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Integration of DC Networks for Electric Vehicle Charging

By

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The electrification of urban mobility creates an infrastructure paradox: the areas of highest electric vehicle (EV) charging demand, such as dense city centres, are those where the distribution grid is least able to accept the additional load. Distribution System Operators are declaring structural congestion on their medium-voltage networks, and new dedicated MV/LV substations are often impractical for economic and legal reasons, including archaeological protection in historic centres.

This thesis presents the results of the Italian demo site of the INCIT-EV H2020 project (Grant Agreement No. 875683), where the pre-existing DC traction infrastructure of urban tramway networks was developed, as Use Case 4, into a native power source for EV charging hubs, up to Technology Readiness Level 7 at the Caio Mario substation of the Gruppo Torinese Trasporti (GTT) network in Turin. Every European city with a tramway network already has a relevant number of DC conversion substations connected to the medium-voltage AC grid, each able to deliver several hundred kW. Their loads are intermittent, set by tram acceleration and braking, with long low-consumption periods in between, especially at night, when most systems stop operating and the installed power is fully available.

A galvanically isolated, bidirectional DC/DC converter connected directly to the 600 V or 750 V omnibus bar removes the AC/DC rectification stage, the dominant cost and space component of a grid-tied fast charger, since the substation already performs it for the tramway; the charging converter need only adapt the voltage and provide galvanic isolation. This reduces capital expenditure by about 50% relative to conventional AC grid-tied alternatives, with a payback of 2.3 to 2.7 years in the conservative reference scenario and below one year in optimistic ones, for both the 150 kW and 350 kW tiers analysed.

The work covers measurement campaigns on load profiles, stress conditions and regenerative braking potential, and the design, procurement, installation and testing of a ten-point 3.6 kW low-power infrastructure and a 150 kW high-power hub. These are based on Silicon Carbide Dual Active Bridge converters, chosen for their wide input voltage range, inherent bidirectionality, galvanic isolation and power

density, developed with Politecnico di Torino and Prima Electro, and are connected to the existing infrastructure with protection coordination specified together with the distribution system operator Ireti.

A dedicated chapter addresses the regulatory and fiscal framework, which AC-centric rules (CEI 0-16, CEI 0-21, Directive 2014/32/EU, Legislative Decree 504/95) do not cover. It documents the consultation with ARERA and ADM, the Branch Point of Delivery concept that separates traction and commercial energy, and the metrological pathway to DC energy measurement through CEI EN 50470-4 and Directive (EU) 2026/706.

A further chapter assesses commercial viability with a ten-year discounted cash flow model and a 5% weighted average cost of capital. It gives positive net present values at 150 kW (as tested) and 350 kW (potential), while the 3.6 kW tier is unsuitable for standalone deployment. A census identifies about 400 tramway cities and about 4,130 conversion substations worldwide, and European cities are grouped by EV adoption stage and infrastructure maturity. The results indicate that the solution is not a niche demonstrator but a scalable, commercially viable paradigm able to accelerate high-power urban EV charging where grid-based approaches are failing.