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Distributed Charging Architecture: Redefining EV Infrastructure

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Executive Summary

The global shift to electric vehicles (EVs) is accelerating, driven by policy support, technological progress, and rising demand for low-emission transport. With the EV passenger vehicle fleet projected to grow at ~28% CAGR and requiring over 122 million charge points by 2030, the need for scalable, flexible charging infrastructure is critical. Yet, market volatility—stemming from fluctuating subsidies and rapid battery innovation—makes growth timing uncertain. In this context, EcoG introduces its second-generation Powerblock reference architecture featuring EcoG Connect, the first fully modular DC switching matrix for Distributed Charging Architectures. EcoG Connect enables intelligent power allocation, hardware efficiency, and long-term serviceability through standardized components. This architecture offers Charge Point Operators (CPOs) and manufacturers a highly adaptable solution that aligns infrastructure investment with demand, optimizes utilization, and ensures future-proof scalability—striking the crucial balance between site readiness, profitability, and the evolving pace of EV adoption.

Keywords: Charging business models, Smart Charging, Smart grid integration and grid management, Optimal charging locations, Fast and Megawatt Charging Infrastructure.

1 Key differences between stand-alone and modular architecture

While a monolithic stand-alone charger with integrated power electronics is the current technical standard, trends suggest a shift toward the modular power-unit/dispenser architecture in which the central power unit includes power electronics and a switching matrix connected to dispensers for greater scalability and flexibility (see Figure 1).

1.1 Stand-alone architecture

All components needed for DC charging and driver-EV interaction, e.g., power modules, active cooling, isolation monitors, charge controllers, and RFID readers, are merged into one monolithic housing of a stand-alone charger. Depending on the power level, the number and rating of integrated power modules and the dimensioning of electrical components differ.

1.2 Modular architecture

Power modules and their thermal management are externalized into a separate power unit that processes AC power supply into DC and provides a central DC power source to dispensers. For efficient operations, power modules are actively cooled. Both air and liquid cooling concepts are used. The power unit is designed modularly, typically ranging from 200 kW up to 2 MW. It can draw from both low- and medium-voltage AC networks. A so called switching matrix consisting of DC breakers inside the power unit dynamically allocates power from the power modules mounted in the power unit to multiple dispensers via DC cables based on demand. As the dispensers are the sub-systems facing EV and driver, they include all components of a stand-alone charger that are not yet included in the power unit. Depending on power rating, components in the dispensers are dimensioned differently. Due to the absence of power modules, dispensers can be more compact than stand-alone chargers. They exist in different shapes that are often specialized to specific applications. With higher charging speeds, charging cables need cooling, e.g., by being connected to the power unit cooling system.

2 Three archetypical use cases to compare stand-alone and modular architecture

To examine the ideal technical setup for CPOs based on required station design and expected growth, we will focus on three archetypical use cases that are most relevant for our comparative analysis.

2.1 Semi-public or destination charging at retailers or supermarkets

CPs located at shopping centers or supermarkets enhance customer convenience by enabling charging while shopping. These retail environments typically feature 50-100 kW chargers, which support 30-60 min charging sessions to align with the average consumer’s shopping time. For these charging locations, we shall use a typical configuration of 4 CPs, each delivering 50 kW, as an example. We anticipate the site size to increase to 20 CPs of 50 kW by 2030.

2.2 Public charging at highways or en-route

Charging sites along major driving corridors provided by traditional fuel stations, CPOs, and some EV manufacturers are crucial for long-distance EV travelers. Highway sites are equipped with powerful 200 to 400 kW HPC stations delivering a quick charge in under 30 minutes to minimize travel duration. Charging hubs along the highway are typically equipped with 8 HPCs of 200 kW at present, which we will use as an example for our comparison. We further project that the size of enroute locations will increase to 24 HPCs by 2030.

2.3 Depot charging of commercial bus or delivery fleets

Commercial operators with substantial EV fleets, such as buses and delivery vans, rely on depot charging stations for streamlined charging management. These facilities are equipped with a wide range of chargers, from 22 kW units for overnight charging to potent 1 MW systems that facilitate quick turnarounds during operational hours. In the case of commercial fleets, we assume a typical depot charging site to combine a total of 10 CPs of different power levels from 50 kW to 200 kW. By 2030, the typical location size is projected to expand to 50 CPs of the same power levels.

3 Functionality advantage for modular architecture in majority of assessed criteria

The comparison of stand-alone vs. modular architecture based on functional criteria and investment cost enables the identification of a tipping point. Focus use cases are mapped on specific site configurations to support CPOs in finding the optimum setup per location.

3.1 Scalability

Stand-alone hardware typically offers up to two or four outlets, which ensures efficiency and low complexity but does not allow for flexible scaling. Increasing the number of CPs or the maximum power per CP of a site usually requires additional hardware. This means additional investment cost and space requirements. In contrast, the power-unit/dispenser layout is particularly convenient when it comes to scaling a site over time. Adding dispensers to electrify more parking lots or increasing the power of existing dispensers is less costly, which makes upgrades and staged investments easier. For CPOs, scalable architecture is crucial to collect real-life experience with a specific site — starting small and scaling with growing EV numbers. This is most relevant for en-route charging but is also highly important for depot charging. For retailers, importance is expected to rise significantly by 2030 as it is the use case with the highest expected growth rate.

3.2 Warranty

When it comes to supplier agreements, CPOs seek contracts that clearly define responsibilities for uptime and timely repair in case of error. Warranty processing is currently, as this is a new trend, still more complex for modular architecture than for the already established stand-alone architecture. Also, warranty tends to be more relevant for en-route and depot charging due to the higher frequency of charging processes compared to retailers.

3.3 Outage Rate

The power unit as the central source of DC supply might also be the source of risk regarding uptime. However, a power unit can be equipped with technical redundancies leading to higher uptimes than with standalone chargers since component defects, e.g., malfunctioning power modules or damaged charging cables, can be covered. Maximum system availability is key for any charging site but crucial for en-route and depot charging to ensure mobility at any time. For retailers, we expect demand for high uptimes to increase by 2030.

3.4 Solution Adaptability

Dispensers are easier to develop than complete stand-alone charging systems due to the separation of power electronics, thermal management, and switching matrix from the EV and driver-facing functions. Hence, customized solutions can be rolled out more quickly and with less effort. This allows brand-specific individual solutions of retailers and adaptations to local requirements of depot sites for charger designs to fit the space and context of the specific site. Highway sites usually require less individual adoption as many of the sites have fewer existing structural constraints.

3.5 Ease of installation

The installation of a stand-alone charger requires a solid foundation and AC cabling from the transformer, as well as transportation, handling, and mounting of the heavy hardware. For modular architecture, a foundation for the power unit is needed, along with the connection of the power unit to the AC supply. Dispensers can be built on a lighter foundation due to their lower footprint and weight. With an increasing number of electrified parking lots, easier installation leads to additional benefits. Ease of installation is most relevant for en-route charging and depot charging where high numbers of chargers are required.

3.6 Charging speed flexibility

Stand-alone chargers usually provide power to an average of two outlets. If both are in use, power and power modules are shared between two EVs, resulting in a speed cap. Moreover, fully charged or non-charging EVs that are not removed from the parking lot or are damaged can lead to outlet blockage. In such cases, stand-alone chargers are limited as power electronics cannot be utilized to the full extent. The power-unit/dispenser layout allows for a dynamic shift of power electronics to another unblocked outlet. For instance, when an EV is already slowing down its charging curve after reaching a state of charge (SoC) >80% or when there are free outlets, power can be redirected to dispensers in use. Thereby, charging speed allocation can be optimized across a modular site. Flexible charging speed is particularly crucial for sites with high power required in a short period of time, e.g., along the highway or at depot sites.

3.7 Time-to-market

In a market phase of high innovation speed and maturing regulatory frameworks, fast development of new products is required to serve demand and keep up with competition. The past has proven that stand-alone charger development projects typically require up to 2 years. The main reason for this is the high complexity of a very integrated system with numerous requirements, e.g., EMC, safety, regulations, payment, and connectivity. The separation of functions into power unit and dispensers positively affects development speed. While the power unit becomes a very grid-connected subsystem with a mix of electrical, thermal, and mechanical requirements, the dispensers ensure the user interface for the driver and the connectivity to the car. This eases up time-to-market for both subsystems, which could potentially be developed by two different companies with component-specific competence profiles. Time-to-market is most relevant for depot charging but also for retailers as development needs are expected for these use cases.

3.8 Site integration

Space constraints can create hurdles to electrify parking lots as ground is costly. For charging infrastructure, this should minimize footprint and integrate into the site space availability in the best possible manner. Dispensers consume significantly less space than stand-alone chargers and can fit into an existing site more easily. Even ceiling-mounted dispensers are possible, highlighting the clear advantage of modular architecture. This is especially relevant for depot charging to ensure enough space for commercial vehicles. Also, retailers with space-efficient site architecture will benefit from more parking lots for customers.

3.9 Product variety

As of today, more stand-alone hardware products are available in the European market. Hence, the available product variety for stand-alone hardware is larger than for power-unit/dispenser systems. Over time, we expect to observe a growth in model and solution variety for modular architecture. For CPOs a broader option space will improve purchasing conditions, quality, supply chain stability, and delivery times. This is most relevant for retailers with a high tendency towards individualization.

In summary, modular architecture offers numerous functional advantages for the analyzed criteria, making it an attractive alternative to stand-alone chargers in all three evaluated use cases. This is highlighted by 45% to 65% higher functionality scores, depending on the use case. Moreover, the advantage of power-unit/dispenser systems against stand-alone chargers is expected to further increase in the future, yielding 60% to 70% higher functionality scores by 2030.

4 Investment cost advantage of modular architecture for large-scale charging sites (see Figure 2).

4.1 Investment cost for retailer / supermarket

Comparing the investment need for both architectures in the assumed setup of 4 CP with 50 kW each reveals a cost delta of 27% (€7k) per CP favoring stand-alone (€23k per CP) over modular (€30k per CP). As the tipping point can be identified at approximately 6 CPs, only above-average dimensioned sites would benefit from lower cost at present with modular compared to stand-alone architecture. Moreover, the modularity of components within the modular architecture causes fluctuations in the total cost per CP for increasing location dimensions. Particularly, the cost of the additional power unit required from 12 CPs drives up the expenses for modular architecture, introducing an additional intersection of both cost curves at around 13 CPs. However, this will not result in a significant cost advantage for stand-alone. Therefore, we would still consider the de facto tipping point at which modular architecture becomes more cost-efficient for retail charging sites to be 6 CPs.

By 2030, the average site size and the cost for both layouts will change: For a typical site with 20 CPs at 50 kW, the power-unit/dispenser layout is expected to be 38% more cost-efficient (€13k per CP) versus standalone (€22k per CP). At this stage, the tipping point is expected to be approximately 4 CPs.

4.2 Investment cost for retailer / supermarket

Based on our assumption of 8 CPs with 200 kW, the current cost delta amounts to 12% (€5k per CP) more for modular (€54k per CP) vs. stand-alone (€49k per CP). Both cost curves intersect multiple times due to additional required power units from 8 CP, 14 CP, and 20 CP, causing a cost per CP increase for the modular architecture. However, for 14 or more CPs, the cost delta in favor of stand-alone is negligible. Therefore, the effective tipping point from which modular is more cost-efficient than stand-alone for HPC hubs is currently at around 10 CPs.

In 2030, the cost delta for the assumed typical location size of 24 CPs with 200 kW is expected to change to 31% (€14k per CP) in favor of modular (€31k per CP) vs. standalone
(€45k per CP). The tipping point will be at 3 CPs by then.

4.3 Investment cost for commercial fleet, bus/delivery

In the case of commercial fleets, we assume a typical depot charging site to combine a total of 10 CPs of different power levels, e.g., 6x 50 kW, 2x 100 kW, and 2x 200 kW. Our analysis reveals a cost advantage of 8% (€2k) per CP for modular (€29k per CP) compared to stand-alone (€31k per CP) for the assumed site configuration. Due to the mixed setup of multiple CPs with different charging power, cost per CP fluctuates for both architectures, resulting in multiple cost curve intersections. Again, there is no relevant cost advantage for stand-alone for the intersection around 22 CP. As a result, the tipping point at present can be located at approximately 17 CPs.

Similarly, in 2030, when a total of 40 CPs with similar power level distribution is expected, the cost-benefit of modular (€20k per CP) vs. stand-alone (€29k per CP) is expected to rise to 30% (€9k per CP). The power-unit/dispenser layout will be more cost-efficient for any site size greater than the tipping point at 4 CPs as cost for modular architecture are expected to decrease much more than for stand-alone in the coming years.

5 A Modular and Scalable Switching Matrix Architecture for Distributed Electric Vehicle Charging: EcoG Powerblock Generation II

The modular architecture contains Powerblock and Dispensers. The powerblcok introduced by EcoG integrates standardized power and switching modules within a reference framework designed for manufacturers and integrators. The system accommodates up to 16 charging dispensers via a fully modular approach, enabled by EcoG Connect. (see Figure 3).

5.1 Switching Matrix and Modularity

The EcoG Connect system constitutes a tray-based switching module that allows dynamic allocation of up to two power converters across as many as four dispensers. These modules can be inserted into a rack system that functions as a configurable matrix, enabling tailored power distribution per site requirements.

Configurations include:
320 kW (4 dispensers): Base setup.
640 kW (8 dispensers): Single switching rack.

640 kW (16 dispensers): Dual switching racks.
1.28 MW (16 dispensers): Maximum configuration within a single powerblock.

Such modularity allows for power scalability through incremental addition of power modules and routing scalability through switching modules, providing a responsive, site-specific architecture.

5.2 Performance and Interoperability

By enabling intelligent, demand-based power allocation, EcoG Connect reduces the total number of power modules required, thereby decreasing capital expenditure and improving system efficiency. Load balancing across dispensers ensures optimal usage of available power without oversizing individual modules.

The architecture is built upon standard industrial components, ensuring broad global component availability, long-term part compatibility across vendors, and simplified serviceability via established maintenance networks.

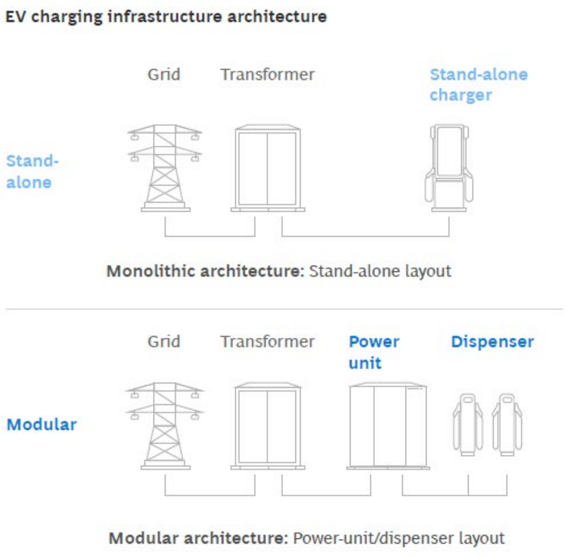
5.3 Manufacturer and CPO Integration

For equipment manufacturers, the reference design simplifies product development through ready-to-use architectural blueprints and validated component interoperability. For CPOs, the modular design facilitates site expansion and supports heterogeneous operational environments with minimal disruption, reducing total cost of ownership (TCO).

The second-generation EcoG Powerblock with EcoG Connect marks a significant advancement in modular charging system design. Its ability to flexibly allocate power, scale with demand, and adapt to site-specific needs establishes a new paradigm for Distributed Charging Architectures. Standardized components, extended serviceability, and streamlined deployment position this system as a reliable foundation for global EV infrastructure expansion.

6 Figures, Tables and Equations

6.1 Figures



Key component

	Stand-alone	Power unit	Dispenser
Power modules	✓	✓	
HV relays	✓	✓	✓
Charging cables	✓		✓
Housing	✓	✓	✓
Active cooling (optional)	✓	✓	✓
Fans and filters	✓	✓	
AC contactors	✓	✓	
Power meters	✓		✓
Isolation monitors	✓		✓
Charge controller/PLC[1]	✓	✓	
Network components	✓	✓	
Payment terminal	✓		✓
RFID reader	✓		✓
Display	✓		✓

Figure1: Similar components, different layout for stand-alone vs. modular architecture

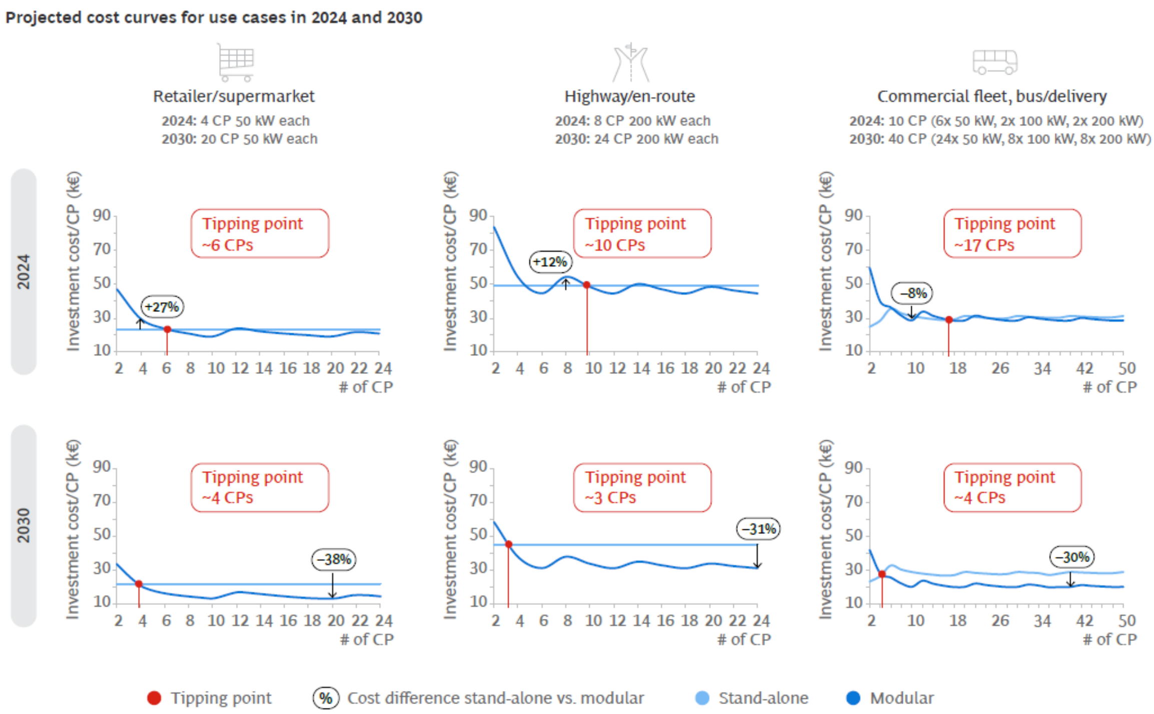


Figure2: Investment cost advantage of modular architecture for large-scale charging sites.

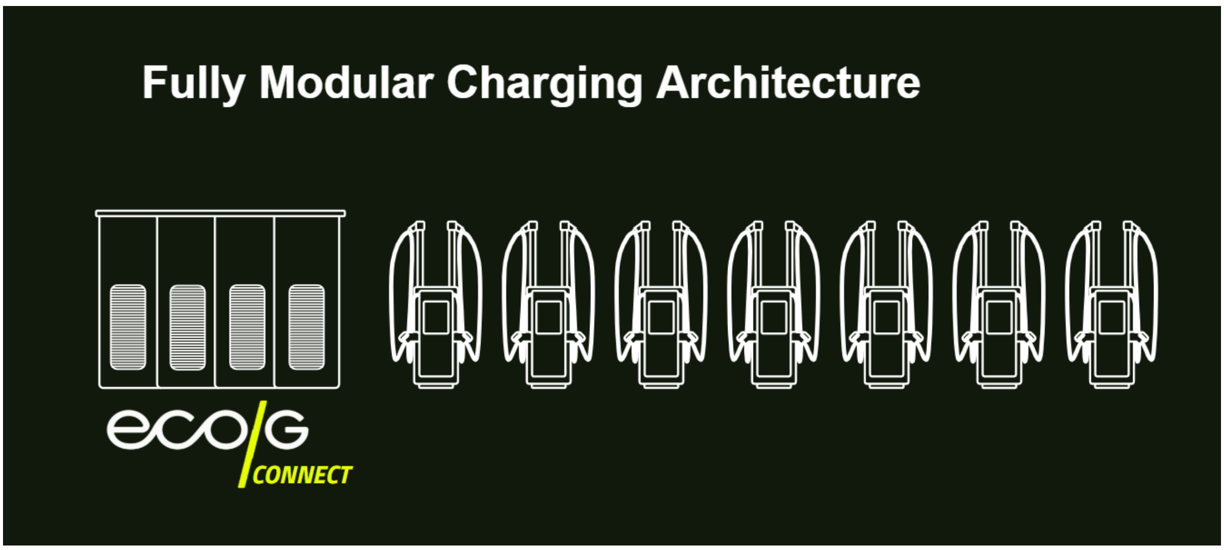


Figure3: Modular architecture powered by EcoG Connect enables flexible and cost-effective charging sites.

Presenter Biography

Dr. Jörg Heuer is co-founder and CEO of the Startup EcoG in Detroit/Munich – providing the EcoG IoT Operating System for EV DC Chargers.

Previously, as Head of embedded networks in Siemens, he drove innovation migrating digitalization and electrification. For instance, with his team he demonstrated how to use ISO15118 for DC high performance charging of vehicles, buses and trucks back in 2013.

In his professional life Joerg led R&D teams in the mobile phone industry, in smart grids prior to electric mobility and has been co-initiator of the startup Caterva.

Joerg received the Dipl.-Ing. degree in Electrical Engineering on digital signal processing and his PhD on visual image recognition, meta data processing and coding from the Friedrich-Alexander University of Erlangen, Germany.

About EcoG GmbH

Headquartered in Munich, Germany and Detroit, Michigan, US, the international tech company EcoG is working on the rapid and efficient expansion of reliable and smart DC charging stations for electric vehicles. Driving forward energy sustainability. With its product, the EcoG Universal Core, an agnostic IoT control platform for EV chargers, EcoG specializes in enabling large manufacturers to get their charging products to market faster and with lower risk. With its charging technology, EcoG is already the market leader in Europe with more than 15% market share in Europe. EcoG is expanding internationally, already with 11% market share in India and first large-scale customers in production in North America. Its clients include several Fortune 500 companies, such as Siemens, Dover Fueling Solutions, ABB and Valeo.