GPC Energy Station:

Grid-Independent EV Charging via Temporal Power Multiplexing and Multi-Source GPC Coordination

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Abstract

Fast-charging infrastructure has a scaling problem that has nothing to do with battery technology. A single high-power charging site in a constrained urban location can require a grid connection upgrade that costs more than the chargers themselves, takes longer to permit than to build, and must be repeated from scratch at every new site. The root cause is simple: existing architectures draw from the grid in proportion to the number of simultaneous charging events. The more vehicles charge at once, the more the grid must provide. No amount of smart scheduling eliminates this proportionality; it only shifts when the demand spike occurs.

This paper describes a charging station architecture that breaks the proportionality. The GPC Energy Station uses temporal power multiplexing — coordinated by a multi-channel Generated Current Pattern (GPC) Distributor — to deliver up to 3,200 kVA of aggregate charging throughput from a fixed 400 kVA grid connection. The station replaces the underground fuel tank footprint of a conventional filling station with six Battery Energy Storage Systems (BESS) and supports eight next-generation dispenser units (Epumps), each rated at 400 kVA. At no point does the station draw more than 400 kVA from the grid, regardless of how many vehicles are charging simultaneously.

The multiplexing mechanism is a round-robin temporal sequencing protocol: each of the four 100 kVA Power Sources within an Epump is activated in strict succession. The vehicle's battery integrates the pulse sequence and perceives a continuous 400 kVA charge. The grid sees only 100 kVA at any instant. BESS units supply the non-grid source slots and recharge overnight on the same 400 kVA connection in approximately 1.4 hours. Green energy sources can feed the BESS directly, without mandatory grid interconnection.

The GPC Distributor does more than manage power timing. Because it implements the full GPC pattern framework — with an extensible pattern library including Sinusoidal, SuperPulse, Gaussian, ChemPat, and others — it delivers electrochemically optimized charging profiles to compatible vehicles, extending the formation-grade charging capability described in Papers I [32] and II [33] to public infrastructure.

Keywords: Generated Current Pattern (GPC), temporal power multiplexing, EV charging infrastructure, BESS, round-robin sequencing, grid-independent charging, GPC Energy Station, peak shaving, ChemPat

1. Introduction

1.1 The Infrastructure Bottleneck

The conventional model for deploying high-power EV charging is straightforward: connect chargers to the grid, size the connection for the maximum expected simultaneous load, and pay whatever the utility charges for peak demand. At small scale, this works. At the scale needed to match petroleum refueling infrastructure — thousands of sites, hundreds of dispensers per corridor, simultaneous service to dozens of vehicles — it becomes a barrier.

Powell et al. modeled deep electrification scenarios for the western United States and found that unmanaged fast charging could increase peak net electricity demand by 25 percent under forecast adoption scenarios, rising to 50 percent under full electrification stress tests [2]. Muratori showed that even moderate EV penetration can sharply reshape residential load profiles and force distribution transformer upgrades [3]. These are not edge cases. They describe what happens when a transportation fuel that was previously stored underground as hydrocarbons is replaced by electricity drawn live from the grid.

BESS co-location has emerged as a partial answer. A storage buffer can absorb peak demand spikes and defer grid upgrades [4, 5, 6, 7]. But existing BESS-buffered architectures retain the fundamental design assumption: worst-case concurrent demand defines the required grid capacity, and storage only smooths the excursions. The grid connection still scales with the number of chargers. The proportionality is moderated, not broken.

The GPC Energy Station breaks it.

1.2 DC, AC, and GPC: A Brief Framing

Direct current was the first medium of electrical energy transfer. Alternating current replaced it for transmission and distribution, enabling the transformer and the global grid. These two forms carry energy — one at fixed amplitude, one in a sinusoidal envelope. The Generated Current Pattern (GPC) is a third form: an algorithmically defined I(t) pattern whose temporal structure encodes instructions to the target electrochemical system, not merely energy.

Papers I [32] and II [33] of this series documented GPC's application at the cell level — controlling SEI formation and managing degradation through pattern-based charging. This paper operates at a different scale. The GPC Distributor applies temporal coordination across multiple distributed power sources to solve an infrastructure problem. The physics are different; the paradigm [31] is the same. Current pattern structure — in this case, the precise timing of source activation — is the control variable.

1.3 Structure of This Paper

Section 2 describes the physical architecture of the GPC Energy Station. Section 3 develops the mathematics of temporal power multiplexing. Section 4 covers BESS-aware adaptive scheduling and the overnight recharge cycle. Section 5 compares the station's grid impact profile against conventional architectures. Section 6 describes the GPC charging capability at the station level. Section 7 presents the open validation framework and the GigaPulse Lab platform. Section 8 discusses infrastructure economics, renewable integration, and carbon implications. Section 9 concludes.

2. System Architecture

2.1 Three-Layer Physical Layout

The reference GPC Energy Station is designed to occupy the footprint of a conventional petroleum filling station. This is deliberate: the permitting, land-use classification, and civil infrastructure of existing fuel retail sites are already adapted to high-throughput vehicle servicing. Repurposing rather than rebuilding is faster, cheaper, and faces less regulatory resistance than greenfield construction.

The station is organized in three layers. Below grade, six BESS units occupy the volume previously used for underground fuel storage. Each BESS is independently manageable and reports state-of-charge, temperature, available discharge current, and fault status to the GPC Distributor in real time. At grade, eight Epump dispenser units serve vehicles at positions physically analogous to petroleum dispensers. The control layer — the GPC Distributor and its associated power electronics — is housed in a weatherproof equipment bay adjacent to the dispensing area.

The only connection to the external grid is a single 400 kVA service. This is the same capacity class already installed at most commercial sites with significant electrical loads. No special grid connection, no new substation negotiation, no feeder upgrade.

2.2 Epump Configuration

Each Epump contains four Power Sources (PS), each rated at 100 kVA. Three PS units draw from BESS units — one BESS per PS — and one PS draws from the grid connection. The 3:1 ratio serves two practical purposes. First, charging continues at reduced power even when BESS capacity is constrained, because the grid PS slot remains always available. Second, distributing the BESS discharge load across three separate storage units per Epump allows the GPC

Distributor to manage SOC balance across the six-unit array without any single unit becoming the bottleneck.

Maximum output per Epump is 4 x 100 kVA = 400 kVA. Across eight Epumps, the station's nominal aggregate output is 3,200 kVA. The mechanism by which 400 kVA of grid input supports 3,200 kVA of output — and why this does not violate energy conservation — is the subject of Section 3.

2.3 The GPC Distributor

The GPC Distributor is a 32-channel control system — one channel per Power Source across all eight Epumps. It performs four distinct functions simultaneously.

First, temporal sequencing: it activates PS units in the round-robin pattern described in Section 3, enforcing the power bound that keeps grid demand at 100 kVA regardless of how many Epumps are active. Second, SOC-aware scheduling: it continuously reads BESS telemetry and adjusts PS priority assignments so that discharge is balanced across the storage array and depleted units are gracefully excluded without interrupting charge sessions. Third, pattern generation: for vehicles that support GPC communication protocols, it delivers optimized I(t) charging patterns from the GigaPulse pattern library rather than static CC/CV profiles. Fourth, safety management: it monitors ground faults, overcurrent conditions, and communication losses, and handles fault isolation without propagating disruption across the station.

3. Temporal Power Multiplexing

3.1 The Core Principle

Energy and power are not the same thing. A grid connection rated at 400 kVA limits instantaneous power draw, not total energy throughput over time. If that 400 kVA is directed exclusively and continuously to a single task, it delivers 400 kWh per hour. If it is time-shared across four tasks in strict rotation — for example, each receiving it for one quarter of a user-defined sequencing period T — each task receives 100 kWh per hour of energy throughput, and the total throughput across all four tasks remains 400 kWh per hour. The instantaneous draw never exceeds 400 kVA. The sequencing period T is a configurable parameter; the operator selects it based on the connected load's time constant and operational requirements.

This is temporal power multiplexing. It is not a new concept in electronics — time-division multiplexing has been fundamental to digital communications since the 1960s. What is new is its application to high-power electrochemical charging, where the load's integrating behavior — the battery's capacitance — makes the vehicle agnostic to whether it is receiving power continuously or in rapid pulses, provided the pulse frequency is high relative to the battery's time constant.

3.2 Single-Epump Round-Robin Model

Consider one Epump with $N = 4$ Power Sources, each limited to $P\_max = 100$ kVA. Define a sequencing period T and phase offset $\Delta t = T/4$. Source i is active during interval $[i\Delta t, (i+1)\Delta t)$ within each period T:

$$P\_i(t) = P\_max \quad \text{if} \quad i\Delta t \leq (t \bmod T) < (i+1)\Delta t, \quad \text{else} \quad 0$$

At any instant t, exactly one source is active. The instantaneous grid or BESS draw is P_max = 100 kVA. Yet the charge delivered per full period T from all four sources is:

$$Q\_total = 4 \times P\_max \times (T/4) = P\_max \times T$$

The effective power perceived by the vehicle — energy delivered per unit time — is Q_total / T = P_max x 4 / 4... but wait. Each source contributes Q_i = P_max x (T/4) per period. Four sources together contribute 4 x P_max x (T/4) = P_max x T per period. Effective vehicle power = P_max x T / T = 4 x P_max = 400 kVA.

The vehicle's battery is not aware that it is receiving pulsed input. Its time constant $\tau = C \times r$, where C is the pack capacitance and r is internal resistance, is large relative to T. The battery integrates the pulse sequence. From its perspective, 400 kVA arrived continuously. From the grid's perspective, 100 kVA was drawn at any given moment. Both are correct.

3.3 Extension to Multiple Simultaneous Epumps

With M Epumps simultaneously requesting maximum power, the Distributor manages M x 4 Power Sources. It partitions the sequencing period T into 4M equal slots and assigns one PS to each slot. Provided T remains small relative to battery time constants — which holds for any T below approximately 100 ms for typical EV pack parameters — each vehicle still receives its full requested power.

The critical result: maximum instantaneous grid demand is bounded at P_max = 100 kVA regardless of M. As M increases, BESS capacity requirements scale proportionally, but the grid connection does not change. This is the decoupling that conventional architectures cannot achieve.

For the reference station with M = 8 Epumps: 32 PS slots per period T. Of these, 8 are grid-connected (one per Epump). With balanced round-robin scheduling, the grid PS slots activate in sequence: grid draw = 100 kVA x (1 slot active at any time) = 100 kVA continuous. The remaining 24 slots are served by BESS.

3.4 Why This Is Not a Free Lunch

Temporal multiplexing does not create energy. It borrows it from BESS and repays it overnight. The station's energy balance per day is straightforward: if X vehicles charge, each receiving an average of Y kWh, the BESS must collectively hold at least X x Y x (3/4) kWh at the start of the day (the three-quarters fraction that comes from BESS rather than the grid PS slot). The grid restores this overnight on the 400 kVA connection. The station is an energy buffer with a fixed daily replenishment rate, not a source of free power.

The constraint this places on station capacity is the daily throughput limit: total kWh dispensed cannot exceed total kWh stored plus total kWh supplied by the grid-connected PS slots during operating hours. Operators dimension BESS capacity to match their expected daily vehicle load, with a safety margin for demand variance.

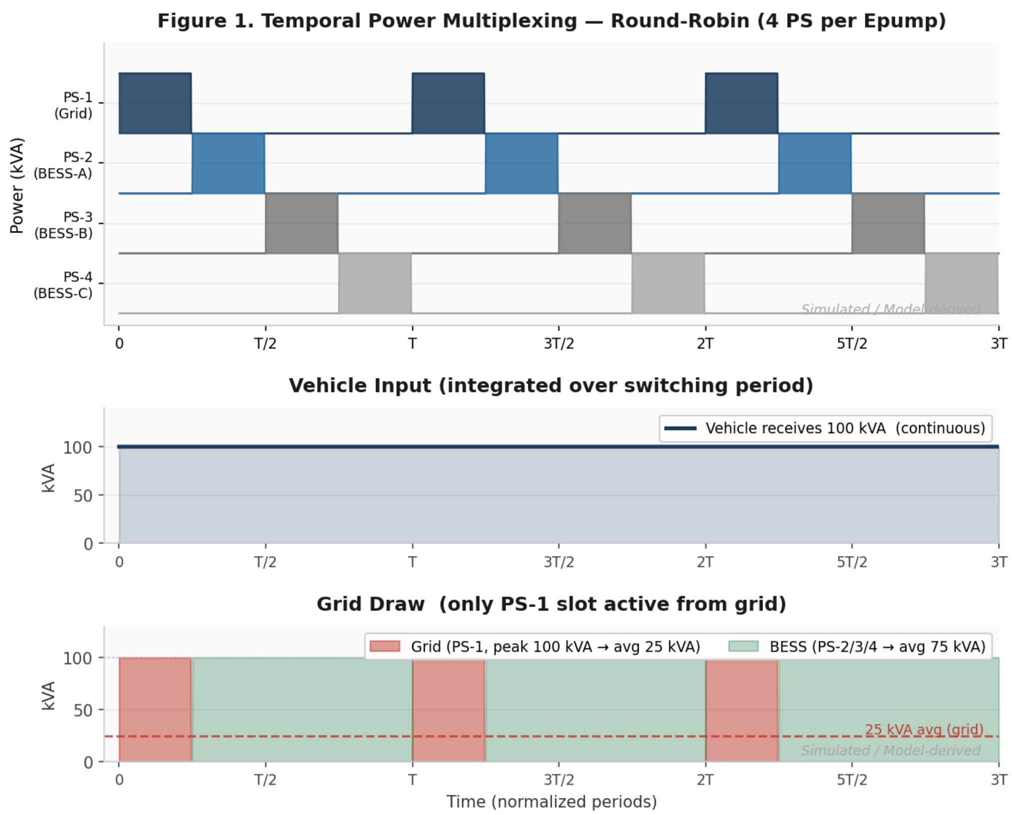

Figure 1. Round-robin temporal sequencing across four Power Sources in a single Epump. Each source activates for T/4 per period (top). The vehicle's battery integrates the sequence to 400 kVA effective throughput; instantaneous grid draw (PS-1 slot) never exceeds 100 kVA (bottom). Model-derived.

4. BESS-Aware Adaptive Scheduling

4.1 SOC Feedback and PS Priority

The clean multiplexing model of Section 3 assumes all PS units are available at full rated output. In practice, BESS units drain at different rates depending on which Epumps they serve and how many vehicles have charged since the last recharge cycle. The GPC Distributor tracks SOC continuously for all six BESS units and adjusts PS scheduling accordingly.

Each BESS unit j has an associated SOC $S_j(t)$ and a minimum threshold S_{min} below which it is excluded from active scheduling. The Distributor ranks available PS units by BESS SOC (highest first, to balance discharge), then by source type (BESS preferred over grid when SOC permits), then by Epump demand urgency. When S_j drops below S_{min}, the PS units fed by that BESS are temporarily reassigned to grid-connected slots. The affected Epump delivers reduced power but the charging session continues without interruption.

This graceful degradation behavior is the practical difference between a resilient station and a fragile one. A BESS-buffered system that halts charging when any storage unit is depleted is not deployable in high-utilization environments. The Distributor's continuous rebalancing ensures that partial BESS availability translates to partial power reduction, not session failure.

4.2 Overnight Recharge Cycle

Between approximately 23:00 and 06:00, when EV charging demand approaches zero, the full 400 kVA grid connection is available for BESS restoration. The required recharge time is:

$$T_{recharge} = E_{depleted} / (400\ \text{kVA} \times \eta_{RT})$$

where $E_{depleted}$ is the energy drawn from BESS during the operating day and η_{RT} is the round-trip efficiency of the BESS (typically 0.90–0.94 for LFP chemistry). For a reference station with 500 kWh total BESS capacity fully depleted and $\eta_{RT} = 0.92$, $T_{recharge} = 500 / (400 \times 0.92) \approx 1.36$ hours. The seven-hour overnight window is more than sufficient even under conservative BESS sizing assumptions.

The GPC Distributor schedules the recharge sequence to balance charge across all six BESS units simultaneously, rather than sequentially, avoiding the situation where early-arriving units reach full charge while late-starting units are still depleted at dawn.

4.3 Direct Renewable Integration

One consequence of the BESS-centric architecture is that the energy source for the storage units does not need to be the grid. Any DC or AC power source — a photovoltaic array, a small wind turbine, a co-located fuel cell — can charge the BESS directly. The GPC Distributor treats all energy in the BESS as equivalent regardless of origin.

This matters for deployment in locations where grid interconnection is slow, expensive, or physically impractical. A GPC Energy Station with a co-located solar array sized to the daily BESS charging requirement operates as a self-contained energy node. The grid connection serves as backup only. In periods of sufficient solar generation, the station runs entirely on local renewable energy. No interconnection agreement, no net metering contract, no export tariff negotiation.

For remote highway corridors, island communities, and off-grid logistics depots — locations where grid extension costs are prohibitive — this architecture enables EV charging infrastructure that would otherwise be economically inviable.

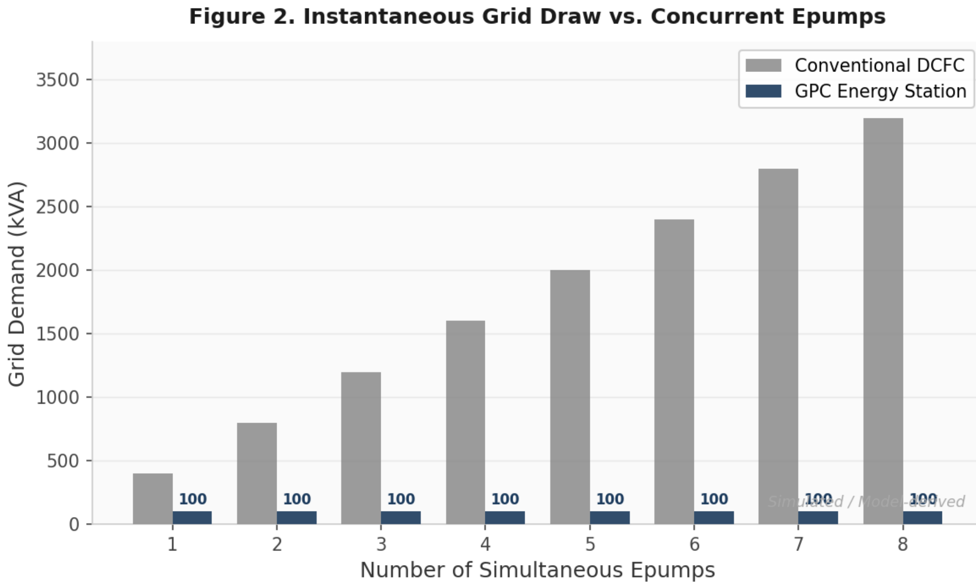

Figure 2. Instantaneous grid draw vs. number of simultaneously active Epumps. Conventional DCFC scales linearly with charger count. GPC Energy Station grid draw is bounded at 100 kVA regardless. Model-derived.

5. Grid Impact Analysis

5.1 Architectural Comparison

Parameter	Conv. DCFC (8×400 kVA)	BESS-Buffered DCFC	GPC Energy Station
Peak grid demand	3,200 kVA	~1,000–1,500 kVA	400 kVA (fixed)
Scales with charger count	Yes — linear	Yes — sub-linear	No — bounded
Grid upgrade per site	Required	Partial reduction	Not required
Direct renewable input	No	Partial	Yes (BESS direct)

GPC charging capability	No	No	Full pattern library
Overnight recharge window	N/A	Required	~1.4 h at 400 kVA
Off-peak grid draw	Unmanaged	Managed	Constant, predictable

Table 1. Grid impact comparison across EV charging architectures.

5.2 The Evening Peak Problem

Muratori identified a specific vulnerability of uncoordinated EV charging: the evening coincidence peak, where large numbers of vehicles connect upon return from daily commutes, stacking demand on a grid already serving residential consumption [3]. Powell et al. quantified the infrastructure cost implications at regional scale, estimating that EV-related grid upgrade costs in California utility territories alone could reach USD 6–20 billion by 2045 under high-adoption scenarios [2].

The GPC Energy Station eliminates the evening peak at the station level. It has no mechanism for demand spikes: its grid draw is capped at 400 kVA at all times, day or night. If all eight Epumps are active simultaneously at 17:30 on a weekday, the grid draw is identical to what it is at 03:00 on a Tuesday. The BESS absorbs the demand; the grid sees nothing.

At national scale, a network of GPC Energy Stations replaces thousands of individually unpredictable demand spikes with thousands of individually constant, predictable loads. Grid operators can plan for this. They cannot plan for the stochastic evening surge of conventional charging.

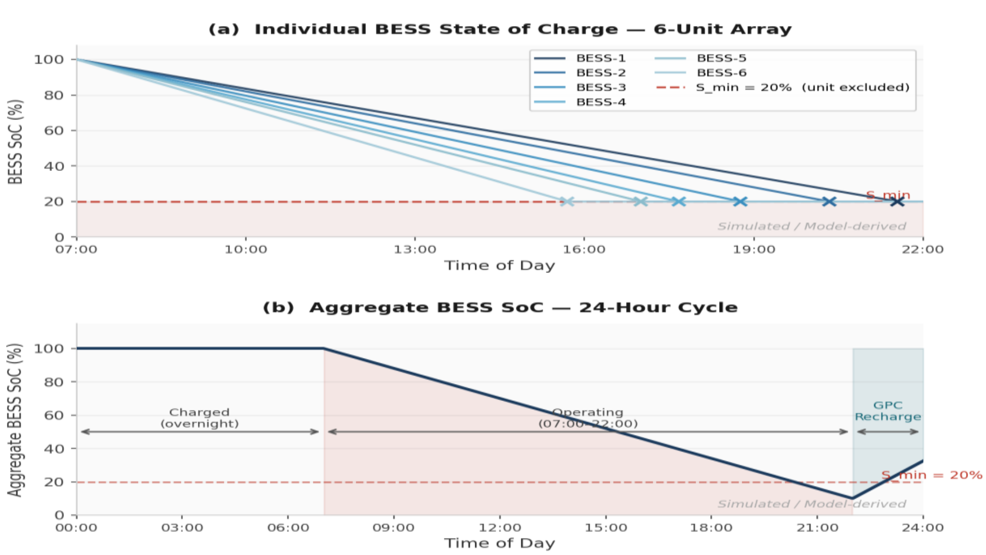

Figure 3. BESS State of Charge — Individual Units and Daily Cycle

Figure 3. Simulated BESS state of charge over a 24-hour operating cycle. Discharge during operating hours (07:00–22:00) is followed by full overnight restoration on the 400 kVA grid connection in approximately 1.4 hours. Model-derived.

6. GPC Charging Capability

6.1 Beyond CC/CV at the Station Level

Public EV charging has always delivered CC/CV. The charger fills the battery; the battery management system decides when to stop. The charger has no knowledge of the cell's electrochemical state, formation history, or degradation trajectory. It applies a ramp, then holds voltage. Every vehicle gets the same pattern.

This is adequate. It is not optimal. As Papers I [32] and II [33] of this series documented, the temporal structure of the charging current directly affects SEI layer growth, lithium plating probability, concentration polarization, and pack-level impedance divergence. A charger that can shape its output pattern is a charger that can protect the battery during every charge event, not just during laboratory formation.

The GPC Distributor implements the full GPC pattern framework at the station level. Its pattern library is architecturally unbounded — built-in types include Sinusoidal, SuperPulse, Tangential, Parabola, Bezier, Triangle, Trapezoid, Sigmoid, Gaussian, Damped Sine, Exponential, Custom LUT, and ChemPat. For a vehicle that communicates its battery chemistry and state via a compatible protocol, the Distributor selects and delivers an appropriate pattern from the library, adapting parameters in real time via closed-loop feedback at 1 ms response resolution. For vehicles without GPC-compatible communication, the Distributor defaults to CC/CV. Backward compatibility is preserved.

6.2 ChemPat at the Station Level

ChemPat, described in Paper I [32], synthesizes a formation pattern directly from a cell's electrochemical parameter set. At the station level, ChemPat operates from the vehicle's reported battery parameters rather than a laboratory calibration file. The fidelity of the result depends on the accuracy of the reported parameters, but even a coarse ChemPat approximation outperforms generic CC/CV by adapting the pattern to the cell's current state rather than applying a fixed profile.

As more vehicles adopt GPC-compatible communication — an evolution analogous to the progression from CHAdeMO to CCS to the current convergence on single-connector standards — the quality of in-field ChemPat charging will improve. The station hardware requires no modification; only the communication protocol and the vehicle's parameter reporting need to evolve.

6.3 Fleet-Level Implications

A public charging network built on GPC Energy Stations delivers formation-grade electrochemical care to every vehicle at every charge event. The per-cycle degradation reduction documented in Paper II [33] — approximately 20% lower effective stress under DPS pattern management — compounds across the life of the fleet. Fewer replacement batteries, lower recycling volumes, extended vehicle operational life. The station is not only an energy delivery infrastructure; it is a battery maintenance infrastructure.

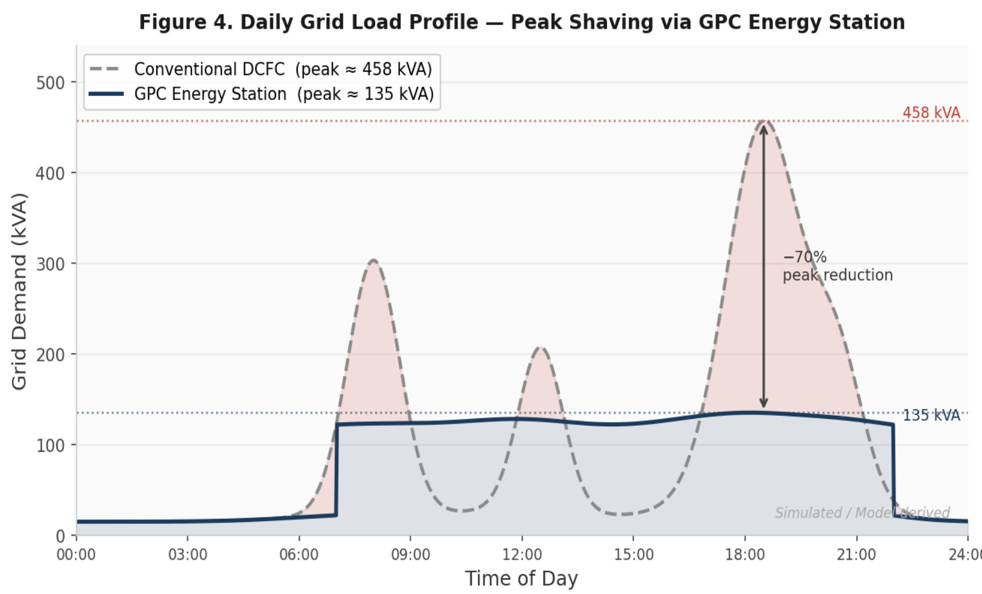

Figure 4. Cumulative energy delivered vs. operating hours for an 8-charger site. GPC Energy Station and conventional DCFC deliver comparable throughput over the operating day; the difference is that GPC achieves this from a 400 kVA grid connection vs. 3,200 kVA. Model-derived.

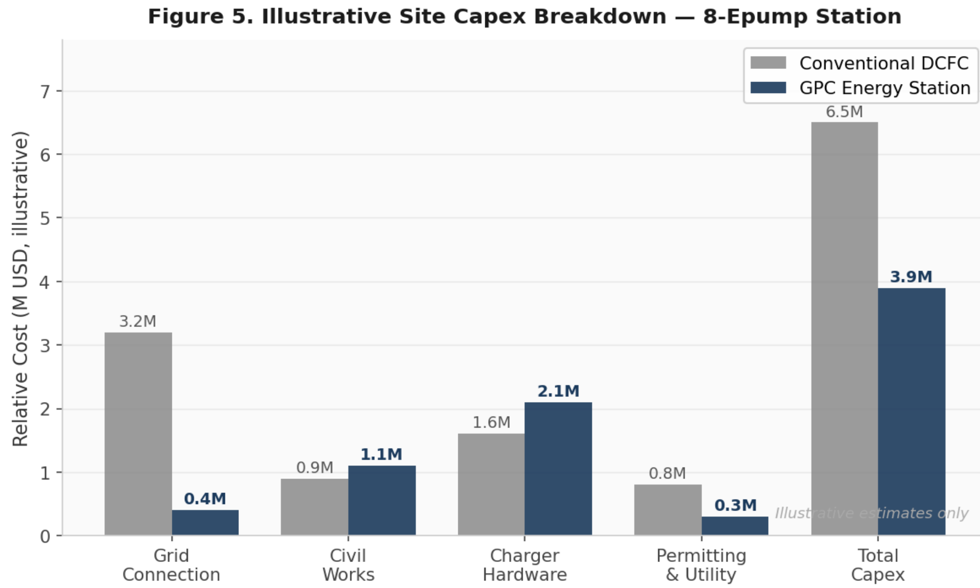

Figure 5. Illustrative site capital expenditure breakdown. GPC Energy Station eliminates the grid connection upgrade that dominates conventional DCFC site costs, shifting spend to BESS hardware that has a multi-decade asset life. Illustrative estimates only.

7. Open Validation Framework

7.1 GigaPulse Lab: Research vs. Deployment Versions

The GigaPulse Lab platform exists in two distinct categories. The 4-channel research version is the reference instrument for academic and independent validation of GPC temporal sequencing algorithms, pattern library performance, and multiplexing behavior. It is the platform through which researchers without access to deployment-scale hardware can reproduce and extend the work described in this paper.

The 8-channel through 40-channel versions are application platforms, designed for deployment in real charging infrastructure rather than laboratory validation. The 40-channel configuration is the maximum production solution, supporting the full 32-channel requirement of the reference eight-Epump station with additional capacity for redundancy and expansion testing. Channel-to-channel synchronization across all versions is maintained at sub-millisecond precision.

The distinction matters for reproducibility: a research group validating the round-robin sequencing protocol needs only a 4-channel GP Lab unit and a suitable battery load. The results scale analytically to the 32-channel deployment case; the physics of temporal multiplexing does not change with channel count. A developer building a production station needs the application-grade platform.

7.2 Validation Methodology

Independent validation of the temporal power multiplexing architecture requires three measurements: confirmation that per-channel instantaneous power remains bounded at P_max during round-robin sequencing; confirmation that the load (battery surrogate) receives the expected aggregate charge throughput per unit time; and confirmation that multi-channel contention — multiple simultaneous Epump demand requests — does not cause grid draw to exceed the bounded value.

Validation Test	Measurement	Pass Criterion
Single-Epump multiplexing	Per-channel instantaneous power during 4-source round-robin	Peak ≤ P_max ± 2%
Aggregate throughput	Energy delivered to load per unit time vs. expected 4×P_max	Deviation ≤ 2%
Multi-Epump contention	Aggregate grid draw during simultaneous N-Epump activation	Grid draw ≤ P_max at all times
BESS degradation mode	Charge delivery continuity when 2 of 6 BESS at low SOC	No session interruption
GPC pattern fidelity	RMS deviation from target I(t) pattern	< 2% RMS deviation
Overnight recharge	Time to full BESS restoration at 400 kVA	≤ available overnight window

The 4-channel GP Lab research unit is sufficient to validate the first three tests using a scaled-down single-Epump configuration (4 channels, one battery load). Multi-Epump contention can be validated on the same platform by sequencing all 4 channels as separate logical Epumps with one PS each. Full 32-channel validation requires the application-grade platform.

7.3 Scaling from Lab to Deployment

The temporal multiplexing result scales with channel count by construction. If round-robin sequencing bounds instantaneous draw at P_max for N = 4 sources, it bounds it at P_max for N = 32 sources — the sequencing period T simply subdivides into more slots. Researchers validating on a 4-channel platform are validating the algorithm, not just its 4-channel instance. The deployment-scale behavior follows from the same mathematics presented in Section 3.

8. Infrastructure Economics, Policy, and Carbon

8.1 The Grid Upgrade Cost

The economic case for the GPC Energy Station is, in one respect, very simple: it eliminates the cost that currently makes dense fast-charging deployment difficult. A developer installing eight 400 kVA conventional chargers at a highway service area faces a utility interconnection process that, depending on jurisdiction, involves a grid impact study, feeder reinforcement, possibly a new substation contribution, and a demand tariff structure that penalizes peak draw. The total infrastructure cost per site can exceed the charger hardware cost by a factor of two or three.

The GPC Energy Station requires a 400 kVA commercial service — the standard connection class already present at most commercial properties with significant electrical loads. No grid impact study for a multi-megawatt connection, no feeder negotiation, no substation contribution. The permitting, civil works, and utility interface are comparable to installing a large HVAC system.

This cost structure changes the deployment economics at every scale. For a single operator, each site requires less capital and less lead time. For a national charging network, the absence of per-site grid upgrade requirements removes a bottleneck that has no technological solution in the conventional model — grid reinforcement simply takes as long as it takes.

8.2 Renewable Integration Without Interconnection

The standard path for deploying renewable energy at a charging site requires grid interconnection: an interconnection agreement, a net metering or export tariff arrangement, and the technical integration of generation into the local distribution network. In markets with slow interconnection queues — which is most markets — this adds months or years to deployment timelines.

The GPC Energy Station's direct BESS coupling removes this requirement for on-site generation. A solar carport or small wind array can feed the BESS directly, with the station as the de facto off-taker. Generation and consumption occur at the same node; no power is exported to the grid, so no interconnection agreement is needed. In markets where interconnection is the binding constraint on renewable deployment, this architecture offers a practical bypass.

In the extreme case, a GPC Energy Station with sufficient renewable generation can operate entirely off-grid. The 400 kVA grid connection becomes a backup supply, drawing only when renewable generation is insufficient to restore BESS overnight. This operating mode is viable for remote sites, island communities, and locations where grid extension costs exceed the entire capital cost of the station.

8.3 Carbon Reduction Pathways

The station contributes to carbon reduction through four independent mechanisms that do not require each other and are additive in effect.

The first is coverage: by enabling EV charging in locations that cannot practically be served by conventional grid-connected infrastructure, the station electrifies journeys that would otherwise remain on hydrocarbon fuel. This is not a marginal improvement over existing infrastructure; in many rural and remote contexts, it is the difference between electrification being viable or not.

The second is generation quality: direct BESS coupling removes the regulatory barrier to co-located renewable deployment. A station that runs on local solar charges vehicles with measurably lower carbon intensity than one drawing from the average grid, particularly in markets where evening peak demand is served by dispatchable fossil generation.

The third is grid profile: a constant, predictable 400 kVA load is easier for grid operators to serve with baseload and renewable generation than a stochastic spike of several megawatts. The marginal generation dispatched to serve an evening demand peak is typically the highest-carbon generation on the grid. Eliminating the peak eliminates the marginal dispatch.

The fourth is battery lifetime: GPC charging reduces per-cycle electrochemical stress, extending battery service life and reducing the frequency of pack replacement. Every battery manufacturing event avoided represents approximately 60–70 kg CO_2 per kWh of capacity in embodied manufacturing emissions. At fleet scale, this is a material carbon reduction that occurs downstream of the station but is causally attributable to it.

9. Discussion

9.1 The TDMA Analogy and Its Limits

Time-division multiple access (TDMA) partitions a fixed-bandwidth channel among multiple users without increasing the channel's total capacity. Each user receives the channel for a fraction of each time slot; the channel appears fully occupied to each user during their slot. The GPC Energy Station applies the same principle to power: the grid connection is the channel, the Epumps are the users, and the BESS is the buffer that allows users to draw their allocation asynchronously from when the channel provides it.

The analogy is useful but has a limit. In TDMA, unused slots are simply empty — their bandwidth is lost if no user claims them. In temporal power multiplexing, unused slots are directed to BESS recharge rather than wasted. The energy accounting is therefore more favorable than the communications analogy suggests: an Epump with no vehicle connected does not waste its slot, it returns energy to storage. The station approaches 100% utilization of its grid connection across the full day, not just during operating hours.

9.2 The Dual Role of the GPC Distributor

A conventional smart charging controller optimizes one thing: grid load management. It shifts demand in time and coordinates charging schedules across vehicles. It does not affect how the current arrives at the cell. The GPC Distributor does both. It enforces the temporal sequencing that bounds grid demand, and it shapes the pattern delivered to the cell to protect battery health. These two functions are not in conflict — they operate on different time scales. The sequencing runs at the millisecond level; the pattern shaping runs at the same resolution but encodes electrochemical intent rather than just power timing.

This dual role means the station's intelligence benefits both the grid operator and the vehicle owner simultaneously. Grid demand is bounded; battery health is protected. The infrastructure and the asset reinforce each other through the same control system. This is not a property that can be achieved by adding a battery-health module to a conventional charging controller, because conventional controllers have no mechanism for pattern shaping. It requires the GPC framework.

9.3 Limitations and Open Questions

The multiplexing model in Section 3 assumes that T is small relative to the battery's integration time constant. For very small packs — two-wheelers, light cargo vehicles — this assumption may require verification. The time constant scales with pack size; a 5 kWh pack has a substantially shorter time constant than a 100 kWh truck pack. Sequencing period T must be selected with the smallest expected load in mind, or the Distributor must adapt T dynamically based on the connected vehicle's pack parameters.

The overnight recharge model assumes predictable daily demand patterns. High-variance operating environments — highway corridors with unpredictable traffic, emergency vehicle charging depots — may require larger BESS buffers or a more dynamic recharge strategy that begins partial recharge during low-demand daytime periods rather than waiting for the overnight window. The Distributor's scheduling algorithm can accommodate this, but the operating parameters must be configured for the specific deployment context.

10. Conclusion

The GPC Energy Station addresses a problem that is not primarily technical — it is structural. High-power EV charging has been built on an assumption that grid capacity must scale with charging capacity. This assumption is not a physical law; it is an artifact of architectures that draw from the grid in real time. Replace real-time grid draw with temporally sequenced BESS-buffered delivery, and the assumption breaks.

The round-robin temporal sequencing protocol developed in this paper bounds instantaneous grid demand at 100 kVA — one Power Source slot — regardless of how many vehicles are charging simultaneously. Eight Epumps, each delivering 400 kVA to a vehicle, draw collectively no more than the equivalent of a single conventional fast charger. The energy comes from BESS, which is restored overnight on the same 400 kVA connection in approximately 1.4 hours. The grid sees a constant, predictable load around the clock.

The GPC Distributor adds a second capability that temporal multiplexing alone does not provide: electrochemically optimized pattern delivery to compatible vehicles. The same controller that enforces the power bound also shapes the charging current to protect battery health, drawing on a pattern library that is architecturally unbounded. Conventional chargers cannot do this. The GPC Distributor does both at once.

Together with Paper I [32] (formation protocol) and Paper II [33] (fast charging and lifetime model), this work completes a three-paper treatment of the GPC paradigm [31] across the full battery lifecycle: from first activation in manufacturing, through in-field operation, to the public charging infrastructure that will serve the next generation of electric vehicles.

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