



IoT-Based Battery Charging and Swapping Stations for Electric Vehicles: A Review of Architectures, Reservation, Security, and Challenges

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ABSTRACT—

Battery swapping has re-emerged as a practical alternative to plug-in charging for electric vehicles (EVs), particularly for electric two-wheelers used in delivery, ride-hailing, and shared-mobility services, where vehicle downtime directly reduces earnings. As swapping networks grow, a station can no longer be a passive rack of chargers: it must continuously know which batteries are charged, reserved, or faulty, and it must release a battery only to the user entitled to it. This paper reviews battery charging and swapping stations from this Internet of Things (IoT) viewpoint. It (i) compares energy-replenishment models and the commercial and policy landscape; (ii) surveys studies of station operation, planning, and user acceptance; (iii) examines IoT sensing, communication, and cloud architectures for real-time battery status monitoring; (iv) analyzes reservation, authentication, and access-control mechanisms and their cybersecurity implications; and (v) discusses charging safety and evaluation metrics. A rule-based battery-state model and a low-cost prototype that combines an ESP32 controller, Li-Po battery bays, RFID/PIN authentication, servo-actuated gates, a Firebase database, and a ReactJS dashboard are presented as an illustrative reference implementation. The reviewed studies largely address operation, planning, or acceptance separately; the review identifies open challenges in integrated real-time monitoring, interoperability, battery-health estimation, security, and standardized evaluation.

Index Terms—battery swapping station, electric two-wheeler, Internet of Things, battery management, reservation, access control, Firebase

I. INTRODUCTION

The transition to electric mobility depends on how quickly energy can be put back into a vehicle. Plug-in charging ties a vehicle to a charger until it reaches an acceptable state of charge (SoC), a manageable inconvenience for private cars but a direct loss of earnings for delivery riders, ride-hailing drivers, and shared-mobility fleets. Battery swapping removes this wait by exchanging a depleted battery for a charged one while the depleted unit is recharged separately by the station [1]. At scale the approach is already proven: NIO reports an average swap time of about three minutes, completed its 100-millionth swap on 6 February 2026, and has deployed 3,790 swap stations worldwide [2].

Electric two-wheelers are a natural fit because their packs are small enough to be exchanged without heavy machinery. In India, an ICCT study carried out with NITI Aayog found that the total cost of ownership (TCO) per kilometer of two-wheelers is lowest in commercial operations with high daily utilization, such as e-commerce delivery and shared mobility [3]; in one ride-hailing case, the TCO of a swapping-enabled model was 15% lower than that of the same model with point charging [4]. NITI Aayog's draft battery swapping policy of April 2022 promotes swapping through battery-as-a-service models and sets out minimum technical and operational requirements for swapping ecosystems [5].

A swapping station, however, is only as useful as the information around it. A user who travels to a station and finds no charged battery gains nothing from swapping, and simulation studies based on real station data show that waiting time rises sharply once utilization passes a threshold [6]. Stations therefore need to know, at all times, which battery is charged, which is reserved, and which is faulty, and they must release a battery only to the user who is entitled to it. These are sensing, communication, and access-control problems, which is why the Internet of Things (IoT) is increasingly central to station design. Yet the swapping literature is largely framed around scheduling, siting, and inventory optimization [7], [8], while the embedded and cloud layers that make such optimization actionable receive far less attention.

This paper reviews battery charging and swapping stations from the IoT perspective, with emphasis on light electric vehicles. Its contributions are: (i) a structured synthesis of operation, planning, and user-acceptance studies; (ii) a layered IoT architecture and a rule-based battery-state model for real-time monitoring; (iii) an analysis of reservation, authentication, and access-control mechanisms and their security implications; (iv) a discussion of

charging safety and health monitoring; (v) a set of evaluation metrics; and (vi) an illustrative low-cost prototype together with a list of open research challenges.

The remainder of the paper is organized as follows. Section II defines the scope of the review. Section III compares energy replenishment models. Section IV surveys station operation, planning, and acceptance studies. Sections V–VII cover IoT architecture, reservation and access control, and battery safety. Section VIII presents the reference prototype, Section IX proposes evaluation metrics, Section X discusses open challenges, and Section XI concludes.

II. SCOPE AND REVIEW APPROACH

This is a narrative review. It considers journal articles, conference papers, preprints, and policy or industry reports on battery swapping and charging stations, with emphasis on (i) two-wheeler and light-vehicle swapping, (ii) IoT and cloud monitoring, (iii) reservation and access control, and (iv) battery safety. Searches combined keywords such as “battery swapping station,” “electric two-wheeler,” “IoT,” “reservation,” “access control,” “battery management system,” and “cybersecurity.” A work was retained if it described a model, system, dataset, or analysis relevant to these themes, and commercial figures were taken from primary company statements where possible. Because swapping research spans power systems, operations research, and embedded systems, studies are grouped by the decision they inform rather than by venue. The review is not a systematic (PRISMA-style) survey, and its coverage reflects sources available as of October 2026.

Fig. 1 summarizes the resulting taxonomy, which also structures the remainder of the paper.

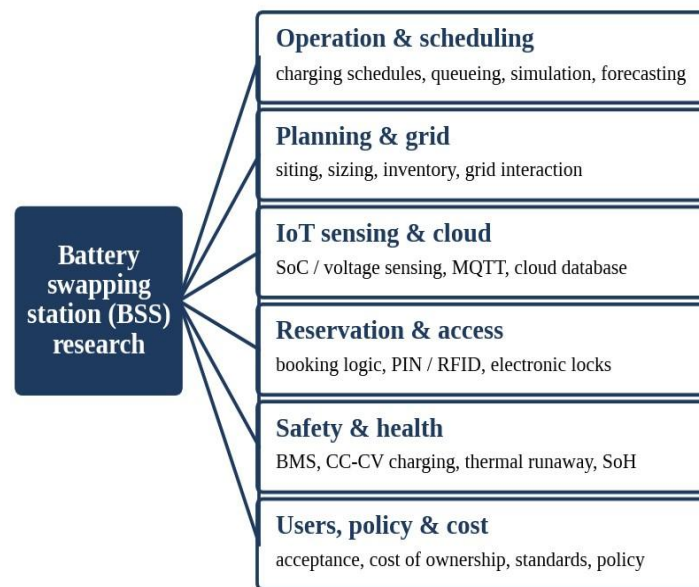


Fig. 1. Taxonomy of battery swapping station (BSS) research used in this review.

III. ENERGY REPLENISHMENT MODELS

A. Plug-In Charging

Plug-in charging requires the vehicle to remain connected to a charger until an acceptable SoC is reached. For commercial operators the main penalty is therefore the idle vehicle rather than the energy bill: the ICCT cost comparison identifies zero opportunity cost as a distinguishing advantage of swapping [4]. Plug-in charging also does not, by itself, maintain an inventory of charged batteries that the next user can collect.

B. Battery Swapping Modes

In a fixed swapping station, depleted batteries are exchanged manually or by automated mechanisms and are then charged on site. A survey of the literature distinguishes four operation modes: a single swapping station, multiple stations, an integrated swapping and charging station, and multiple swapping and charging stations [7]. A mobile alternative uses a battery swapping van that carries many charged batteries and drives to the vehicle, making swapping locations more flexible [9]. For two-wheelers, swappable models are sold without a pre-fitted battery, which lowers the upfront vehicle cost [3].

C. Commercial and Policy Landscape

Commercial networks show what is achievable. NIO's stations centrally manage and monitor batteries, and the company describes each swap as a battery health check [2]. Two-wheeler networks such as Gogoro in Taiwan and SUN Mobility in India follow a similar battery-as-a-service logic with smaller packs. Such systems depend on standardized batteries, purpose-built stations, and proprietary back-ends, which are difficult to replicate in campuses, small fleets, and research laboratories; lowcost IoT stations are a useful complement in those settings. Table I summarizes the differences between the two replenishment models.

TABLE I

PLUG-IN CHARGING VERSUS BATTERY SWAPPING

Aspect	Plug-in charging	Battery swapping
Replenishment time	Until acceptable SoC is reached	A few minutes [3]; about 3 min average for NIO cars [2]
Vehicle downtime	Vehicle idle while charging	Zero opportunity cost [4]
Upfront vehicle cost	Battery included in price	Lower when sold without battery [3]
Station needs	Chargers and parking bays	Chargers plus battery inventory, identification, and access control [7]
Main service risk	Charger occupancy	Battery shortage and queueing at high utilization [6]
Information needed	Charger status	Per-battery state, reservations, and health

IV. STATION OPERATION, PLANNING, AND ACCEPTANCE

Table II lists representative studies; the discussion below groups them by the decision they inform.

A. Charging Scheduling and Operation

Because batteries are charged independently of vehicles, the station becomes a controllable load. Mahoor et al. treated the station as an intermediary between EV users and the grid and proposed a charging-scheduling model from the owner's perspective [1]; the same group later addressed least-cost operation under random customer requests [10]. Sarker et al. studied optimal operation and service scheduling of a station [11], and Nayak and Misra proposed an operational scheduling framework that accounts for demand uncertainty [12]. For mobile swapping, Shao et al. set request priority from SoC and proposed a minimum-waiting-time strategy based on priority and satisfaction, evaluated by simulation [9].

B. Capacity, Queueing, and Simulation

Wu et al. built discrete-event simulation models from real data of eight swapping stations in Guangzhou; average waiting time grew with utilization and deteriorated markedly beyond a threshold, while larger stations benefited from economies of scale [6]. Marchesano et al. combined agent-based simulation, discrete-event simulation, and linear programming to represent charging speed, battery degradation, grid power limits, and customer behavior [13]. Earlier planning work addressed infrastructure for EVs with battery swapping [14], and Zheng et al. compared charging and swap stations in distribution systems and proposed optimal planning [15].

C. Network Planning, Forecasting, and Grid Interaction

At network level, Ai et al. proposed an integrated location–inventory–grid model and reported that centralized charging combined with frequency regulation lowers cost and strengthens grid stability [16]. Qi et al. showed that the case for a “swap locally, charge centrally” network rests mainly on faster charging at central hubs reducing the system-wide battery stock, rather than on pooling charging demand alone [17]. Because inventory must be planned against demand, arrival forecasting has attracted attention; Suri et al. compared hybrid neural-network models and preferred a genetic-algorithm-trained backpropagation network owing to its lower overfitting [18]. Zhan et al. review siting, sizing, scheduling, and cost–benefit analysis [19].

D. Reservation and Routing

Reservation couples demand to inventory. Adler and Mirchandani addressed online routing combined with battery reservations for EVs with swappable batteries [20]. Such network-level formulations assume that reservations are honored; ensuring this at the station requires binding each reservation to a physical battery and an authenticated user, as discussed in Section VI.

E. User Acceptance

Adoption depends on trust as well as technology. Huang studied user acceptance of a battery swap station for electric scooters in Taiwan [21]. Adu-Gyamfi et al. extended innovation diffusion theory with attitude, perceived risk, green self-identity, and task–technology fit, and recommended

swapping standardization, incentives, and better battery performance [22]. In German commercial transport, Noto and Mostofi collected 146 qualitative responses on electric trucks and swapping and found overwhelmingly positive answers to the classified questions but many open questions in individual statements [23]. Live battery availability and secure release are therefore design requirements rather than conveniences.

F. Existing Surveys

Wu classifies swapping stations by operation mode and surveys decision scenarios in five areas: charging schedule, service policy, construction and planning, dispatching and routing, and power management [7]. Cui et al. review operation-optimization approaches, objectives, constraints, and mathematical-programming methods [8]. Ahmad et al. discuss the opportunities and challenges of swapping stations [24], and Raj et al. review the integration of charging and swapping using metaheuristics [25]. These surveys center on optimization and planning; the sensing, communication, and access-control layer treated here is not their main subject.

TABLE II

REPRESENTATIVE STUDIES ON BATTERY SWAPPING STATIONS

Ref.	Focus	Method	Main contribution
[1]	Station scheduling	Optimization model	Charging schedule from the owner's perspective
[9]	Mobile swapping	Queueing model, MWT-PS scheduling, simulation	SoC-based request priority; waitingtime-minimizing strategy
[6]	Capacity, economics	Discrete-event simulation, data from 8 stations	Waiting time deteriorates beyond a utilization threshold
[13]	Station performance	Agent-based, discrete-event, and linear programming	Captures charging speed, degradation, and grid limits
[18]	Arrival forecasting	Hybrid neural networks	GA-trained back-propagation network preferred
[17]	Network design	Location and repairable-inventory model	Faster central charging lowers battery stock
[16]	Network and Continuous approximation		Central charging with frequency regulation cuts cost
[20]	Reservation Online routing formulation		Battery reservations for swappablebattery EVs
[21]	User acceptance- Empirical study, Taiceptance wan		Acceptance of an e-scooter swap station
[22]	Willingness	Extended diffusion to use theory, survey	Attitude, risk, and task–technology fit studied
[7]	Survey Literature review		Four operation modes; five decision areas

V. IOT ARCHITECTURE FOR SMART SWAPPING STATIONS

A smart swapping station can be organized into four layers (Fig. 2): the battery and charging layer; the sensing and control layer; the network and cloud layer; and the application layer. The reference design in Fig. 2 centers on an ESP32 controller that receives inputs from a fuel gauge, an RFID scanner, and a keypad, and drives an LCD, a buzzer, a servo motor, and the bay-unlock gate.

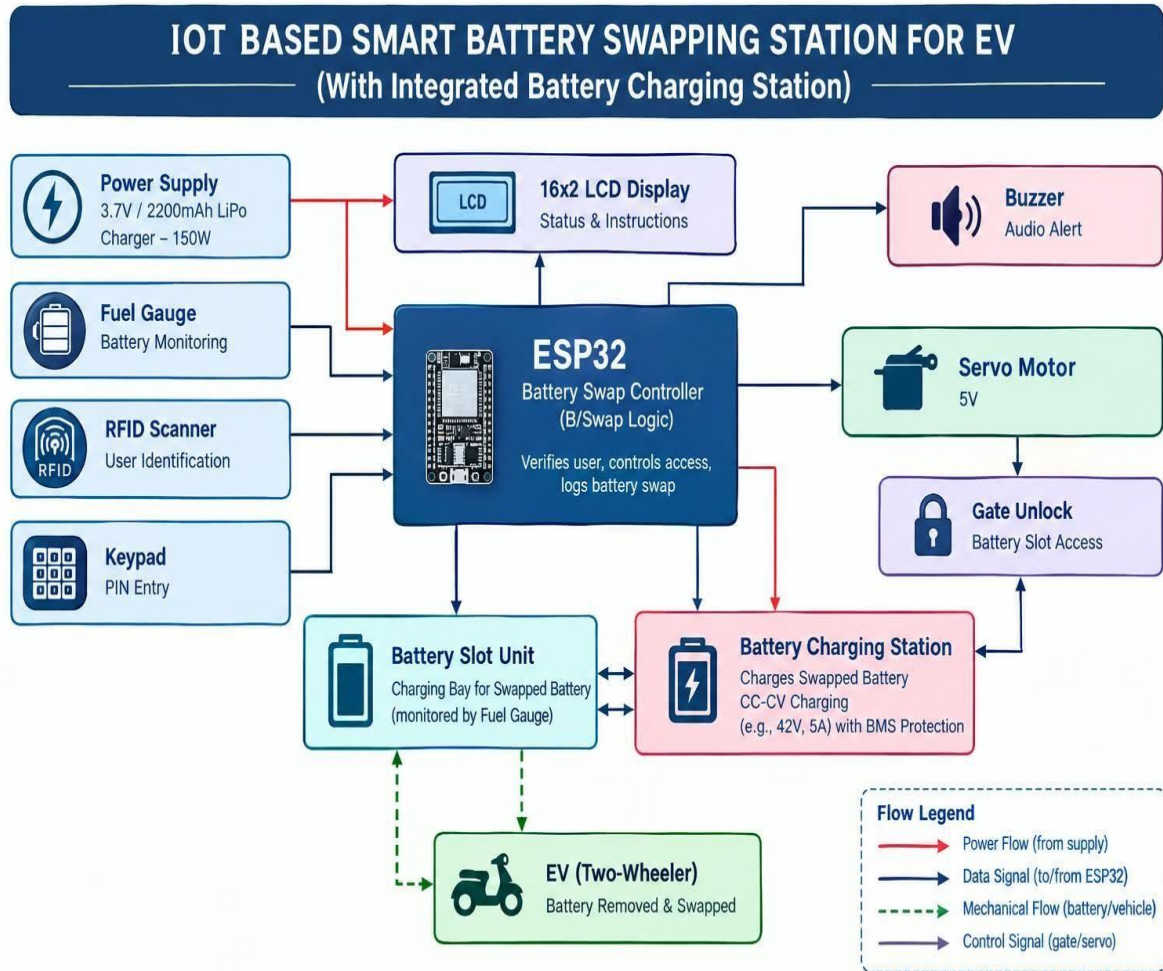


Fig. 2. Reference block diagram of an IoT-based smart battery swapping station with integrated charging. Power, data, mechanical, and control flows are distinguished in the legend of the diagram.

A. Sensing and Embedded Control

The sensing layer measures per-slot battery voltage and, where available, current, temperature, and SoC through a fuelgauge device. A microcontroller with built-in Wi-Fi, such as the ESP32, samples these values, validates them, classifies the battery state, drives actuators (locks, buzzer, display), and publishes updates. Fischer et al. demonstrate IoT devices for high-resolution power monitoring and control of EV charging, including as a retrofit to existing chargers [26], and Thangavel et al. review battery management, charging stations, and traction motors in EVs [27]. A monitoring cycle consists of acquisition, validation, state classification, cloud synchronization, and local actuation. A reading outside the valid range, or a failed sensor, must mark the battery unavailable rather than bookable.

B. Communication and Cloud Layer

Station-to-cloud communication typically uses either lightweight publish/subscribe messaging such as MQTT [28] or the client library of a managed real-time database. A managed backend such as Firebase removes the need for a custom server: the controller writes timestamped battery records, and the web application subscribes to changes so that every user sees the same live state. The trade-offs are dependence on continuous Internet connectivity and on a single vendor, and the need to enforce database security rules, discussed in Section VI. Data are organized into five record groups—user, battery, reservation, measurement, and access event—so that each physical battery maps to exactly one digital record and every reservation is traceable to a user and a battery.

C. Battery State Classification

Let V_b be the measured voltage of a battery, C_s its charging flag, O_s its occupancy flag, and R_s its reservation flag. The usable range is

$$V_{\min} \leq V_b \leq V_{\max} \quad (1)$$

Table III gives the classification rules and Fig. 3 the resulting transitions. A rule-based classifier is preferable to a learned model here because the decisions are discrete and safety-related: explicit rules can be explained to users and maintainers, are cheap enough for a microcontroller, and give the same response to the same inputs in repeated tests.

TABLE III

BATTERY STATE CLASSIFICATION RULES

State	Condition	Bookable
Available	$C_s = 0, O_s = 0, R_s = 0$, and V_b in usable range	Yes
Charging	$C_s = 1$	No
Reserved	$R_s = 1$ and $O_s = 0$	No (held)
Occupied (issued)	$O_s = 1$	No
Unavailable	Measurement, communication, or battery check fails validity criteria	No

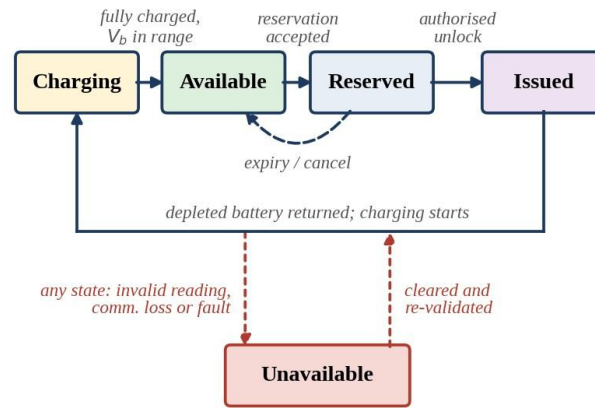


Fig. 3. Battery state transitions in the proposed rule-based model. Reservations that expire return the battery to the Available state.

D. Dashboard and User Roles

The application layer should offer two role-based views. Users register, authenticate, see which batteries are available and how far charging has progressed, and book a battery; administrators monitor charging status, battery parameters, reservations, and access events. A responsive web application, for example one built with ReactJS, serves laptops and smartphones without a separate native app.

VI. RESERVATION, AUTHENTICATION, AND ACCESS CONTROL

A. Reservation Logic

After authentication the application lists bookable batteries. When the user selects one, the system must check and set the reservation state in a single atomic operation, for example a database transaction, so that two users cannot reserve the same battery; a later request is rejected because the battery is no longer in the Available state. The reservation record binds a user identifier U_{ID} , a battery identifier B_{ID} , a timestamp, and a status. A time limit on the reservation returns unclaimed batteries to the Available state (Fig. 3), which prevents no-shows from blocking inventory.

B. Authentication and Unlocking

Unlocking is permitted only when the user is authenticated, the battery is in the Reserved state, and the user and battery identifiers match the stored reservation:

$$\begin{aligned}
 \text{Unlock} &= \text{Auth} \wedge (R_s = \text{Reserved}) \\
 &\wedge (U_{ID} = R_U) \wedge (B_{ID} = R_B) \quad (2)
 \end{aligned}$$

where *Unlock* and *Auth* take the value 1 when true and 0 otherwise, and R_U and R_B are the user and battery stored in the reservation. If the condition fails, the lock stays closed and the attempt is logged as rejected. At the kiosk, the identity factor can be an RFID tag, a keypad PIN, or a one-time passcode issued at booking; the prototype in Section VIII uses RFID and PIN entry. After release, the slot is marked as issued, and the returned depleted battery is placed in the freed bay, where charging starts and booking stays blocked until the battery is recharged.

C. Security Considerations

Connected charging infrastructure sits at the intersection of the power grid, communication networks, and vehicles, which creates an attractive attack surface [29]. Acharya et al. discuss vulnerabilities of smart EV charging and their consequences for the power grid [30]; Bhusal et al. review cyber-physical threats to charging equipment and smart-charging management systems [31]; and Hijgenaar et al. examine the cyber resilience of EV charging in the Dutch smart grid [32]. A small swapping station has little leverage over the grid, but it holds valuable assets, so the main concerns are unauthorized unlocking, tampering with reservation records, and replayed or guessed credentials. Practical safeguards include encrypted transport and authenticated database access with least-privilege rules; server-side verification of the reservation before an unlock command is accepted; short-lived, single-use passcodes with limits on failed attempts; tamper-evident access logs; and a failsafe default in which locks stay closed if communication or power is lost.

VII. BATTERY CHARGING, SAFETY, AND HEALTH MONITORING

Swapping does not remove battery management; it moves charging from the vehicle to the station. Lithium-ion packs are normally charged with a constant-current, constant-voltage (CC–CV) profile under the supervision of a battery management system (BMS) [33]. At the station, the minimum safety logic is an interlock: a battery must never be offered or unlocked while it is charging, reserved by another user, or marked faulty. Beyond voltage, stations should add temperature and current sensing, because thermal runaway in lithium-ion cells is triggered by abuse conditions such as overcharge, overheating, and short circuit, and can propagate to neighboring cells [34], [35]. Batteries in a shared pool may also cycle more intensively than batteries assigned to a single vehicle, so SoC, state-of-health (SoH), and cycle-count tracking are needed to retire packs safely; the ICCT highlights operational safety and end-of-life care as priorities for swapping operators [3]. Low-cost stations that measure only voltage and charging status leave advanced diagnostics—SoC and SoH estimation, remaining-useful-life prediction, and cell balancing—for future work.

VIII. ILLUSTRATIVE REFERENCE IMPLEMENTATION

To make the architecture concrete, this section describes a low-cost prototype developed by the student authors at the Department of Electrical Engineering, Priyadarshini College of Engineering, Nagpur. The prototype is a three-bay station for 3.7 V, 2200 mAh lithium-polymer (Li-Po) batteries. Its ESP32 controller reads a battery fuel gauge, authenticates users through an RFID reader and a keypad, drives servo-actuated bay gates and a buzzer, and shows prompts on a 16×2 LCD. Each battery pack carries a BMS module and a DC–DC buck converter, and a relay module is included in the control assembly (Fig. 4).

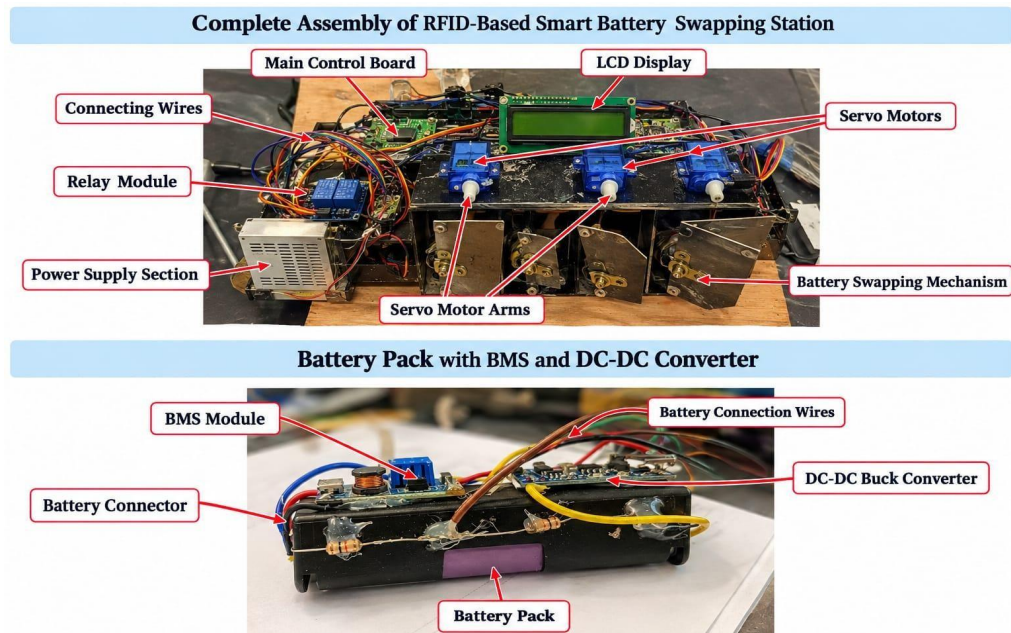


Fig. 4. Prototype of the RFID-based smart battery swapping station. Top: complete assembly with main control board, LCD display, relay module, servo motors and arms, power supply section, and battery swapping mechanism. Bottom: battery pack with BMS module, DC–DC buck converter, and connection wires.

Battery records, reservations, and access events are synchronized with a Firebase real-time database. A ReactJS web application deployed through Firebase (battery-swapping-nagpur.web.app) lets users view availability, reserve a battery, and obtain the credential needed at the kiosk, while administrators monitor charging status and station activity. The station-side logic implements the state model of Table III and the unlock rule in (2).

The prototype is intended for laboratory demonstration, electric bicycles, and small scooters; it is not directly applicable to commercial EV battery packs without hardware changes, depends on continuous Internet connectivity, and does not yet provide payment, QR-code authentication, GPS-based station discovery, or a native mobile application. Quantitative evaluation with the metrics of Section IX is in progress, and no performance results are claimed in this review.

IX. EVALUATION METRICS

Swapping systems have been evaluated using service time, waiting time, utilization, battery inventory, and user acceptance [6], [13], [21]. Station-level IoT systems need additional metrics for information correctness, latency, and access-control integrity (Table IV). State accuracy and cloud update latency are defined as

$$Accstate = (N_{match} / N_{total}) \times 100\% \quad (3)$$

$L_{cloud} = t_{dash} - t_{sense}$ (4) where N_{match} is the number of readings whose cloud state equals the ground-truth state out of N_{total} , t_{sense} is the time a measurement is taken, and t_{dash} is the time the dashboard shows it.

TABLE IV

PROPOSED EVALUATION METRICS

Metric	Definition	Source
Swap time	Time from request to battery release	About 3 min for NIO cars [2]
Waiting time	Queueing delay as a function of utilization	[6]
Availability	Share of time at least one bookable battery exists	Proposed
State accuracy	Eq. (3)	Proposed
Update latency	Eq. (4)	Proposed
Reservation conflicts	Double bookings divided by bookings (target: zero)	Proposed
Unlock accuracy	Correct releases per authorized attempt; unlocks on unauthorized attempts	Proposed
Safety events	Over-temperature or fault trips per charging cycle	Proposed

X. RESEARCH GAPS AND FUTURE DIRECTIONS

Integrated, open prototypes. Among the studies reviewed here, most address a single decision—scheduling, siting, forecasting, or acceptance—whereas few describe an end-to-end, low-cost station combining monitoring, reservation, and physical access control with reproducible evaluation. Open reference designs and shared datasets would make results comparable.

Standardization and interoperability. The draft Indian policy specifies minimum technical and operational requirements [5], and consumer studies recommend swapping standardization [22]. Common connectors, identification schemes, and data models would let one reservation system serve stations of several operators.

Battery health analytics. SoC and SoH estimation, remaining-useful-life prediction, and degradation-aware scheduling [13] should be driven by the data that IoT stations already log; artificial-intelligence-based health prediction is a natural extension.

Demand-aware reservation. Combining arrival forecasting [18] with reservation [20] could set booking limits and precharge targets for each station.

Grid and renewables. Network-level results show value in coordinated charging and frequency regulation [16], [17]; small stations could expose the same flexibility through local scheduling and solar charging.

Security and privacy. Formal threat models for swapping stations, hardware-backed credentials, and protection of user location and usage logs remain largely unexplored [29], [30].

Services and scale. Payment and billing, QR-code authentication, GPS-based station discovery, a native mobile app, multi-station inventory management, offline-tolerant edge operation, and blockchain-based battery authentication are further directions.

XI. CONCLUSION

Battery swapping shortens energy replenishment to minutes, but its benefit depends on knowing and controlling the state of every battery in the station. This review has shown that the literature on operation, planning, and acceptance is rich, whereas the IoT layer that provides real-time battery status, reservation integrity, and secure release is less developed and rarely evaluated end to end. A layered architecture with a rulebased battery-state model, atomic reservations, and a strict unlock condition offers a transparent and low-cost foundation, as illustrated by the reference prototype. Future work should add battery-health analytics, security hardening, standardized interfaces, and quantitative evaluation with the metrics proposed here.

REFERENCES

- [1] M. Mahoor, Z. S. Hosseini, A. Khodaei, and D. Kushner, "Electric vehicle battery swapping station," arXiv:1710.06895, Oct. 2017.
- [2] NIO Inc., "NIO achieves 100 million battery swaps," Press release, Shanghai, China, Feb. 6, 2026. [Online]. Available: <https://www.nio.com/news/20260206001>
- [3] J. Callahan, P. Gode, and S. Kohli, "Battery swapping for electric two-wheelers in India: Strategy hinterlands," Int. Council Clean Transp. (ICCT), Washington, DC, USA, May 2022.
- [4] P. Gode, S. Kohli, and J. Callahan, "Cost comparison of battery swapping, point charging, and ICE two-wheelers in India," Int. Council Clean Transp. (ICCT), Washington, DC, USA, 2022.
- [5] NITI Aayog, "Draft battery swapping policy," Government of India, New Delhi, India, Apr. 2022.
- [6] Y. Wu, S. Zhuge, G. Han, and W. Xie, "Economics of battery swapping for electric vehicles—Simulation-based analysis," *Energies*, vol. 15, no. 5, p. 1714, Feb. 2022.
- [7] H. Wu, "A survey of battery swapping stations for electric vehicles: Operation modes and decision scenarios," *IEEE Trans. Intell. Transp. Syst.*, vol. 23, no. 8, pp. 10163–10185, Aug. 2022, doi: 10.1109/TITS.2021.3125861.
- [8] D. Cui, Z. Wang, P. Liu, S. Wang, D. G. Dorrell, X. Li, and W. Zhan, "Operation optimization approaches of electric vehicle battery swapping and charging station: A literature review," *Energy*, vol. 263, Art. no. 126095, 2023, doi: 10.1016/j.energy.2022.126095.
- [9] S. Shao, S. Guo, and X. Qiu, "A mobile battery swapping service for electric vehicles based on a battery swapping van," *Energies*, vol. 10, no. 10, p. 1667, Oct. 2017.
- [10] M. Mahoor, Z. S. Hosseini, and A. Khodaei, "Least-cost operation of a battery swapping station with random customer requests," *Energy*, vol. 172, pp. 913–921, 2019, doi: 10.1016/j.energy.2019.02.018.
- [11] M. R. Sarker, H. Pandžić, and M. A. Ortega-Vazquez, "Optimal operation and services scheduling for an electric vehicle battery swapping station," *IEEE Trans. Power Syst.*, vol. 30, no. 2, pp. 901–910, Mar. 2015.
- [12] D. S. Nayak and S. Misra, "An operational scheduling framework for electric vehicle battery swapping station under demand uncertainty," *Energy*, vol. 290, 2024.
- [13] M. G. Marchesano, V. Popolo, A. Rozhok, and G. Cavalaglio, "Performance evaluation of battery swapping stations for EVs: A multi-method simulation approach," *Energies*, vol. 17, no. 23, p. 5969, 2024.
- [14] H.-Y. Mak, Y. Rong, and Z.-J. M. Shen, "Infrastructure planning for electric vehicles with battery swapping," *Manage. Sci.*, vol. 59, no. 7, pp. 1557–1575, Jul. 2013.
- [15] Y. Zheng, Z. Y. Dong, Y. Xu, K. Meng, J. H. Zhao, and J. Qiu, "Electric vehicle battery charging/swap stations in distribution systems: Comparison study and optimal planning," *IEEE Trans. Power Syst.*, vol. 29, no. 1, pp. 221–229, Jan. 2014.
- [16] W. Ai, H. Cheng, and W. Qi, "Optimizing urban electric vehicle charging and battery swapping infrastructure: A location-inventory-grid model," arXiv:2511.14308, Nov. 2025.
- [17] W. Qi, Y. Zhang, and N. Zhang, "Scaling up electric-vehicle battery swapping services in cities: A joint location and repairable-inventory model," *Manage. Sci.*, vol. 69, no. 11, 2023, doi: 10.1287/mnsc.2023.4731.
- [18] M. Suri, N. Raj, and K. Sireesha, "Prediction of EV arrivals at battery swapping station using hybrid neural network models," *J. Phys., Conf. Ser.*, vol. 2062, Art. no. 012021, 2021.
- [19] W. Zhan, Z. Wang, L. Zhang, P. Liu, D. Cui, and D. G. Dorrell, "A review of siting, sizing, optimal scheduling, and cost-benefit analysis for battery swapping stations," *Energy*, vol. 258, 2022.

- [20] J. D. Adler and P. B. Mirchandani, "Online routing and battery reservations for electric vehicles with swappable batteries," *Transp. Res. B, Methodol.*, vol. 70, pp. 285–302, 2014.
- [21] F.-H. Huang, "Understanding user acceptance of battery swapping service of sustainable transport: An empirical study of a battery swap station for electric scooters, Taiwan," *Int. J. Sustain. Transp.*, vol. 14, 2020.
- [22] G. Adu-Gyamfi, H. Song, E. Nketiah, B. Obuobi, Q. Wu, and D. Cudjoe, "Refueling convenience and range satisfaction in electric mobility: Investigating consumer willingness to use battery swap services for electric vehicles," *J. Retailing Consum. Serv.*, 2024, doi: 10.1016/j.jretconser.2024.103800.
- [23] F. Noto and H. Mostofi, "Acceptance analysis of electric heavy trucks and battery swapping stations in the German market," *Systems*, vol. 11, no. 9, p. 441, 2023, doi: 10.3390/systems11090441.
- [24] F. Ahmad, M. S. Alam, I. S. Alsaidan, and S. M. Shariff, "Battery swapping station for electric vehicles: Opportunities and challenges," *IET Smart Grid*, vol. 3, no. 3, pp. 280–286, Jun. 2020.
- [25] N. Raj, M. Suri, and K. Deepa, "Integration of battery charging and swapping using metaheuristics: A review," in *Lecture Notes in Electrical Engineering*, vol. 768. Singapore: Springer, 2022, pp. 247–258.
- [26] G. M. Fischer, S. B. Poore, R. E. Alden, D. D. Lewis, and D. M. Ionel, "Smart systems for employing IoT devices for monitoring and control of electric vehicle residential charging," in *Proc. IEEE Int. Conf. Renew. Energy Res. Appl. (ICRERA)*, Nagasaki, Japan, Nov. 2024, doi: 10.1109/ICRERA62673.2024.10815321.
- [27] S. Thangavel *et al.*, "A comprehensive review on electric vehicle: Battery management system, charging station, traction motors," *IEEE Access*, vol. 11, p. 20994, 2023, doi: 10.1109/ACCESS.2023.3250221.
- [28] *MQTT Version 3.1.1*, OASIS Standard, Oct. 2014. [Online]. Available: <http://docs.oasis-open.org/mqtt/mqtt/v3.1.1/mqtt-v3.1.1.html>
- [29] J. Bean and D. M. Manias, "Cybersecurity of electric vehicle charging infrastructure: Recent advances, open challenges, and future directions," arXiv:2605.24190, 2026.
- [30] S. Acharya, Y. Dvorkin, H. Pandžić, and R. Karri, "Cybersecurity of smart electric vehicle charging: A power grid perspective," *IEEE Access*, vol. 8, 2020, doi: 10.1109/ACCESS.2020.3041074.
- [31] N. Bhusal, M. Gautam, and M. Benidris, "Cybersecurity of electric vehicle smart charging management systems," in *Proc. North Amer. Power Symp. (NAPS)*, 2020, arXiv:2008.07511.
- [32] S. Hijgenaar *et al.*, "Cyber resilience of electric vehicle charging in smart grids: The Dutch case," *IEEE Access*, vol. 13, pp. 111454–111483, 2025, doi: 10.1109/ACCESS.2025.3580856.
- [33] L. Lu, X. Han, J. Li, J. Hua, and M. Ouyang, "A review on the key issues for lithium-ion battery management in electric vehicles," *J. Power Sources*, vol. 226, pp. 272–288, Mar. 2013.
- [34] X. Feng, M. Ouyang, X. Liu, L. Lu, Y. Xia, and X. He, "Thermal runaway mechanism of lithium ion battery for electric vehicles: A review," *Energy Storage Mater.*, vol. 10, pp. 246–267, Jan. 2018.
- [35] C.-H. Chang *et al.*, "Lithium-ion battery thermal event and protection: A review," *SAE Int. J. Electrified Veh.*, vol. 13, no. 3, pp. 357–397, 2024, doi: 10.4271/14-13-03-0019.