



Smart Adaptive EV Fast Charging System with Real-Time Battery Temperature and Dynamic Power Management

Abhade Yogita Ramdas¹ and Dhanashri Shantaram Dhanwate²

^{1,2} Department of Electrical Engineering, NIT's Late Annasaheb Patil, Polytechnic, Nashik, Maharashtra, India
Yogitasonawane575@gmail.com, dhanshridhanwate96@gmail.com

ABSTRACT—

Fast charging is the key to making electric vehicles (EVs) as convenient as petrol vehicles, but high charging current heats the battery, and heat is the main enemy of battery safety and life. Most chargers today use a fixed current profile and react to overheating only by switching off. This paper presents the concept, design and prototype plan of a Smart Adaptive EV Fast Charging System that measures the battery temperature in real time and continuously adjusts the charging current through a dynamic power management algorithm. The system consists of a power-conversion stage, temperature, voltage and current sensors, a microcontroller-based controller and a communication link with the battery management system (BMS). A lumped thermal model of a 40 kWh, 96-cell pack is used to compare fixed-current charging with the proposed adaptive strategy at a hot ambient condition. In the simulated 10–80% charge, the adaptive controller kept the pack below the 45 °C limit (peak 43.0 °C against 46.8 °C), reduced resistive heat loss by about 25%, and needed 7.2 minutes more charging time. A low-cost scaled prototype for diploma-level laboratories is also described.

Index Terms—electric vehicle, fast charging, battery thermal management, dynamic power management, battery management system, lithium-ion, adaptive control.

I. INTRODUCTION

The number of electric vehicles on the road is increasing every year, and India is among the fastest-growing markets for electric two-wheelers, three-wheelers and cars [1]. A buyer decides about an EV mainly on three questions: how far it runs, how much it costs, and how long it takes to charge. Range and cost are improving through better cells and manufacturing, but charging time remains the most visible difference between an EV and a conventional vehicle. A petrol tank is filled in three minutes, while a typical home charger needs several hours [4].

DC fast chargers of 50–150 kW reduce this time to 20–40 minutes. However, a large current flowing into a lithium-ion battery produces heat, because every battery has internal resistance. The heat produced is proportional to the square of the current (I^2R), so doubling the current gives four times the heat. If the heat is not removed, the temperature rises, the battery ages faster, and in the worst case a thermal runaway can occur [2], [3]. Charging in cold weather creates a different problem, lithium plating, which also damages the cell.

In many existing chargers the charging profile is fixed in advance, and the charger reduces power only after the BMS reports an over-temperature condition. This is a reactive approach. A better approach is to use the temperature measurement continuously and to *adapt* the power every second, so that the battery is charged as fast as is safely possible and not faster.

A. Problem Statement

To design a fast charging system that (i) senses the battery temperature in real time, (ii) adjusts the charging current dynamically using the temperature, state of charge (SOC) and voltage, and (iii) protects the battery and the charger from over-temperature, over-voltage and over-current faults, while keeping the charging time as short as the safety limits allow.

B. Objectives

- To study the heat-generation mechanism of a lithium-ion battery during fast charging.
- To design the hardware architecture of an adaptive charger with real-time temperature sensing.
- To develop a dynamic power management algorithm and verify it by simulation.
- To plan a low-cost scaled prototype that can be built in a polytechnic laboratory.

C. Scope of the Paper

The paper is a technical concept and prototype plan. The results in Section VI are obtained from a simplified simulation and are meant to show the trend and the working principle, not to replace experimental measurement. The prototype in Section V is a scaled low-voltage model for learning, and it must not be connected to a real vehicle.

II. BACKGROUND AND RELATED WORK

A. Charging Levels and Standards

EV charging is classified as AC Level 1, AC Level 2 and DC fast charging, with increasing power [5]. In DC fast charging the AC-to-DC conversion is done inside the charger, so the charger feeds the battery directly. Connector and safety requirements are defined by standards such as IEC 61851-23 for DC charging stations [6], while ISO 15118 defines digital communication between the vehicle and the charger [7]. In India, the Bharat DC001 and CCS2 type connectors are in use in public chargers.

B. Charging Algorithms

The most widely used algorithm for lithium-ion cells is constant current–constant voltage (CC–CV). The cell is charged at constant current until its terminal voltage reaches the upper limit, then at constant voltage while the current falls. Boost charging and multi-stage constant current methods charge faster by using high current at low SOC and reducing it in steps as the cell fills [10]. A review of fast-charging research shows that the choice of current, temperature and SOC window decides the balance between speed and degradation [3].

C. Thermal Considerations

Keyser *et al.* showed that the thermal behaviour of a pack, and not only the cell chemistry, limits the practical fast-charging rate [2]. Heat is generated mainly by ohmic loss, polarization and, to a smaller extent, reversible entropy change. The internal resistance falls as the temperature rises, but the ageing rate rises at the same time, so a high temperature during charging is harmful even though it appears to help the current flow. Most manufacturers recommend keeping the cell between about 15 °C and 45 °C during fast charging.

D. Battery Management Systems

A BMS measures the cell voltages, pack current and temperatures, estimates the SOC and state of health, balances the cells and communicates the permitted charge current to the charger [8], [9]. The proposed system uses the BMS limits as *upper bounds* and adds a second, charger-side layer of temperature-aware power management.

E. Comparison of Charging Approaches

TABLE I

COMPARISON OF CHARGING APPROACHES

Method	Uses temperature?	Main limitation
CC–CV	No (BMS cut-off only)	Fixed profile; heat not managed
Multi-stage CC	Rarely	Steps tuned for one condition
Temp.-adaptive (proposed)	Yes, continuously	Needs sensors and tuning

F. Battery Cooling Methods

The thermal management system decides how fast heat can leave the pack. *Air cooling* with fans is simple and cheap but limited to moderate power. *Liquid cooling* circulates a water–glycol mixture through cold plates in contact with the cells and is the most common choice in fast-charging cars. *Immersion cooling* places the cells in a dielectric fluid and gives very uniform temperature, but it is costly. *Phase-change materials* absorb heat when they melt and can handle short peaks. Whatever the method, its capacity is finite, so the charger should not demand more heat generation than the cooling can remove. This is the main motivation for coupling the charging power to the measured temperature.

In cold weather the problem is reversed. The pack may need to be warmed before fast charging, using a resistive heater or the heat pump of the vehicle, because the permitted charge current at 0 °C is much lower than at 25 °C. The proposed controller handles this by the cold zone of Table II, where the current is limited until the pack warms.

III. SYSTEM ARCHITECTURE

Fig. 1 shows the block diagram of the proposed system. It has two parts: the *power path*, through which energy flows from the grid to the battery, and the *control and sensing path*, which decides how much power should flow.

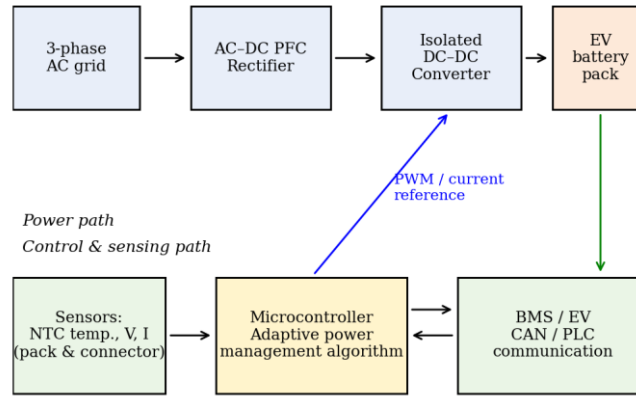


Fig. 1. Block diagram of the smart adaptive EV fast charging system.

A. Power Stage

A three-phase AC–DC rectifier with power factor correction (PFC) converts the grid supply to a regulated DC link, which keeps the grid current close to sinusoidal and the power factor near unity. An isolated DC–DC converter (for example a phase-shifted full bridge or LLC resonant converter) provides galvanic isolation and the controlled output voltage and current needed by the battery. The output current is set by a reference signal coming from the controller, so the controller can change the charging power without changing the hardware.

B. Sensing Unit

The sensing unit has three groups of sensors. (i) *Temperature*: negative-temperature-coefficient (NTC) thermistors or digital sensors placed at several points on the battery pack, plus one at the charging connector, because connector heating is a real safety concern at high current. (ii) *Voltage*: a resistive divider or isolated amplifier on the pack terminals. (iii) *Current*: a Hall-effect or shunt-based sensor in the output path. Using several temperature points allows the controller to use the *hottest* reading, which is the safe choice.

C. Controller

A microcontroller (for example an STM32 or ESP32) reads the sensors at a fixed rate of 10–100 Hz, filters the signals, runs the adaptive algorithm of Section IV and writes the current reference to the converter through a PWM or DAC output. It also logs the data for display and later analysis.

D. Communication and Protection

The controller exchanges the requested and permitted current and voltage with the BMS over a CAN bus (or power-line communication in a full-scale charger, following ISO 15118 [7]). Independent hardware protection, consisting of over-current, over-voltage and over-temperature comparators that trip a contactor, is added so that a software fault can never leave the battery unprotected.

IV. METHODOLOGY

A. Heat Generation Model

The battery pack is represented by a lumped thermal model in which the whole pack has one temperature T . The heat generated by the resistance of the pack is balanced by the heat removed by the cooling system:

$$C_{th} dT/dt = I^2 R(T) - UA(T - T_c) \quad (1)$$

where C_{th} is the thermal capacity of the pack (J/K), R the pack resistance, UA the effective heat transfer coefficient to the coolant (W/K), and T_c the coolant or ambient temperature. The resistance decreases with temperature and is approximated by

$$R(T) = R_{25} \exp[-\beta(T - 25)] \quad (2)$$

with R_{25} the resistance at 25 °C and β a fitting constant. The state of charge is obtained by coulomb counting:

$$SOC(k+1) = SOC(k) + I\Delta t / Q \quad (3)$$

where Q is the pack capacity in coulombs and Δt the sampling time. The terminal voltage is $V = V_{oc}(SOC) + IR$.

B. Dynamic Power Management Algorithm

The controller computes the charging current reference as the product of the maximum current and two reduction factors, one for temperature and one for SOC:

$$I_{ref} = I_{max} \cdot f_T(T) \cdot f_S(SOC) \quad (4)$$

The temperature factor is flat at 1 below a start temperature T_{on} , then falls linearly to a minimum value at the temperature limit T_{lim} :

$$f_T = \text{clip}[(T_{lim} - T)/(T_{lim} - T_{on}), f_{min}, 1] \quad (5)$$

The SOC factor f_S reduces the current gradually in the upper SOC range, where the cell voltage rises quickly. Finally the current command is limited by the charger power rating and by the voltage limit:

$$I_{cmd} = \min\{I_{ref}, P_{max}/V, (V_{max} - V_{oc})/R\} \quad (6)$$

The steps executed in every control cycle are:

- 1) Read pack temperatures, voltage and current; take the maximum temperature.
- 2) Read the current limit received from the BMS.
- 3) Update SOC and compute f_T , f_S and I_{ref} from (4)–(5).
- 4) Apply the power and voltage limits of (6) and the BMS limit.
- 5) If any fault limit is crossed, set the current to zero and open the contactor.
- 6) Send I_{cmd} to the converter, update the display and log the data.

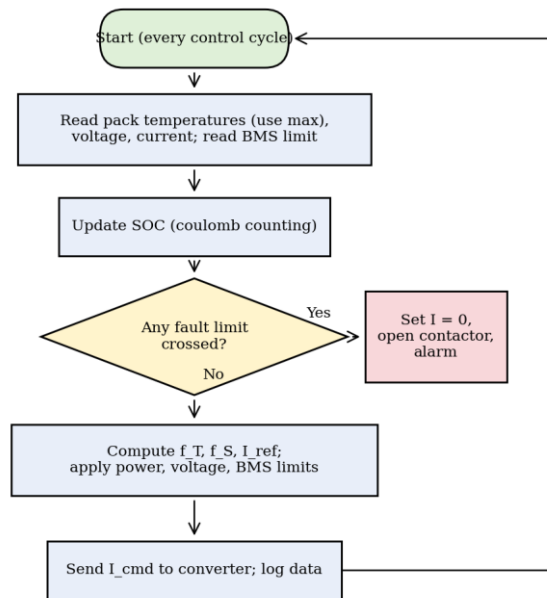


Fig. 2. Flowchart of the adaptive power management algorithm executed in every control cycle.

C. Software Implementation

The algorithm is short enough to run on a low-cost microcontroller. A simplified pseudo-code is given below, with the same symbols as in (4)–(6). The temperature input is first low-pass filtered to remove noise, and the new current command is limited in rate (slew limit) so that the converter output changes smoothly.

every 100 ms:

$T = \max(\text{read_temps}())$

if $\text{fault}(T, V, I, \text{BMS})$: $I_{cmd} = 0$; open()

else:

$f_T = \text{clip}((T_{lim} - T)/(T_{lim} - T_{on}), f_{min}, 1)$

$f_S = \text{clip}((0.95 - \text{SOC})/0.20, 0.25, 1)$

$I_{ref} = I_{max} * f_T * f_S$

$$I_cmd = \min(I_ref, P_max/V, I_bms, I_vlim)$$

$$I_cmd = \text{slew_limit}(I_cmd, dI_max)$$

$$\text{write_pwm}(I_cmd); \log(T, V, I, SOC)$$

D. Temperature Zones

Table II summarizes how the controller behaves in different temperature zones. A short cold zone is included because charging a cold battery at high current causes lithium plating.

TABLE II

TEMPERATURE ZONES AND CONTROLLER ACTION

Zone	Pack temp.	Controller action
Cold	< 10 °C	Low current; wait for heating
Normal	10–40 °C	Full current ($f_T = 1$)
Warm	40–45 °C	Linear current reduction
Hot	≥ 45 °C	Minimum current, fan at full speed
Fault	> 55 °C	Stop charging, trip contactor

E. Design Example: Heat and Cooling Estimate

A quick calculation shows why adaptive control is needed. At 38 °C the pack resistance from (2) is about 40 m Ω . At 315 A the heat generated is $I^2R \approx 3.9$ kW. To hold the pack only 7 K above a 38 °C coolant (that is, at 45 °C) in steady state, the cooling system would need $UA \approx 3900/7 \approx 560$ W/K, about three and a half times the 160 W/K assumed in Section VI. Oversizing the cooling by this factor adds weight, cost and energy use. Reducing the current by 30% in the warm zone cuts the heat by half ($0.7^2 \approx 0.49$), which is a far cheaper solution.

F. Protection Thresholds

Table III gives the example protection limits for the full-size model. The values must always be taken from the datasheet of the actual cell and from the BMS.

TABLE III

EXAMPLE PROTECTION LIMITS

Fault	Limit	Action
Pack over-temperature	> 55 °C	Trip
Connector over-temperature	> 90 °C	Trip
Cell over-voltage	> 4.25 V	Trip
Over-current	> $1.1 \times I_{max}$	Trip
Sensor open / short	Out of range	Stop, alarm
BMS link lost	> 1 s	Stop

Because the temperature, voltage and BMS communication are all supervised, a failed sensor is treated as a fault and not as a normal reading.

V. PROTOTYPE IMPLEMENTATION PLAN

A full-size fast charger works at hundreds of volts and tens of kilowatts, which is unsafe for a student laboratory. Therefore a *scaled* prototype is proposed. It uses a small lithium-ion pack of about 14.8 V (4S) and 5 Ah, charged from a programmable buck converter at a maximum of 10 A. The same algorithm and sensing scheme are used, so the learning outcome is the same. Table IV lists the main components.

TABLE IV

MAIN COMPONENTS OF THE SCALED PROTOTYPE

Block	Component
Controller	STM32 / ESP32 development board
Power stage	Adjustable buck converter, 0–24 V, 10 A, with MOSFET switch
Battery	4S1P 18650 Li-ion pack with 4S BMS board
Temperature	10 k Ω NTC thermistors (3 nos.) or DS18B20
Current / voltage	ACS712 Hall sensor; resistor divider
Cooling	12 V fan with PWM speed control
Protection	Fuse, relay or contactor, over-temperature cutout
Display / logging	OLED display; serial or SD-card data log

A. Hardware Build Steps

- 1) Assemble the battery pack with the BMS and fix the NTC sensors on the cells with thermal paste and tape.
- 2) Build the power stage and verify the output current control with a resistive load before connecting the battery.
- 3) Calibrate the temperature, voltage and current sensors against a reference thermometer and multimeter.
- 4) Load the control program, first with the adaptive function disabled, then with it enabled.

B. Test Plan

Two tests are planned on the same pack under the same starting conditions: (1) a fixed-current charge, and (2) the adaptive charge. A hair-dryer or a heating pad can be used to raise the starting temperature safely. The recorded quantities are the temperature at each sensor, current, voltage, charging time from 10% to 80% SOC, and the energy delivered. The results are compared with the simulation of Section VI.

C. Evaluation Metrics

The performance of the prototype is judged by the quantities in Table V. They allow a fair comparison of the fixed and adaptive tests and make the final report objective.

TABLE V

EVALUATION METRICS FOR THE PROTOTYPE

Metric	Instrument	Target
Peak temperature	NTC / DS18B20	Below limit
Charge time 10–80%	Data log	Report both tests
Energy delivered	V and I log	$\pm 5\%$ of meter
Temp. sensor error	Reference thermometer	$\pm 1^\circ\text{C}$
Control response	Step test	Settles in < 5 s

D. Laboratory Safety

Lithium-ion cells can catch fire if overheated, over-charged or short-circuited. The prototype must therefore be built on a non-flammable surface, fused at the battery, supervised during every test, and kept within the cell manufacturer's limits. The software over-temperature stop must be supported by an independent hardware cutout.

VI. SIMULATION RESULTS AND DISCUSSION

A. Simulation Setup

The model of Section IV was run in Python with a one-second time step for a 40 kWh-class pack of 96 cells in series with a capacity of 105 Ah. The charge window was 10% to 80% SOC, which is the part of the charge where fast chargers deliver the largest share of energy. A hot-climate case was chosen: coolant at 38 °C and an initial pack temperature of 37 °C. Table VI lists the parameters.

TABLE VI

SIMULATION PARAMETERS

Parameter	Value
Cells in series, capacity	96, 105 Ah
Pack resistance R_{25} , β	55 m Ω , 0.025 /°C
Thermal capacity C_{th}	240 kJ/K
Cooling UA, coolant temp.	160 W/K, 38 °C
I_{max} , P_{max} , V_{max}	315 A (3C), 120 kW, 403 V
T_{on} , T_{lim} , f_{min}	41 °C, 45 °C, 0.20

The *fixed-current* case charges at the maximum current of 315 A (3C) whenever the voltage limit allows. The *adaptive* case uses the algorithm of (4)–(6).

B. Results

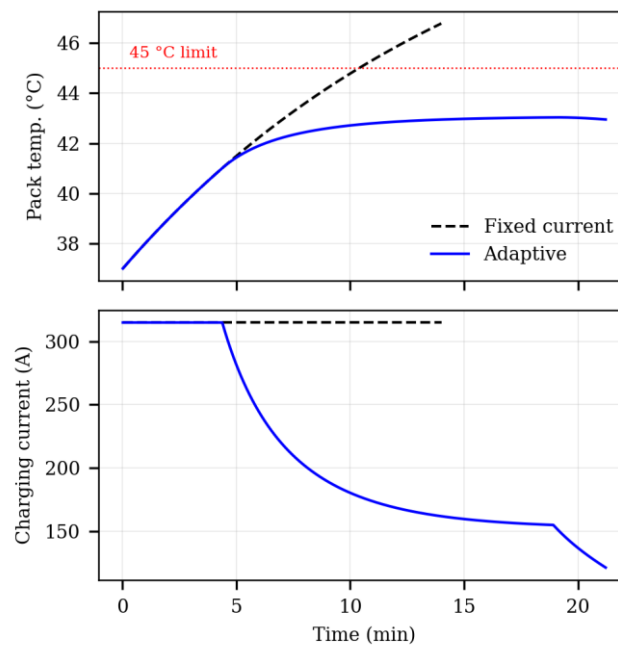


Fig. 3. Simulated pack temperature (top) and charging current (bottom) for fixed-current and adaptive charging from 10% to 80% SOC.

Fig. 3 shows that the fixed-current charge keeps the current at its maximum and the temperature rises steadily, crossing the 45 °C limit and reaching 46.8 °C. In the adaptive case the current stays at its maximum only while the pack is cool. As the temperature enters the warm zone, the current is reduced smoothly, so the temperature rise slows and the peak remains at 43.0 °C. Table VII gives the numerical comparison.

TABLE VII

COMPARISON OF FIXED AND ADAPTIVE CHARGING

Quantity	Fixed	Adaptive	Change
Charge time (10–80%)	14.0 min	21.2 min	+52%
Peak temperature	46.8 °C	43.0 °C	–3.7 °C
Time above 45 °C	217 s	0 s	–217 s
Resistive heat loss	2.96 MJ	2.23 MJ	–25%
Average power	113 kW	74 kW	–35%
Peak power	122 kW	110 kW	–10%

C. Discussion

The results show the central trade-off of thermal management. The adaptive controller removes the over-temperature period and cuts the resistive heat by about 25%, because heat grows with the square of the current and even a modest current reduction in the warm zone saves a large amount of heat. The price is a longer charging time, 21.2 minutes instead of 14.0. In a hot climate such as that of Maharashtra in summer, this is a reasonable price for avoiding accelerated ageing and the risk of a thermal event.

With better cooling, for example a chilled liquid loop, the pack stays below the warm zone for longer and the adaptive controller automatically gives a charging time very close to the fixed case, since the algorithm reduces current only when it is needed. This is an advantage over fixed derating schedules, which slow the charge in all conditions.

D. Sensitivity Analysis

Two parameters were varied to see how the adaptive controller behaves. First, the start temperature T_{on} of the derating band was changed (Table VIII). A lower T_{on} makes the controller act earlier, which lowers the peak temperature but lengthens the charge; a higher value does the opposite. This single parameter lets the designer choose between a faster and a gentler charge.

TABLE VIII

EFFECT OF DERATING START TEMPERATURE (COOLANT AT 38 °C)

T _{on} (°C)	Charge time (min)	Peak temp. (°C)
39	23.8	42.3
41	21.2	43.0
43	18.9	43.9

Second, the coolant (or ambient) temperature was changed (Table IX). In cool conditions the two strategies behave almost the same, since the controller does not need to reduce the current. In hot conditions the fixed profile overheats, while the adaptive profile trades time for safety automatically.

TABLE IX

EFFECT OF COOLANT TEMPERATURE

Coolant	Fixed time	Fixed peak	Adapt. time	Adapt. peak
30 °C	14.0 min	40.5 °C	14.2 min	40.4 °C
34 °C	14.0 min	43.6 °C	15.7 min	42.3 °C
38 °C	14.0 min	46.8 °C	21.2 min	43.0 °C

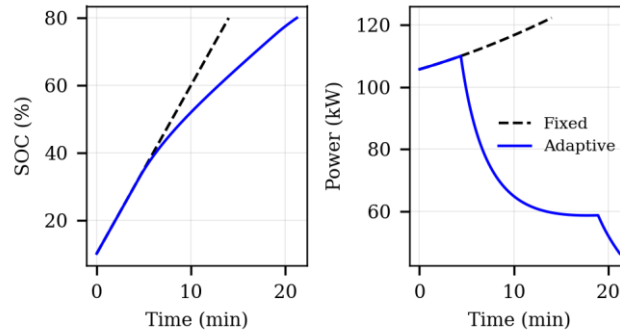


Fig. 4. Simulated SOC (left) and charging power (right) versus time for the two strategies (coolant at 38 °C).

Fig. 4 shows that the adaptive charge delivers close to full power in the first minutes and then settles to a lower power as the pack warms, which is the expected behaviour of the temperature-aware controller.

E. Limitations

- A single-temperature lumped model ignores temperature differences inside the pack; real packs have hot spots, which is why several sensors are used.
- Only ohmic heat is modelled; polarization and entropic heat are neglected.
- The parameters are representative values, not measured from a specific battery, so the numbers should be read as trends.
- Battery ageing is not modelled; the benefit for life is expected from the literature [2], [3] but is not quantified here.

VII. STANDARDS, SAFETY AND CHALLENGES

A commercial charger must satisfy electrical safety, electromagnetic compatibility and communication standards before it can be used with a vehicle. The relevant documents include IEC 61851-23 for the charging station [6], ISO 15118 for vehicle–charger communication [7], and the local connector and grid-connection rules. The adaptive algorithm of this paper does not replace these requirements; it works inside them. The permitted current sent by the BMS is always an upper bound, and the hardware protection of Table III remains independent of the software.

Several practical challenges remain. First, temperature sensors measure the surface and not the core of the cell, so the core can be several degrees hotter during a fast charge; a margin must be kept below the real limit. Second, the controller depends on correct sensor readings, so open-circuit and short-circuit detection are essential. Third, tuning T_{on} and T_{lim} for a given pack needs measurements at different temperatures and SOC values. Fourth, the user experience matters: a charger that slows down for thermal reasons should display the reason and the expected time, so that the driver is not surprised.

VIII. ADVANTAGES AND APPLICATIONS

The proposed system keeps the battery within its safe temperature window without needing a larger cooling system, extends battery life by avoiding long periods at high temperature, and gives the driver a predictable charging time through the displayed power. It can be applied in public DC fast-charging stations, bus and fleet depots, battery-swapping stations, and in educational laboratories as a hands-on platform for power electronics, control and battery technology.

For diploma students the project combines several subjects: power electronics (converters), sensors and instrumentation, microcontroller programming, control systems, and electric vehicle technology. Students also learn practical skills such as sensor calibration, data logging, safety practice and technical report writing in IEEE style.

IX. CONCLUSION AND FUTURE WORK

This paper presented a smart adaptive EV fast charging system that uses real-time battery temperature to manage the charging power dynamically. The architecture, the thermal model, the control algorithm and a scaled prototype plan suitable for diploma students were described. In the simulated hot-climate case, the adaptive controller avoided the over-temperature condition, reduced the peak temperature by 3.7 °C and the resistive loss by about 25%, at the cost of 7.2 extra minutes of charging.

Future work includes building and testing the scaled prototype, tuning T_{on} and T_{lim} with measured data, adding a multi-node thermal model, estimating SOC and state of health with an observer, using predictive control with weather and grid information, and integrating the charger with ISO 15118 communication and renewable energy sources.

ACKNOWLEDGMENT

The authors thank the Head of the Department, the guide and the laboratory staff of [Name of Polytechnic] for their guidance and support.

REFERENCES

- [1] International Energy Agency, *Global EV Outlook 2024*. Paris, France: IEA, 2024.
- [2] M. Keyser *et al.*, “Enabling fast charging – Battery thermal considerations,” *J. Power Sources*, vol. 367, pp. 228–236, Nov. 2017.
- [3] A. Tomaszewska *et al.*, “Lithium-ion battery fast charging: A review,” *eTransportation*, vol. 1, Art. no. 100011, Aug. 2019.
- [4] M. Ehsani, Y. Gao, S. Longo, and K. Ebrahimi, *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles*, 3rd ed. Boca Raton, FL, USA: CRC Press, 2018.
- [5] M. Yilmaz and P. T. Krein, “Review of battery charger topologies, charging power levels, and infrastructure for plug-in electric and hybrid vehicles,” *IEEE Trans. Power Electron.*, vol. 28, no. 5, pp. 2151–2169, May 2013.
- [6] *Electric Vehicle Conductive Charging System – Part 23: DC Electric Vehicle Charging Station*, IEC Standard 61851-23.
- [7] *Road Vehicles – Vehicle to Grid Communication Interface*, ISO Standard 15118.
- [8] G. L. Plett, *Battery Management Systems, Volume I: Battery Modeling*. Norwood, MA, USA: Artech House, 2015.
- [9] H. J. Bergveld, W. S. Kruijt, and P. H. L. Notten, *Battery Management Systems: Design by Modelling*. Dordrecht, The Netherlands: Kluwer, 2002.
- [10] P. H. L. Notten, J. H. G. Op het Veld, and J. R. G. van Beek, “Boostcharging Li-ion batteries: A challenging new charging concept,” *J. Power Sources*, vol. 145, no. 1, pp. 89–94, Aug. 2005.