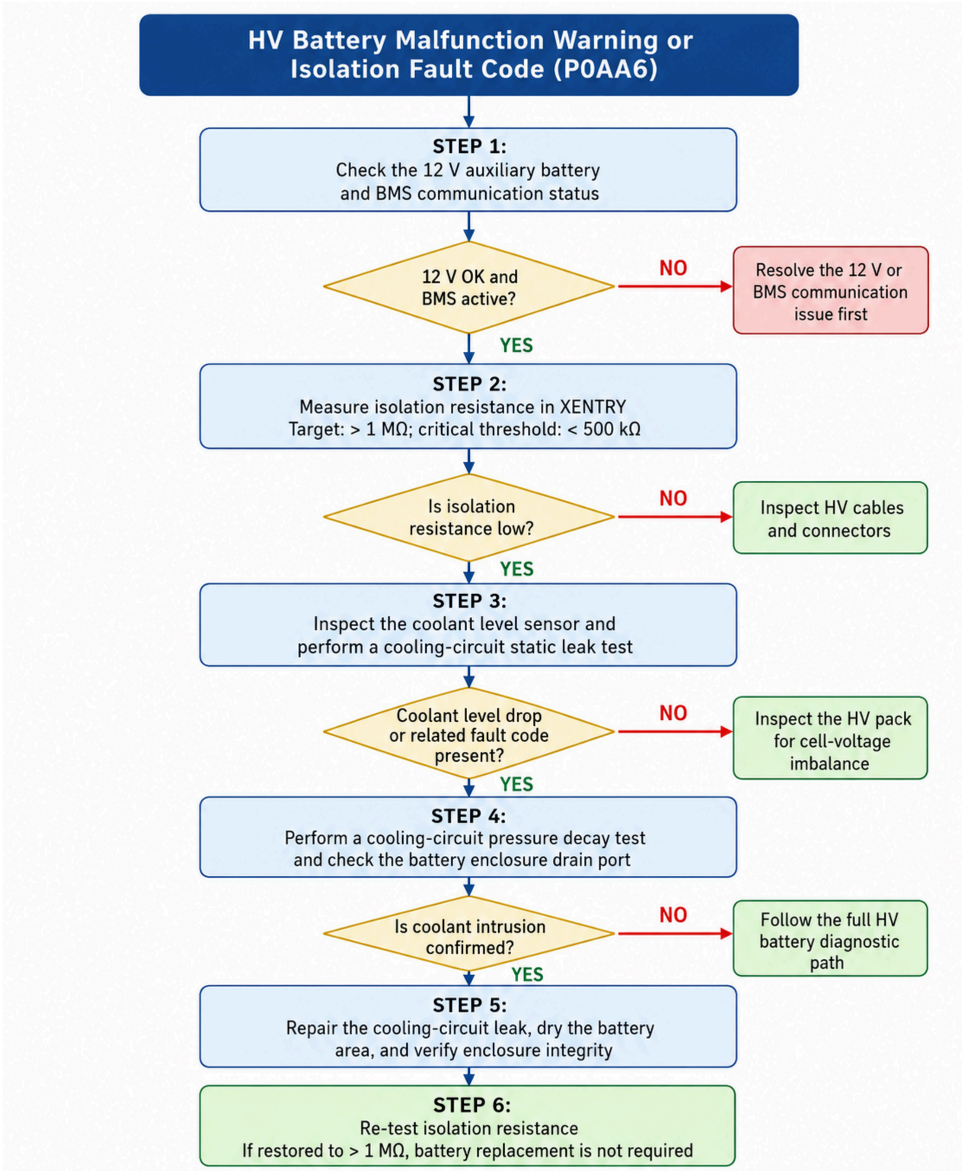

Figure 3. Six-Step Diagnostic Protocol for Coolant Intrusion in Mercedes EQ HV Battery Systems (author's original design based on [4, 5, 9, 10, 14, 20]).

Step 1 verifies 12V ancillary battery health and BMS communication status. A depleted or failing 12V battery is documented as a cause of false HV fault presentations in multiple EV platforms [10, 17]; addressing this first prevents misinterpretation of secondary codes. Step 2 involves reading isolation resistance directly through XENTRY, which reports the value in the high-voltage battery diagnostics menu. A value consistently above 1 MOhm indicates the HV circuit is healthy, and the fault is likely transient or software-related. A value below 500 kOhm, particularly when observed at operating temperature, warrants proceeding to Step 3.

Step 3 is the critical differentiation point: the technician checks coolant system fault codes alongside the isolation fault. The presence of codes in the P0E1B family (coolant pump actuation fault) or B3A007x (cooling system fault) alongside the isolation fault constitutes a strong positive indicator for coolant involvement. Step 4 performs a static pressure decay test on the coolant circuit to confirm active leakage, and visual inspection of the battery enclosure drain port for coolant traces. This step converts the presumptive diagnosis into a confirmed diagnosis.

Step 5 addresses the root cause: repair the leak source (replacement of the faulty expansion valve, changeover valve, pump seal, or hose fitting as identified), dry the affected area within the enclosure using compressed clean air, and verify enclosure integrity. Step 6 is the confirmation test: re-measure isolation resistance after coolant repair and enclosure drying, with the vehicle at operating temperature. If isolation resistance restores to above 1 MOhm, pack replacement is not indicated. If isolation resistance remains depressed after confirmed coolant removal, the fault has another root cause and the diagnostic pathway continues to full HV pack assessment.

The proposed decision matrix, presented in Figure 4, operationalizes the diagnostic logic described above into a reference tool for dealership technicians. It compares three primary scenarios against five diagnostic indicators and provides a binary recommendation on pack replacement. The matrix is intended to be applied after XENTRY fault code reading and before any disassembly of the battery pack.

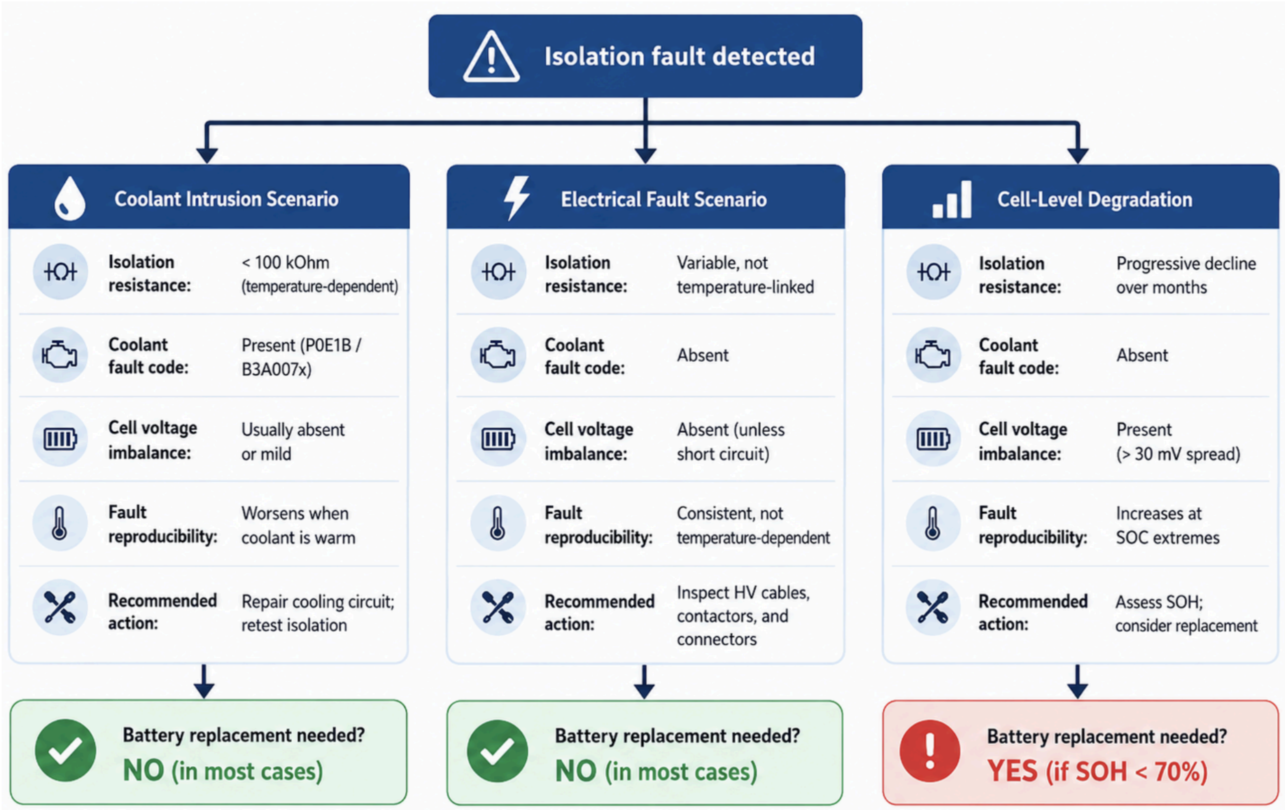

Figure 4. HV Battery Replacement Decision Matrix for Isolation Faults in Mercedes EQ Systems (author's original design based on [5, 8, 10, 14, 18, 19]).

The central recommendation of this matrix is that coolant intrusion and electrical fault scenarios should resolve without pack replacement in the majority of cases. Only confirmed cell-level degradation with state-of-health below 70% warrants a hardware replacement of the pack. This threshold aligns with federal and most state-level EV battery warranty standards, which require manufacturers to cover battery degradation below 70% of original capacity within the warranty period [6].

From a dealership management perspective, implementing the protocol and matrix offers several concrete benefits. First, it reduces the incidence of unnecessary warranty claims for battery pack replacement, which benefits OEM-dealer financial relationships. Second, it builds technician competency in EV-specific diagnostics, which is a competitive differentiator as EV market share grows. Third, it directly protects customers from bearing out-of-warranty replacement costs for a condition that is treatable through a much less expensive cooling system repair.

A practical recommendation for dealership service managers is to establish a mandatory hold on HV battery replacement authorizations until Steps 1 through 4 of the proposed protocol have been documented in the repair order. This procedural change requires no capital investment and can be implemented through service policy update alone. Training technicians on the temperature-dependent behavior of coolant-induced isolation faults, specifically that these faults are most pronounced at warm coolant temperatures, is another low-cost intervention with high diagnostic yield.

Table 3 provides a quantitative reference for key parameters used in the diagnostic protocol and decision matrix, grounded in technical literature on EV battery insulation monitoring.

Table 3. Key Diagnostic Thresholds for Isolation Resistance in EQ Platform HV Battery Systems (compiled by the author based on [5, 14, 15, 17, 18]).

Parameter	Threshold Value	Status Interpretation	Recommended Action
Isolation resistance (healthy system)	> 1 MOhm	Normal	Continue routine service; monitor for recurrence
Isolation resistance (caution zone)	500 kOhm - 1 MOhm	Marginal / investigate	Proceed to cooling system inspection (Step 3)
Isolation resistance (fault threshold)	< 500 kOhm	Fault / BMS shutdown risk	Full diagnostic protocol activation; do not drive
Coolant conductivity (warm, glycol-water 50:50)	~100-200 uS/cm at 40°C	Sufficient to create isolation path	Coolant intrusion of even small volume can cause fault
Regulatory minimum isolation requirement (400V system)	> 200 kOhm (500 Ohm/V)	Legal minimum; practical target is 5x higher	BMS shutdown typically set at 100-200

			kOhm to provide safety margin
Post-repair acceptance threshold	> 1 MOhm at operating temperature	Acceptable; pack replacement not needed	Document in repair order; schedule follow-up at 30 days

Note: Values derived from regulatory standards (UNECE R100) and peer-reviewed literature on EV battery insulation monitoring. MBE = Mercedes-Benz Engineering. uS/cm = microsiemens per centimeter.

The diagnostic protocol proposed in this paper is grounded in technical literature and documented case evidence but has not been validated through a prospective clinical-style study at a sample of dealerships. A rigorous validation would require tracking diagnostic outcomes (including follow-up isolation resistance measurements) for a cohort of EQ vehicles presenting with isolation fault codes, which is beyond the scope of this review-based study. Additionally, the protocol has been developed specifically for the 400 V platform architecture of the EQ model range; EV systems operating at 800 V (such as certain Porsche and Hyundai platforms) may require modified threshold parameters.

Future research should quantify the proportion of Mercedes EQ battery fault cases at authorized dealerships in which coolant intrusion is the confirmed root cause. This would provide an empirical basis for the hypothesis at the core of this study. Additionally, the long-term effects of coolant exposure on cell chemistry in the EQ platform remain an open research question: while this study argues that early-stage coolant intrusion does not cause irreversible cell damage, the threshold duration and volume of exposure above which permanent degradation occurs has not been characterized in the literature for this specific pack architecture.

Conclusion

This study addressed the causes, diagnostic indicators, and misdiagnosis risk associated with coolant intrusion in Mercedes EQ high-voltage battery systems. The analysis confirms that coolant ingress into the battery enclosure is a documented failure mode across the EQA, EQB, EQC, and EQS platforms, with multiple physical entry points in the thermal management circuit, including the expansion valve Y140/1, changeover valves, pump seals, and hose connections in proximity to the battery housing. The conductive properties of warm glycol-water coolant are sufficient to reduce isolation resistance below BMS shutdown thresholds, generating fault codes that are clinically indistinguishable from primary battery failure without a structured diagnostic sequence.

The diagnostic differentiation protocol developed in this paper provides a six-step triage pathway that dealership technicians can execute with standard authorized equipment. The key differentiating indicators are: temperature dependence of the isolation fault, concurrent presence of coolant system fault codes (particularly P0E1B and B3A007x), and the absence of cell voltage imbalance in early-stage coolant events. The proposed HV Battery Replacement Decision Matrix operationalizes these indicators into a practical reference tool that supports the conclusion: in coolant intrusion and HV cable fault scenarios, battery pack replacement is not warranted as an initial intervention. Pack replacement becomes appropriate only when confirmed cell-level degradation with state-of-health below 70% is established through a complete diagnostic sequence.

The goals stated in the abstract have been achieved: the technical causes of coolant intrusion have been characterized, the diagnostic indicators distinguishing this event from primary battery failure have been identified, and a structured protocol reducing the risk of unnecessary replacement has been proposed. The scientific novelty of this contribution lies in the first systematic integration of these elements into a vehicle-specific decision tool for the EQ platform. With global EV sales forecast to exceed 20 million in 2025 and the Mercedes EQ fleet expanding across all major markets, the practical relevance of this diagnostic guidance for authorized dealers, independent EV specialists, and automotive service engineers is both immediate and growing.

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