WHITE PAPER

IQ Bidirectional EV Charger

Applicable regions: North America

Contents

1. About this document

This whitepaper provides an overview of the Enphase IQ Bidirectional EV Charger, highlighting its technology, architecture, and role in enabling vehicle-to-home (V2H) and vehicle-to-grid (V2G) capabilities. It outlines key features, system compatibility, and use cases that support a flexible, standards-compliant approach to residential energy management.

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2. Introduction

The Enphase IQ Bidirectional EV Charger marks a significant advancement in residential energy systems, enabling electric vehicles (EVs) to serve as both energy consumers and distributed energy resources (DERs). Built on the proven Enphase microinverter platform and AI-driven energy management algorithms, the system supports vehicle-to-home (V2H) and vehicle-to-grid (V2G) operations within a standards-compliant, scalable architecture.

It converts AC grid power into clean, stable DC power for direct EV battery charging, and converts DC power from the EV into clean, stable AC power that meets local grid codes and compliance requirements. It provides split-phase and neutral support for North American grids, and one- or three-phase electricity for European and rest-of-world electrical systems.

It is compatible with all EVs that support ISO 15118-20 and ISO 15118-2 communication protocols, and works with nearly all grid types globally. It supports OCPP 2.1, OCPP 2.0.1, and IEEE 2030.5 for smart grid interoperability, making it a versatile and future-proof solution.

It integrates into the proven Enphase energy management platform that unifies solar, storage, EV charging, and grid interaction through a single, intelligent ecosystem. This enables homeowners to optimize energy use, maximize savings, and enhance backup capabilities—all controlled via the Enphase App.

With flexible system configurations—from easy-to-install standalone setups to full integration with solar and battery storage—the IQ Bidirectional EV Charger helps reduce costs, increase resilience, and support grid stability. This whitepaper outlines the technology, architecture, and use cases that position Enphase at the forefront of the clean energy transition.

3. Understanding bidirectional EV charging

Bidirectional EV charging transforms an electric vehicle from an energy consumer into an active energy resource. With the right system architecture, EVs can support home loads during outages, help stabilize the grid, and reduce energy costs through intelligent scheduling. This section provides a quick overview of what bidirectional EV charging is, followed by a look at different approaches.

In a typical unidirectional charging process, an electric vehicle (EV) draws power from the grid to charge its battery—energy flows in only one direction, from the grid to the EV. Bidirectional charging builds on this by enabling energy to also flow in the opposite direction, from the EV back to the grid or home.

3.1 Bidirectional EV charging: AC vs. DC approaches

Bidirectional charging can be implemented using either alternating current (AC) or direct current (DC) pathways, each with distinct technical architectures and integration points. In the AC approach, power is exchanged over the AC, with bidirectional power conversion handled inside the vehicle. In contrast, DC bidirectional charging uses a dedicated DC interface, with power electronics outside the vehicle and as part of the charger to manage the conversion.

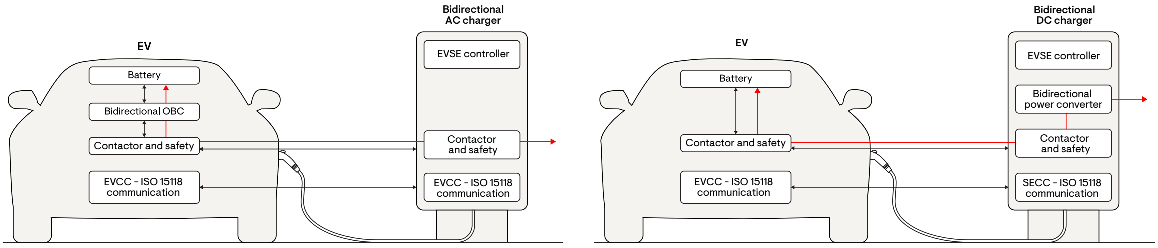

Figure 1: Bidirectional EV charging: AC vs. DC

The choice between AC and DC impacts vehicle complexity, charger complexity, installation costs, reliability, and regulatory compliance—making it a critical design decision for both EV manufacturers and energy system providers.

Table 1: Bidirectional EV charging: AC vs DC comparison

Category	Bidirectional AC charging (inverter in EV)	Bidirectional DC charging (inverter in charger)
Power conversion location	Inside the EV bidirectional onboard charger (OBC).	Inside the charger.
Grid code compliance	Managed by EV; standards are still evolving. Because the EV is mobile, maintaining and enforcing regional grid code compliance becomes more complex.	Fixed at installation; grid codes are always known and fixed. This reduces complexity, simplifies compliance and certification, and builds trust with utilities for consistent power quality.
Installation flexibility	Simplified charger, but requires a bidirectional ready EV. Difficult to upgrade if the EV hardware does not support bidirectional operation.	Easier for charger upgrades. Supports upgrade from 11 kW to 22 kW. Compatible with more EVs.
System complexity	Higher for EV original equipment manufacturers (OEMs). Auto OEMs need to develop additional expertise in grid interoperability, and manage region-specific compliance requirements.	Higher for charger OEMs. Complexity is shifted to a stationary system with a known installation context, simplifying vehicle design.
Cost distribution	Shifts cost to the vehicle.	Shifts cost to the charger.
Maintenance and support	Vehicle service is needed for power electronics issues. Becomes a single point of failure and can prevent vehicle charging.	Field-replaceable charger components allow faster repair and less vehicle downtime. Redundancy is built in: if the charger's

Category	Bidirectional AC charging (inverter in EV)	Bidirectional DC charging (inverter in charger)
		inverters fail, the EV's onboard charger can still be used for unidirectional AC charging.

At Enphase, we recognize that both AC and DC bidirectional chargers play a role in the evolving EV ecosystem. We are actively developing solutions for both AC and DC bidirectional chargers. In this whitepaper, we focus on the IQ Bidirectional EV Charger, which uses DC power to both charge and discharge the EV. This charger reduces onboard vehicle complexity, ensures consistent compliance with local grid codes, and supports robust grid-forming and grid-following capabilities.

By offloading the inverter to a stationary, grid-connected charger, Enphase enables faster time-to-market for automotive OEMs, who no longer need to build and certify complex bidirectional power systems inside the vehicle. This design reduces engineering overhead and removes the burden of supporting a wide range of global grid configurations—such as split-phase systems in North America, and single- or three-phase systems in Europe and other regions, each with unique electrical characteristics and regulatory requirements.

For example, within North America alone, there are several types of electrical services, including 120/240 V split-phase, 208Y/120 V three-phase WYE, 240 V three-phase Delta, and 277/480 V three-phase WYE. Expanding globally introduces even greater diversity in grid voltages, frequencies, grounding schemes, and protection standards. This heterogeneity makes it extremely complex for automotive OEMs to develop in-vehicle inverters that can safely and reliably interoperate across different markets.

Leveraging two decades of Enphase experience in power conversion, grid code implementation, and compliance across multiple geographies—including active deployments and installer networks in over 160+ countries—this DC approach allows automakers to deploy bidirectional features more quickly and with lower integration risk. With over 4.8 million homes powered by Enphase systems and support for 1000+ grid codes and electrical parameters, the platform ensures broad compatibility and simplifies the challenges of global integration.

4. System configurations

The IQ Bidirectional EV Charger integrates seamlessly with the Enphase Energy System and the Enphase App to produce, store, monitor, export, control, and analyze energy throughout the home—offering a flexible and intelligent approach to home energy management.

Built for scalability, the system adapts to evolving homeowner needs. A typical journey may begin with just the IQ Bidirectional EV Charger and the IQ Meter Collar, enabling vehicle-to-grid (V2G) and vehicle-to-home (V2H) functionality—even in homes without solar or battery storage. Over time, solar PV can be added to reduce grid dependence, and IQ Batteries can be integrated for increased resilience and to ensure backup power when the vehicle is away or fully discharged.

This modular architecture allows homeowners to balance performance and cost—starting small and scaling up as their energy needs grow, without requiring major upgrades or infrastructure changes.

The following configurations illustrate how the system can be deployed across a range of use cases:

- IQ Bidirectional EV Charger + IQ Meter Collar
- Integrated Enphase Energy System

4.1 IQ Bidirectional EV Charger + IQ Meter Collar

In this configuration, the IQ Bidirectional EV Charger is installed together with an IQ Meter Collar. This integrated setup enables grid-agnostic use cases, advanced energy management functionalities, and enhanced home resiliency.

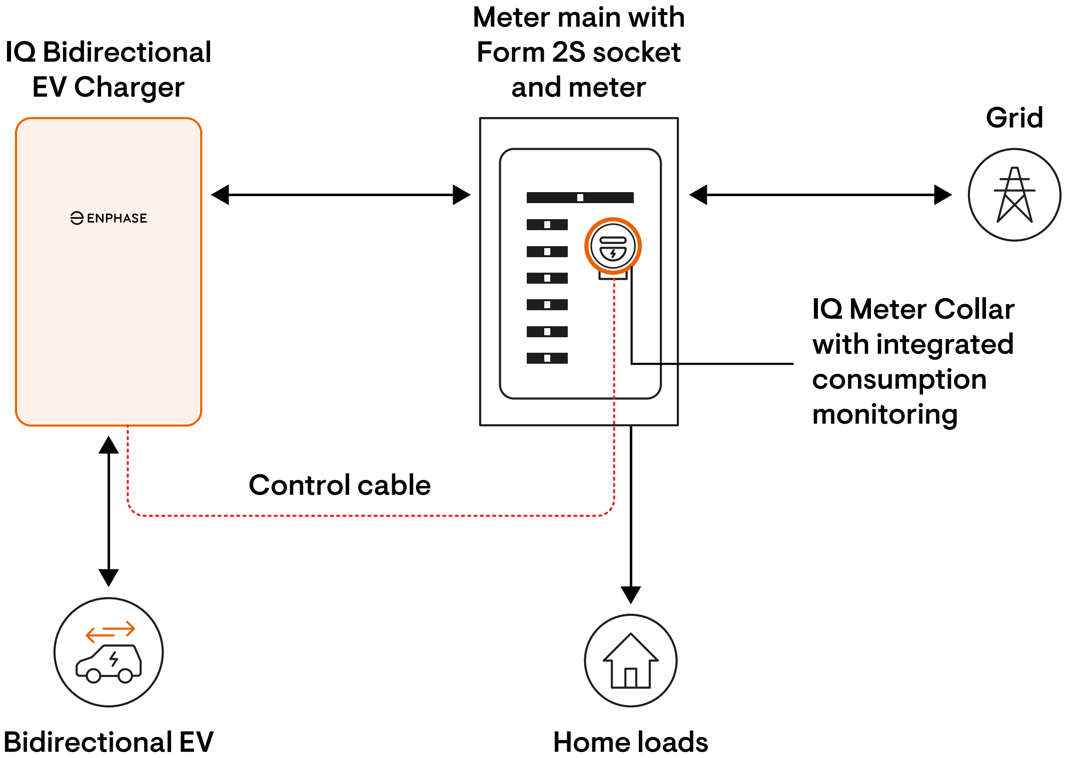

Figure 2: IQ Bidirectional EV Charger + IQ Meter Collar

The IQ Meter Collar is a metering and islanding device. It provides real-time data on current and power import/export by the home. The IQ Bidirectional EV Charger uses this information to operate within grid interconnection and busbar limits, implementing power control systems and dynamic charging.

In the event of a grid outage, the IQ Meter Collar automatically disconnects the home from the utility grid, allowing the IQ Bidirectional EV Charger to power the home using energy from the EV. After grid power is restored, the IQ Meter Collar works with the charger to seamlessly reconnect the home to the utility—ensuring smooth and safe transitions.

This configuration provides the following features and capabilities:

- **Export to Grid (V2G):** Enables vehicle-to-grid energy export.
- **Smart Charging (V1G):** Charges based on dynamic electricity tariffs control from the utility and Time-of-Use (ToU) rates.
- **Scheduled Charging:** Allows users to create custom charging schedules.
- **Commanded Charging:** Enables remote start/stop of charging via the app.
- **Dynamic Charging and Power Control System (PCS):** Limits power at the grid interface to avoid main panel upgrades.

- **AI Optimization Profile:** Dynamically schedules charging and discharging to maximize cost savings, optimize battery life, and ensure energy availability for both mobility and home resilience.
- **Seamless Emergency Home Backup (V2H):** Powers the home during outages when the EV is plugged in.
- **Black Start Capability:** Supports powering up a fully de-energized home, enabling advanced features such as vehicle-to-home (V2H) and Black Start.

4.2 Integrated Enphase Energy System

In this configuration, homeowners can upgrade their energy system by integrating the full Enphase Energy System—including photovoltaic (PV) solar panels, IQ Batteries, and bidirectional EV charging. This comprehensive solution maximizes resilience, energy independence, and cost savings, while providing seamless backup power even when the EV is not present.

In addition to the features supported by the IQ Bidirectional EV Charger and IQ Meter Collar, this setup also enables capabilities such as Green Charging and Self-Consumption. The AI Optimization profile is enhanced to include inputs from both solar and storage.

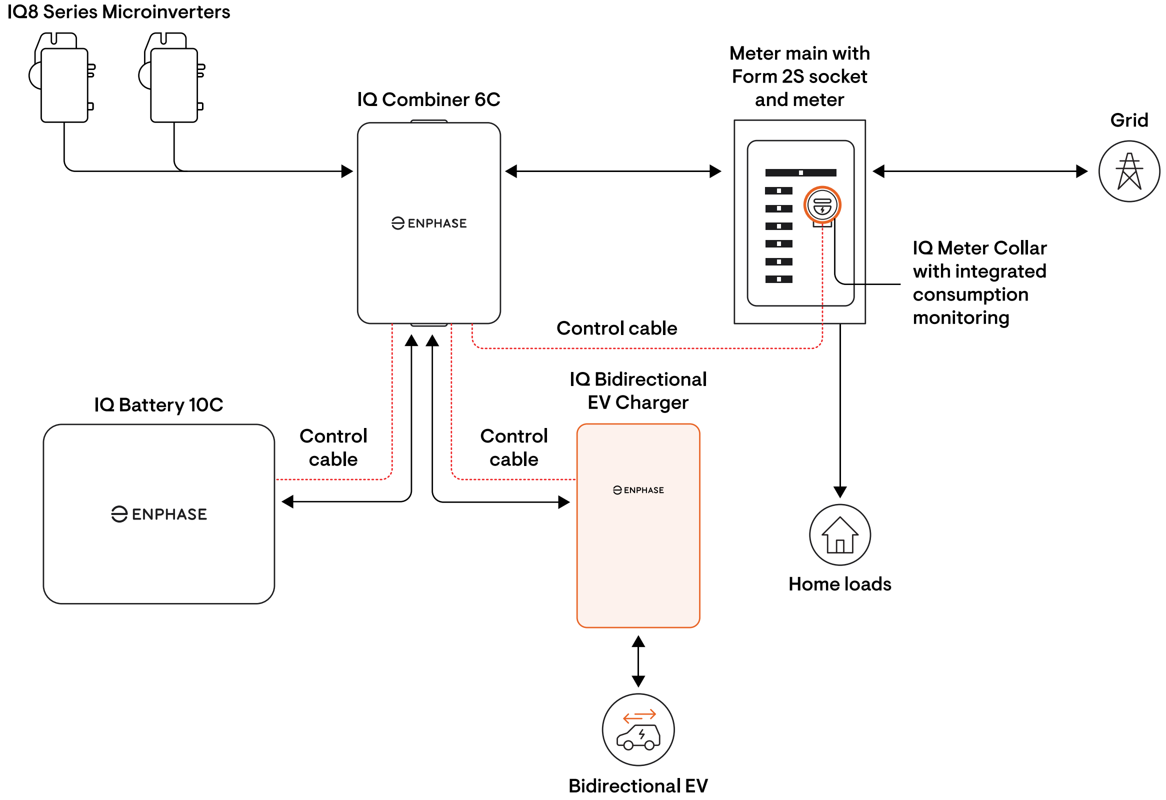

Figure 3: An IQ Bidirectional EV Charger as part of 4th-gen Enphase Energy System

5. Technology overview

Architecturally, the IQ Bidirectional EV Charger is built on the same foundation as the IQ Battery, leveraging field-proven microinverter technology that has been deployed in millions of homes worldwide. It features a robust hardware platform for control, communication, and intelligent energy orchestration. Building on the IQ Battery design, the charger adds ISO 15118-20-compliant EV communication and OCPP-based cloud connectivity, ensuring seamless interoperability with both electric vehicles and backend platforms. This makes the system highly adaptable for homeowners and automotive OEMs alike.

By enabling the EV to function as a mobile energy storage asset, the charger effectively turns the vehicle into a plug-in equivalent of the IQ Battery. Whenever the EV is connected, it can provide the same core stationary storage capabilities—such as backup power during outages, energy export to the grid, and intelligent, tariff-optimized charging behavior.

In the event of a grid outage, an internal auxiliary battery provides Black Start capability. This allows the charger to power up independently, establish communication with the EV, and restore home power—even if the vehicle is plugged in only after the outage has begun.

The system supports AI-optimized charging and discharging based on real-time electricity tariffs, the vehicle's state-of-charge, user-defined departure schedules, and personal energy preferences, enabling significant savings and enhanced energy control. Advanced operational modes like vehicle-to-home (V2H) and vehicle-to-grid (V2G) are fully integrated and can be managed either through the Enphase App or via automotive OEM APIs.

Designed for broad compatibility, the charger supports any EV that complies with open communication standards, eliminating the need for extensive rewiring. It incorporates dynamic power limiting and is fully compliant with local grid codes. Backed by a 10-year warranty, the IQ Bidirectional EV Charger delivers long-term performance, simplified installation, and exceptional reliability for today's energy-conscious households.

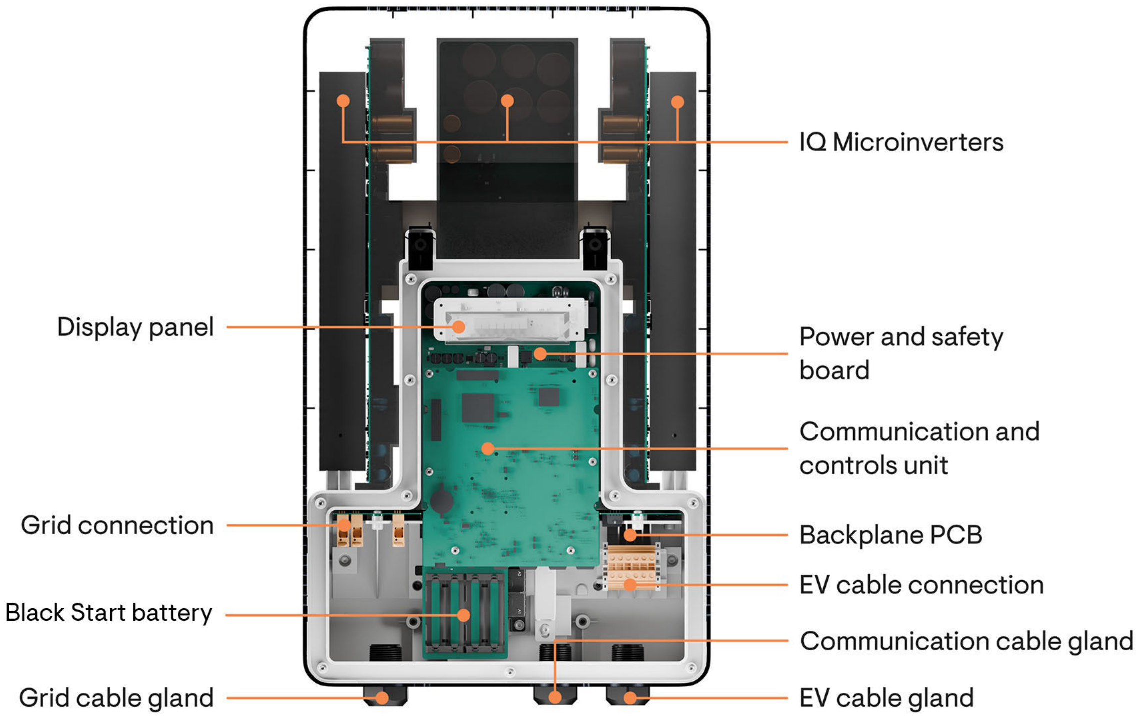

Figure 4: IQ Bidirectional EV Charger

5.1 Product specifications

Feature	Description
Connection type	Home to charger: AC, charger to car: DC
Operating grid voltage	240 VAC (single-phase/split-phase)/400 VAC (three-phase)
DC voltage range	200–1000 VDC
Rated power	11.52 kW (on AC side), both charging and discharging
Dimensions	650 mm × 400 mm × 180 mm
Connector type	NACS (US)/CCS Type 1 (US)/CCS Type 2 (ROW)
Supported protocols	EV communication: ISO 15118-20, ISO 15118-2, DIN 70121, SAE J2847 Cloud communication: OCPP 1.6, OCPP 2.0.1, OCPP 2.1 Grid: IEEE 2030.5
Connectivity	Wi-Fi, Ethernet, Bluetooth, cellular LTE CAT 4, CAN
User interface	Enphase App Multi-color notification LEDs Black Start switch
Features	**V2G:** Export power from the vehicle, back to the grid when the grid needs it **V2H and Emergency Backup:** Power the home during an outage and seamless grid transitions **Charging modes:** AI Optimization, Green Charging, ToU schedule, and custom schedule **Integrated with Enphase solar and battery installation to provide unified energy management for the home** **Power Control System (PCS):** Import/Export Current Limiting, Main Panel Upgrade Avoidance **Black Start:** Power up a completely off-grid home
Data	Available through the Enphase Cloud API

5.2 Product architecture

The IQ Bidirectional EV Charger is engineered for intelligent energy management, modular scalability, and exceptional reliability. It is built on a DC-coupled architecture for EV connection and an AC-coupled architecture for grid interconnection—simplifying installation, supporting modular system expansion, and enabling seamless integration with home and utility infrastructure.

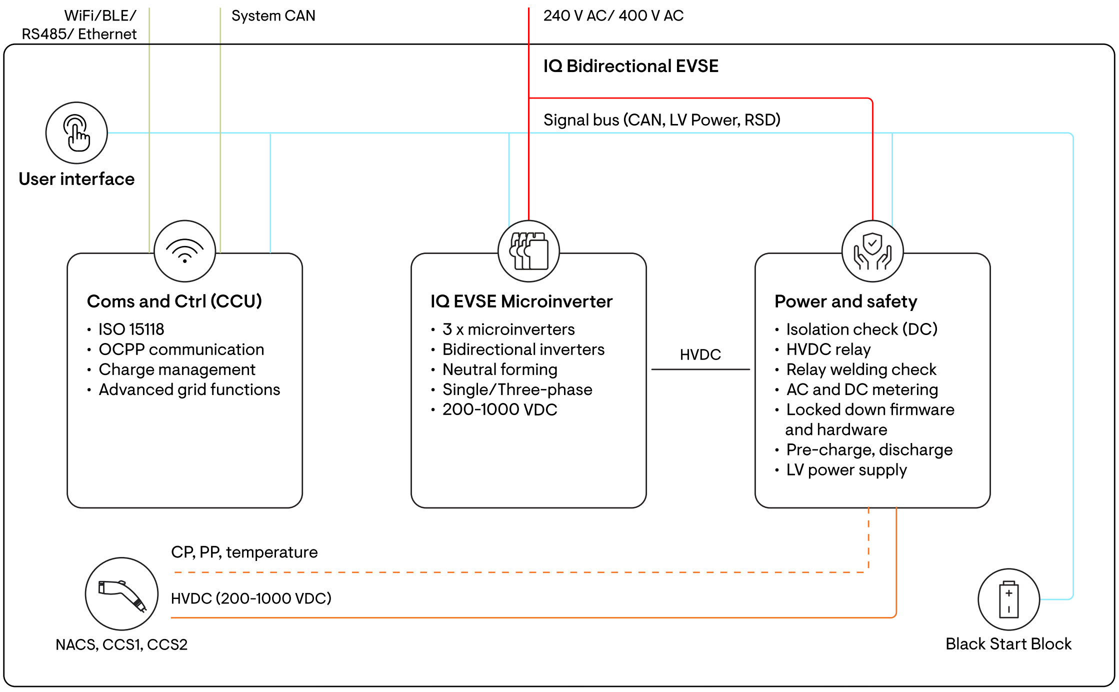

Figure 5: IQ Bidirectional EV Charger architecture

The charger is fully compatible with all common residential electrical configurations, ISO 15118-20–compliant EVs, utilities, and charge point operators. Its intelligent power routing supports both 400 V and 800 V battery platforms while minimizing contactor wear, connector fatigue, and other electromechanical stress—ultimately extending the service life of both the EV and the charger.

To achieve this high level of functionality and robustness, the IQ Bidirectional EV Charger uses several core internal modules. The first is a set of microinverters that handle high-efficiency, bidirectional AC power conversion. Each charger integrates three IQ10 EV Microinverters, passively cooled and built with gallium nitride (GaN) FETs. Each microinverter delivers 3.84 kW of power, totaling 11.52 kW across the charger. Central to their operation is the custom-designed Kestrel ASIC from Enphase, a high-performance silicon controller that enables advanced grid-forming functions including islanding, Black Start, voltage and frequency regulation, and both split-phase and three-phase grid forming. These capabilities deliver exceptional real-time power regulation, high conversion efficiency, and superior system scalability.

The microinverters support both grid-following and grid-forming modes and are designed to form a stable neutral on North American split-phase grids. Each inverter can tolerate up to 16 A of phase imbalance, or 48 A aggregate per charger. In three-phase configurations, all inverters operate in a phase-aware manner, working in unison to generate high-quality, grid-compliant power across all phases. Designed and tested to UL 1741 and IEEE 1547 standards, these microinverters inherit a legacy of reliability proven across millions of field deployments. Their fanless, passively cooled construction and modular redundancy allow for silent, resilient operation and superior uptime.

The second key module is the Communication and Controls Unit, which ensures seamless interoperability across EVs, grid systems, cloud services, and the broader Enphase Energy System. This unit supports industry protocols including ISO 15118-20, ISO 15118-2, DIN 70121, and SAE J2847 for EV communications; IEEE 2030.5 for grid and DER interfaces; and OCPP 1.6, 2.0.1, and 2.1 for full compatibility with back-end charge point operator systems. Internally, it interfaces with the Enphase Energy System over a proprietary CAN bus, allowing the charger to function as an integrated energy asset. In standalone mode, it acts as a local IQ Gateway, managing system behavior and coordinating energy flow. It also oversees the health, operational state, and over-the-air (OTA) software updates for each subsystem in coordination with the Enphase Cloud.

The third module, the Power and Safety Unit, is responsible for system protection and hardware compliance. It includes continuous isolation monitoring, contactor control with weld detection, and both AC and DC revenue-grade metering to support accurate energy reporting and utility program participation. This unit also manages precharge operations during a Black Start event, utilizing an internal Black Start battery to safely initiate communication and power delivery after a grid outage. Auxiliary power supplies are integrated to support startup and critical system functions under all conditions.

Complementing these subsystems is a built-in user interface, which provides real-time visibility into charging status, energy usage, and system diagnostics. This local display helps installers and homeowners verify system operation, troubleshoot events, and monitor performance directly at the charger.

All of these features are wrapped in a durable, passively cooled enclosure with hardened power electronics and a robust system design. The IQ Bidirectional EV Charger is backed by an industry-leading 10-year warranty, providing long-term assurance to energy-aware homeowners and future-proofing their investment in clean mobility and home energy independence.

To optimize performance across different operating modes, the IQ Bidirectional EV Charger supports a range of energy management profiles tailored to diverse homeowner objectives, utility requirements, and vehicle capabilities. These profiles define how energy is charged into or discharged from the EV based on variables such as pricing signals, state of charge (SoC), home energy usage, and solar availability. Users can choose from predefined modes or allow the system to adapt dynamically based on real-time inputs.

5.2.1 AI Optimization profile

At the core of the smart charging capabilities of Enphase is the AI Optimization profile. This profile leverages the Enphase AI optimization engine to continuously evaluate a wide range of parameters and automatically determine the most cost-effective charging and discharging strategy. It uses:

- Grid tariff data, including time-of-use (ToU) rates and demand charges
- EV departure time and target state of charge (SoC), ensuring the vehicle is ready when needed
- A configurable SoC bandwidth, defining how much energy can be charged above or discharged below the target SoC
- EV-specific parameters, such as battery size, usage history, odometer readings, and OEM-provided data on battery health, warranty limits, and performance characteristics
- Solar generation data, including real-time production and forward-looking forecasts
- Home energy consumption and load forecasts, to anticipate overlapping demands
- User preferences, such as prioritizing EV charging over home battery discharge or reserving energy for backup during outages
- Utility-specific profiles, including NEM 3.0 export rules, demand response programs, and grid services participation requirements

By aggregating and processing this multidimensional dataset, the AI Optimization profile dynamically schedules charging and discharging events to maximize cost savings, extend battery life, and ensure energy availability for both mobility and home resilience.

It continuously adapts to changing conditions—such as cloudy days, shifting energy prices, or an earlier-than-expected EV departure time—delivering intelligent, autonomous energy management that aligns with homeowner goals and grid conditions.

The following figure shows an example of a home equipped with the Enphase Energy System, where AI Optimization is applied to manage EV charging. The unidirectional EVSE case (left) represents the original system behavior, in which the EV can only draw power from the grid or solar to charge. The bidirectional EVSE case (right) is a simulated enhancement, where bidirectionality has been added to the EV charging profile to demonstrate the potential for both economic and energy performance improvements.

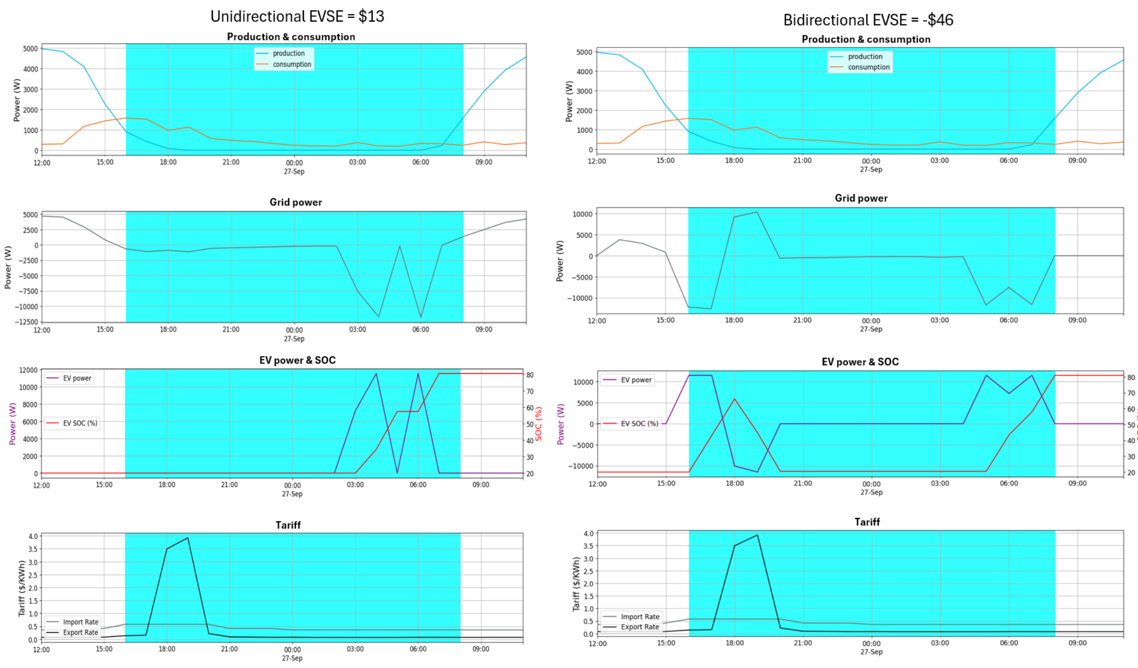

Figure 6: AI optimization for a home equipped with the Enphase Energy System

The preceding figure compares both scenarios over a 24-hour period across four key dimensions:

- Solar production and home consumption
- Grid import and export
- EV power and state of charge (SoC)
- Applicable import/export tariff structure

The portion highlighted in blue indicates the period when the EV is plugged in and can actively charge or discharge based on input from the algorithm.

During this 24-hour period, the home produced 61.1 kWh of solar energy and consumed 26 kWh in home loads. The EV was unplugged around 8:00 AM and plugged back in at approximately 4:00 PM, reflecting typical daily usage. It returned with an SoC of 20% and was configured to charge up to 80%. The EV battery capacity is 65 kWh.

In the unidirectional charging scenario, the EV followed an intelligent charging pattern—avoiding peak tariff periods, charging during low-tariff windows until reaching the target SoC, and remaining idle thereafter. As a result, the total daily energy cost was $13.

When we simulated the same dataset for bidirectional charging, the EV was charged ahead of the peak export window and then discharged back to the grid during hours when electricity is most valuable. The algorithm considers multiple real-time and forecasted data inputs, including EV departure time, target state of charge (SoC), SoC bandwidth, solar production and forecasts, home energy usage, EV-specific battery and warranty parameters, and utility tariff structures (e.g., NEM 3.0). Despite discharging to the grid, the system ensures the EV still meets the user-defined SoC at the required time.

This simulation resulted in a net credit of –$46, turning the EV into a revenue-generating grid resource. It demonstrates the substantial value unlocked when bidirectional charging is paired with intelligent energy management—lowering costs and enabling a more active role in supporting grid operations.

5.2.2 Green Charging

In systems equipped with solar and battery storage, the IQ Bidirectional EV Charger can be configured to operate in Green Charging mode—an energy strategy focused on maximizing self-consumption and sustainability. When solar generation exceeds the home's immediate needs, the surplus energy is directed to charge the EV. If household demand temporarily exceeds solar availability, the system draws power from the EV battery to support home loads, reducing reliance on the grid.

In the following figure, the home is generating 4.2 kW of solar power and consuming 1.8 kW for household loads. The remaining 2.4 kW is directed to EV charging.

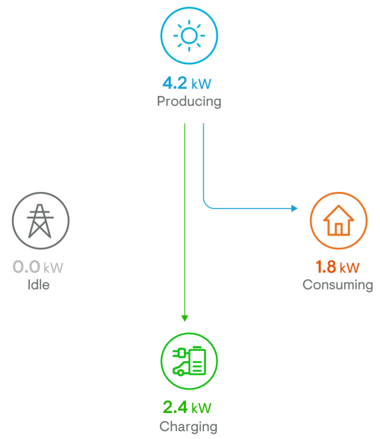

Figure 7: EV battery charging only from solar energy

Crucially, in this mode, no energy is exported to the grid—ensuring that every kilowatt-hour of clean solar energy is consumed within the home. This approach supports eco-conscious homeowners seeking to minimize their environmental footprint, as well as those in regions where grid export is restricted or not economically viable.

5.2.3 Phase-aware bidirectional charging

The IQ Bidirectional EV Charger, when paired with the IQ Meter Collar, enables advanced dynamic load balancing that intelligently adjusts EV charging and discharging power in real time—based on per phase home loads, grid interconnection limits, and main panel or busbar constraints.

For example, in a multiphase grid scenario—such as a 120/240 V split-phase home with a 100 A main breaker (80 A available)—the system intelligently routes power between underloaded phases. Let's say, if L1 is at 60 A and L2 at 40 A, traditional charging would be limited to 20 A (4.8 kW). With phase-aware control enabled by the IQ Meter Collar, the IQ Bidirectional EV Charger can draw an additional 20 A from L2 to neutral (2.4 kW), delivering a total of 7.2 kW—a 50% boost—while staying within the 80 A interconnection limit.

This functionality:

- Avoids costly main panel upgrades
- Maximizes charging under constrained conditions
- Maintains full compliance with NEC and interconnection rules

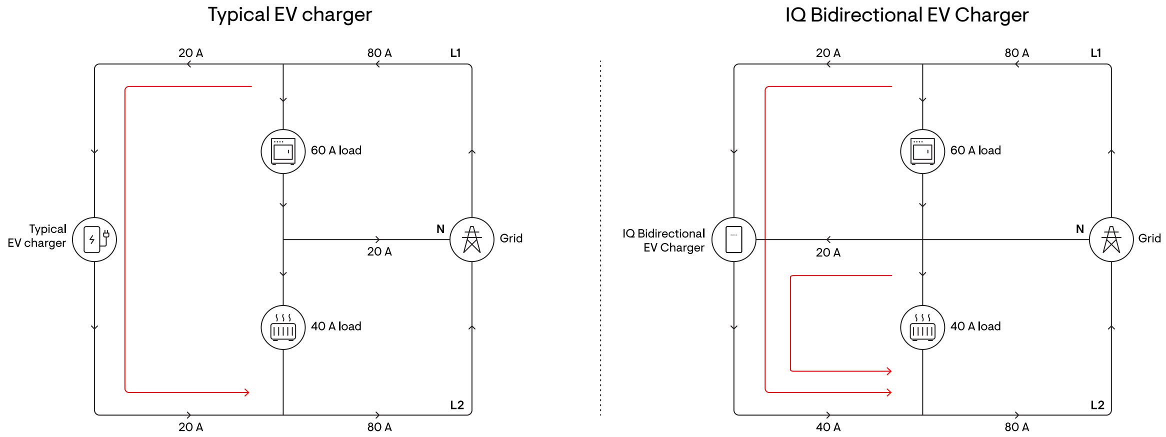

Figure 8: Typical EV charger vs IQ Bidirectional EV Charger

5.3 Modes of operation

The IQ Bidirectional EV Charger transforms an electric vehicle into a dynamic, distributed energy resource for the home, the grid, and the broader energy ecosystem. It supports core operational modes such as vehicle-to-home (V2H), vehicle-to-grid (V2G), and intelligent charging and discharging through energy management profiles—including AI Optimization and Green Charging. These modes are enabled through seamless coordination with the Enphase Energy System and open, standards-based vehicle communication.

The operational modes define how the IQ Bidirectional EV Charger interacts with the home and grid—enabling backup power, energy export, and intelligent charging based on real-time conditions and system priorities.

5.3.1 Vehicle-to-home charging (V2H)

In V2H mode, the charger supplies power from the EV battery to the home during a grid outage. This process is fully automated, leveraging the Enphase Energy System's integrated hardware and software to ensure seamless transitions and reliable microgrid formation.

5.3.1.1 Case 1: EV present and connected during a power outage

When an outage occurs and the EV is already connected:

- The IQ Meter Collar detects the outage and disconnects the home from the grid.
- The IQ Bidirectional EV Charger switches to discharging mode instantly.
- IQ Microinverters convert DC power from the EV into AC to form a microgrid and power the home.
- After the utility grid returns and stabilizes, the system automatically reconnects the home.

No manual switches or special backup panels are needed, and home appliances experience no power outage. This fast, intelligent backup provides peace of mind during emergencies.

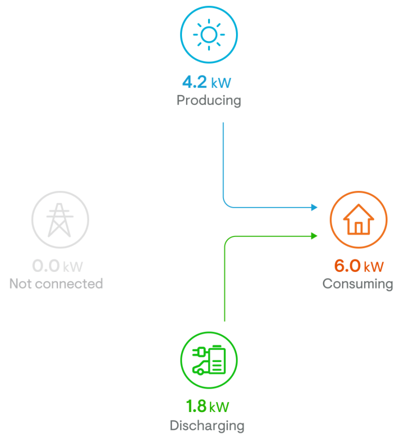

Figure 9: The Enphase App showing vehicle-to-home (V2H) during a grid outage

5.3.1.2 Case 2: EV not connected during a power outage

If the EV is not connected when the outage starts:

- The system still isolates the home to ensure safety, taking it off-grid.
- When the EV is plugged in, the charger initiates a Black Start using its internal Black Start battery to establish communication with the EV.
- The EV begins discharging, and the IQ Microinverters in the IQ Bidirectional EV Charger form a microgrid to power the home.
- Upon grid restoration, the home is automatically reconnected.

This ensures that even if the EV returns mid-outage, the system can restore power without any user intervention.

5.3.2 Vehicle-to-grid charging (V2G)

V2G mode allows the EV to export stored energy to the utility grid, enabling participation in programs like Virtual Power Plants (VPPs) and demand response. This extends the value of the EV beyond transportation, transforming it into a grid resource. When a utility request is initiated:

1. The Enphase Cloud receives a signal from the grid operator.
2. Participating homes in the affected area are identified.
3. The cloud dispatches a command to eligible Enphase Energy Systems.
4. The IQ Bidirectional EV Charger begins exporting energy from the EV to the grid, within limits defined by the homeowner.

Built on the proven IQ Battery platform, the charger inherits robust compliance with utility protocols, telemetry, and control logic. Users can configure export preferences and manage participation in grid services directly through the Enphase App.

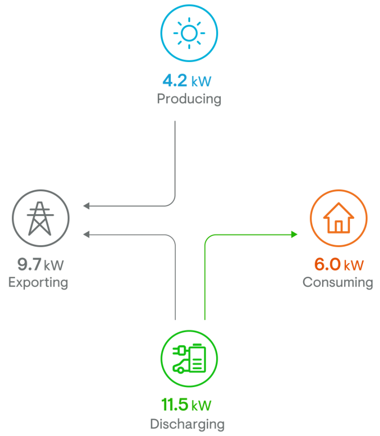

Figure 10: The Enphase App showing vehicle-to-grid (V2G) export

6. Standards-based design: Navigating complexity for compatibility, safety, and scalability

The IQ Bidirectional EV Charger is built on a robust, standards-based architecture, ensuring safe and seamless integration across four critical interfaces—grid, home, EV, and Cloud. Each interface is governed by distinct regulatory bodies, technical standards, and regional variations. Compliance with these standards is not just a technical necessity—it is a complex design challenge involving safety, interoperability, and regulatory approval across geographies.

6.1 The challenge of multi-domain compliance

At the core of this complexity is the fact that each domain—grid infrastructure, home electrical systems, electric vehicle interfaces, and cloud connectivity—has its own evolving set of standards. These standards often overlap, conflict, or require custom interpretations based on regional grid codes, utility policies, vehicle OEM implementations, and cybersecurity requirements. Enphase addresses this challenge by developing a modular, software-defined charging platform that supports all relevant interfaces while dynamically adapting to local codes and third-party requirements.

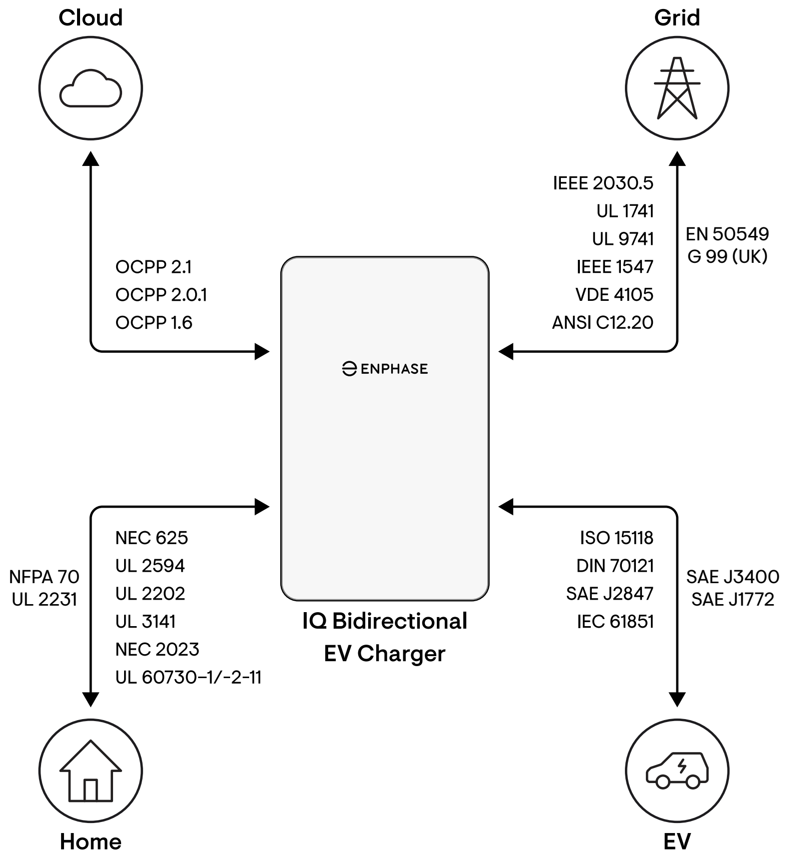

Figure 11: Some examples of multi-domain compliance standards

6.1.1 Home-to-charger integration: NEC and UL standards

Integrating a bidirectional charger with a home requires strict adherence to residential electrical safety and installation standards. The IQ Bidirectional EV Charger complies with the following regulations and standards:

- NEC 625: Governs electric vehicle power transfer systems in residential and commercial buildings, including cord lengths, overcurrent protection, and wiring methods.
- UL 2594: Safety standard for Electric Vehicle Supply Equipment (EVSE).
- UL 2202: Applies to power conversion equipment used in EV charging systems.
- UL 3141: Establishes safety and reliability requirements for electronic systems that actively manage and limit electrical current or power. Key features include overload prevention and safe integration of diverse Distributed Energy Resources (DER) such as solar, battery storage, and EV charging. This standard is essential for efficient energy management and can help avoid costly electrical infrastructure upgrades.
- Local AHJ Requirements: Authorities Having Jurisdiction (AHJs) may impose additional requirements related to breaker placement, load calculations, or energy monitoring.

Because homes vary widely in panel sizes, breaker capacities, and legacy wiring, installation flexibility is essential. The IQ Bidirectional EV Charger accommodates this by supporting Power Control Systems (PCS) for dynamic current limiting and enabling compatibility with meter collars to help avoid expensive panel upgrades.

6.1.2 Grid interface: Compliance across jurisdictions

Exporting power to the grid introduces a new layer of complexity, requiring compliance with diverse standards designed to prevent instability and unsafe backfeeding. These include:

- IEEE 1547-2018: Defines interconnection requirements between distributed energy resources (DERs) and the utility grid, indirectly influencing home integration.
- IEEE 2030.5: Communication protocols for DER integration with utility systems.
- UL 1741: Governs inverters and power control systems for grid-tied and standalone use.
- UL 1741 SA & SB: Supplements that add grid support features like voltage ride-through and frequency-watt curves.
- UL 9741: A dedicated safety and performance standard for bidirectional EV chargers, referencing UL 1741 and IEEE 1547 while defining hardware and software safety for power export.
- IEC 62116: Provides anti-islanding protection to ensure safe disconnection from grid during outages.
- Regional grid codes: Utility-specific or national regulations that define acceptable voltage, frequency, power factor, and phase characteristics.
    - California Rule 21
    - Hawaii Rule 14H
    - Germany's VDE-AR-N 4105
    - India's CEA Technical Standards

To manage this complexity, Enphase integrates grid code libraries directly into the charger firmware, allowing the system to automatically configure itself during commissioning based on locale and utility requirements. This approach ensures rapid deployment and proactive compliance.

6.1.3 EV interface: Bidirectional communication and control

Effective bidirectional charging requires standardized communication between the EV and charger for authentication, power negotiation, and control. Key standards include:

- ISO 15118-2: Defines unidirectional PLC-based communication (e.g., plug & charge).
- ISO 15118-20: Adds bidirectional power transfer (BPT), enabling V2H and V2G, and introduces SoC communication, departure time awareness, and grid coordination.
- DIN 70121: Legacy DC communication protocol still used by several OEMs.
- OEM-specific extensions: Many automakers add proprietary enhancements over ISO standards (e.g., custom certificate handling, encryption methods, SoC reporting).
- SAE J2847/1 & J2931/1: Define home energy management signaling and PLC profiles.

The IQ Bidirectional EV Charger supports TLS 1.3 encryption over ISO 15118-20, ensuring the highest level of data security during V2G and V2H transactions. It also accommodates custom implementations to enable rapid onboarding of OEM partners with non-standard interfaces.

6.1.4 Cloud connectivity: CSMS and OCPP integration

Intelligent energy flow management and remote diagnostics rely on integration with Charging Station Management Systems (CSMS). The IQ Bidirectional EV Charger supports:

- OCPP 1.6, 2.0.1, and 2.1: Open Charge Point Protocol versions for cloud connectivity. OCPP enables charger-to-platform communication for status reporting, firmware updates, session control, pricing, and fault diagnostics. OCPP 2.1 specifically adds communication and control parameters for bidirectional EV charging.

- Enphase proprietary protocols: Used to integrate with the Enphase App, enabling real-time user control and optimization across solar, storage, and EV components.
- Cybersecurity: Includes encrypted communication, secure key storage, and compliance with evolving regional cybersecurity mandates.
- API support: Enables integration with third-party energy services, VPPs, or utility-managed DR programs.

6.2 Regional complexity: The problem of divergent standards

Perhaps the most significant challenge in compliance to standards is geographic variation. A charger compliant in California may require firmware reconfiguration or even hardware modification to meet requirements in Texas, Germany, or India. Consider the following variations:

- Voltage and frequency differences: 120/240V, 60 Hz split-phase (North America) vs. 230 V, 50 Hz single- or three-phase (Europe, Asia)
- Grid stability requirements: Island grids (e.g., Hawaii) often impose tighter export limits and ride-through specifications.
- Utility interconnection rules: Some utilities require remote disconnect capability, demand response support, or utility-issued commissioning files.
- Cybersecurity mandates: Certain regions demand hardware security modules (HSMs), encrypted data logs, and utility-level access for bidirectional systems.

To navigate this diversity, the Enphase platform draws on its global experience in deploying microinverters, energy storage, and EV chargers across dozens of regulatory environments. Enphase offers a mature compliance framework and an actively maintained certification suite, ensuring readiness for new markets and standards.

Standards-based design is a foundational pillar of the IQ Bidirectional EV Charger—enabling scalability, safety, and cross-domain integration. By addressing the full spectrum of home, EV, grid, and cloud requirements through industry-certified hardware and adaptive software, Enphase ensures compliance with local codes and third-party requirements. This results in a solution that performs safely, reliably, and intelligently—across regions, vehicles, and energy scenarios—now and into the future.

7. Summary and key takeaways

The IQ Bidirectional EV Charger delivers unmatched value by combining the proven leadership of Enphase in energy technology with a robust, standards-based platform for bidirectional charging.

This white paper outlines how Enphase leverages its decades of expertise in distributed energy, power electronics, and intelligent energy management to bring a reliable, scalable, and future-proof bidirectional EV charging solution to market. Backed by the trusted microinverter technology and AI optimization engine from Enphase, the charger enables seamless vehicle-to-home (V2H), vehicle-to-grid (V2G), and advanced energy management capabilities.

- For automotive OEMs, Enphase reduces system complexity, accelerates time-to-market, and ensures seamless integration across the home, grid, and EV ecosystem.
- For homeowners, it offers energy independence, cost savings through tariff arbitrage, blackout resilience, and simple upgrade paths—turning EVs into mobile energy storage assets.

The standards-based architecture ensures broad compatibility with EVs, utilities, and home systems, while delivering a premium user experience through the Enphase App.

With a nationwide installation and support network, Enphase is not just building a product—it's enabling a smarter, more resilient energy future.

The charger's architecture is designed to:

- Comply with global grid codes
- Support seamless AI-optimized energy management
- Enable rapid installation using standard 240 V AC wiring—eliminating costly panel upgrades
- Deliver emergency backup and Black Start capabilities
- Provide monetizable grid participation through virtual power plants (VPPs)
- Scale easily with future-ready Enphase components like solar and battery storage
- Ensure interoperability with ISO 15118 and OCPP standards for seamless integration of EV and backend software
- Empower homeowners to schedule and control energy flows via a mobile app

This unified platform reduces engineering overhead for OEMs, simplifies energy decisions for users, and sets a new benchmark for reliability, control, and flexibility in EV charging.

8. Revision history

Revision	Date	Description
WHP-00031-3.0	August 2025	Editorial updates.
WHP-00031-2.0	August 2025	Updated the Enphase App images.
WHP-00031-1.0	July 2025	Initial release.

Previous releases.