FORM 2

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(See Section 10 and Rule 13)

COMPLETE SPECIFICATION

TITLE OF THE INVENTION

Predictive charging controller and a method thereof

APPLICANTS:

Name : Prakash Balekundri

Nationality : Indian

Address : 3/14, 11th A Main, Padmanabha Nagar
Bengaluru 560061

Name : Khushi Balekundri

Nationality : Indian

Address : 3/14, 11th A Main, Padmanabha Nagar
Bengaluru 560061

The following specification particularly describes the invention and the manner in which it is to be performed: -

Technical field

[0001] The disclosed subject matter in general relates to charging control for electric vehicles (EVs), and more particularly to a method and controller for controlling transition between fast charging and slow charging modes based on predicted state-of-charge requirements derived from navigation data.

Background

[0002] Electric vehicles are increasingly equipped with fast charging capability to reduce downtime during travel. However, frequent or prolonged fast charging accelerates battery degradation due to high current and elevated temperature conditions. Existing systems typically allow the user to manually select a charging mode like fast or slow, or set a maximum state of charge (SoC) threshold for fast charging.

[0003] Some navigation-assisted systems predict energy consumption for a planned route and schedule charging stops accordingly. While such systems assist in route planning, they do not explicitly provide user-facing control for terminating or switching charging modes once the minimum required SoC for reaching the destination is achieved.

[0004] The prior art US 10295355 B2 discloses trip planning with energy constraint. It discloses trip planning that uses current SoC and route information to present energy-Vs-distance measures and plan charging.

[0005] The prior art US20120109515A1 discloses a battery electric vehicle (BEV) navigation routing system and routing methods, in which a traveling route is determined from the current vehicle location to the destination location by preferentially selecting low speed routes over higher speed routes if the present state of charge of the vehicle battery is insufficient to reach the destination location using shortest time or shortest distance routes.

[0006] However none of the known arts disclose predictive charging control for switching between fast charging and slow charging of the battery, based on navigation data.

[0007] There remains a need for a predictive charging control device and method that integrates navigation-derived SoC prediction with a user interface enabling real-time charging decisions, thereby improving battery life, charging efficiency, and user flexibility.

Summary

[0008] The subject matter is defined in the independent claims. Further details are defined in the dependent claims.

[0009] The subject matter provides a predictive charging controller and a method for controlling predictive charging of an electric vehicle. The predictive charging controller detects initiation of fast charging, requests a navigation unit for navigation data comprising a distance to a set destination or a distance to a predefined home location when no destination is set, predicted travel time, traffic data, terrain data, weather data on the route to the set destination or the home location, distance to the set destination or the home location, historical driving data etc.

[0010] Based on the navigation data, a required SoC including a safety buffer is predicted/computed.

[0011] The SoC of the battery is monitored continuously during charging. When the monitored SoC of the vehicle battery reaches or exceeds the required SoC, a notification is generated for the user. The notification provides selectable options including: (i) terminating charging, (ii) switching from fast to slow charging, or (iii) continuing fast charging. The controller executes the option selected by the user.

[0012] The subject matter improves battery life by reducing unnecessary fast charging, enhances charging station throughput by shortening fast charging sessions, and provides users with flexibility to balance convenience and battery longevity.

[0013] Brief description of the drawings

[0014] The detailed description is described with reference to the accompanying figures. In the figures, similar reference numerals are used throughout the drawings to reference like features and components.

Figure 1 illustrates a vehicle with a charging controller according to an embodiment

Figure 2 illustrates details of the charging controller according to an embodiment

Figure 3 illustrate details of memory unit, according to an embodiment

Figure 4 illustrates a method for predictive charging of a vehicle, according to an embodiment

Detailed description

[0015] The subject matter now will be described with exemplary embodiments. However, the claimed subject matter may be embodied in many different forms and should not be construed as limited to the embodiments described herein. These embodiments are provided only as examples so that this disclosure is clear and concise.

[0016] Only the details/components required to describe the claimed subject matter in specific, are disclosed in this document. The details/components which are commonly known or understood by people skilled in the art may not be covered in this document.

[0017] In this document some terms may be used interchangeably. The term ‘vehicle’ may refer to the electrical vehicle, hybrid vehicle or any other vehicle which uses electrical power for driving. The terms ‘vehicle’ and ‘electrical vehicle’ may be used interchangeably.

[0018] The subject matter provides a method and a charging controller for controlling charging of an electric vehicle based on navigation data.

[0019] The slow charging uses alternating current (AC), typically from home outlets or wall chargers. Charging power ranges from 3 kW to 7 kW. The EV's on-board charger converts AC to DC to charge the battery.

[0020] Fast Charging uses direct current (DC) from high-power public charging stations. Power ranges from 50 kW to 350 kW.

[0021] The switching from fast charging to slow charging may happen in different ways.

[0022] Automatic Detection: When the EV is connected to a charging station, the EV's Battery Management System (BMS) detects the type of current and adjusts accordingly.

[0023] Through communication protocols: The EV and charging station exchange data (via protocols like Combined Charging System, CCS; CHAdeMO (short for *"CHArge de MOve"*) to negotiate charging speed, voltage, and current.

[0024] By onboard limiting: The EV converts the power to suit its hardware, by limiting the current.

[0025] Based on State of Charge (SoC): Fast charging typically slows down after 80% to protect battery health. The charging station automatically reduces current flow.

[0026] Figure 1 illustrates a vehicle 100. The vehicle 100 comprises a charging system 102, a communication unit 104, a navigation unit 106 and a notification unit 108. The communication unit 104 may comprise one of a Bluetooth module, or any other wireless communication module which can establish communication with an external device, like a mobile phone 128. The navigation unit 106 is responsible for route guidance for the vehicle100 and also provides navigation data like, distance to destination, traffic conditions, weather conditions etc. The notification unit 108 may be at least one of a display of the infotainment device, instrumentation cluster, a lamp, a buzzer, an audio output device, keys for user selection etc. In an embodiment the notification device may be the registered mobile phone 128. The mobile phone 128 is paired with the charging controller 112 using Bluetooth module during the setup.

[0027] The charging vehicle 100 is connected to a charging station 101 through the connector 126.

[0028] The charging system 102 further comprises a charging unit 110, a charging controller 112, a battery 114 and a Battery Management System, BMS 116.

[0029] The charging unit 110 comprises at least one of a DC-DC converter 118 and an AC-DC converter 120 or both, protection circuits 122, and a fail-safe relay 124. There are also current limiting components which are not shown. The current limiting components comprise a power factor correction (PFC) circuit, Silicon devices etc. The PFC circuit comprises interleaved boost converters, MOSFETs, Inductors and gate drivers. The silicon devices comprise MOSFETS, diodes etc.

[0030] The AC-DC and DC-DC Converters 120, 118 are capable of stepping down voltage/current from a charging station 101 for charging the battery 114. The AC-DC, DC-DC converters 120, 118 comprise high-power MOSFETs, and/or Insulated Gate Bipolar Transistor, IGBTs, with gate drivers for regulating duty cycle; inductor & capacitors for energy storage for voltage smoothing and current regulation, current sense resistor/hall-effect sensor for real-time current measurement at output side.

[0031] The Pulse Width Modulation, PWM, duty cycle of MOSFETs in the DC-DC converter 118 is dynamically adjusted by the charging controller 112 to regulate current flow. Feedback loop ensures constant current (CC) or constant voltage (CV) mode as per recipient power parameters. If over-current/over-temperature is detected, the charging controller 112 reduces PWM duty cycle or shuts down the AC-DC, DC-DC converters 120, 118 by opening the fail-safe relay 124.

[0032] In an embodiment the DC-DC converter 118 is a programmable DC-DC converter which can be programmed/controlled by the charging controller 112.

[0033] The protection circuits 122 comprise overcurrent protection components like fuses, relays, circuit breakers; overvoltage and under-voltage cutoff circuits, surge protection and reverse polarity protection. The protection circuits 122 are controlled and monitored by the charging controller 112. The protection circuits 122 also comprise isolation circuits to enable the charging of the battery 114 while blocking high currents. Typical example of isolation circuits are isolation transformers.

[0034] The fail-safe relay 124 is an electromechanical or solid-state relay. If a fault occurs, the fail-safe relay 124 is made to default to the safe state, usually open circuit/disconnected state, by the charging controller 112. In vehicle charging, this prevents uncontrolled current flow which might cause battery damage.

[0035] The connector 126 comprises standardized charging interfaces such as Combined Charging System, CCS, connector, CHAdeMO (short for *"CHArge de MOve"*) connector etc.

[0036] Figure 2 illustrates block diagram of the charging controller 112. The charging controller 112 comprises a processor unit 200, a memory unit 202, input output interfaces 204, power electronics driver circuits 206, navigation interface 208 and a detection unit 210.

[0037] The processor unit 200 may comprise one or more of microcontrollers, central processing units (CPU), graphical processing units (GPU), digital signal processors (DSP), application specific integrated circuits (ASIC), a controller, field programmable gate arrays (FPGA), or any other hardware device, a firmware device, or any combination of these. The processor unit 200 is configured using its control registers, input output ports, firmware, input output interfaces 204 etc. to perform the operations described herein.

[0038] In an embodiment, the memory unit 202 comprises one or more volatile and non-volatile memory components which are capable of storing data and instructions to be executed.

[0039] The input output interfaces 204 may comprise input ports and output ports of the processor unit 200, connected to input output devices like displays, buzzer, audio output unit etc. The input output interfaces 204 are also connected to Power electronics driver circuits 206 to control and monitor the charging of the vehicle 100. The power electronics driver circuits 206 are interfaces between a low-power processor unit 200 and a high-power switching device (MOSFET or IGBT) of the DC-DC, AC-DC converters 118, 120.

[0040] The charging controller 112 outputs low-voltage logic signals through the input output interfaces 204. The power switches (MOSFETs/IGBTs) need higher drive voltages and fast current pulses to charge and discharge their capacitances. The power electronics driver circuits 206 amplify and isolates these signals so the power switches can turn on/off efficiently and safely.

[0041] The navigation interface 208 may comprise a Controller Area Network bus (CAN Bus), or Media Oriented Systems Transport, MOST, bus. The CAN bus is used by the navigation unit to send and receive data such as navigation data, vehicle speed, steering angle, and GPS coordinates2. MOST bus is used to transmit multimedia data.

[0042] The detection unit 210 may comprise current detection circuits like current sensors.

[0043] Figure 3 illustrates the firmware modules Navigation interface module 300, Monitoring module 302, SoC prediction module 304, User interface module 306 and Control module 308 and Fail-safe handling module 309. These modules are described in subsequent paragraphs.

[0044] The working of the charging system 102 is described below with reference to figures 1-3.

[0045] When the charge in the battery 114 in the vehicle 100 is running low, the user may decide to charge the battery 114. If the charging is done at home, the charging may be slow charging using AC. If the charging is done at a charging station, the charging may be a fast charging using DC. Frequent fast charging impacts the life of the battery 114 because of degradation due to lithium plating, temperature rise, and accelerated cell aging. This leads to reduced battery life. The slow charging eliminates this impact. However, the charging time is more in slow charging. When the user is in a hurry or at a public charging station, the longer waiting time may cause inconvenience to user. Hence, the user may prefer fast charging. The slow charging is useful when the vehicle is at home and longer charging time does not matter. Hence, based on the location, time available, the combination of fast charging and slow charging can be used efficiently to have advantages of both, i.e. fast charging at public charging station thereby avoiding long waiting time, slow charging at home thereby eliminating battery degradation.

[0046] When the vehicle 100 is outside and the battery 114 is low, the user goes to the charging station 101 and connects the vehicle 100 to the charging station 101 through the connector 126 for charging. The fast charging starts. The detection unit 210 detects the start fast charging. The detection signal is communicated to the charging controller 112. The charging controller 112 determines that the fast charging has started.

[0047] The charging controller 112 requests the navigation unit 106 for the navigation data comprising a distance to a set destination or a distance to a predefined home location when no destination is set, predicted travel time, traffic data, terrain data, weather data on the route to the set destination or the home location, distance to the set destination or the home location, historical driving data etc. The request may be sent by the navigation interface module 208 through the navigation interface which is a standard bus like CAN bus to the navigation unit 106.

[0048] The navigation unit 106 obtains the route conditions, traffic condition, terrain information, weather conditions etc. from a cloud server. Weather data is collected by the cloud provider (from meteorological services, satellites, government weather agencies, etc.). The Traffic data comes from multiple sources: GPS probes from vehicles, mobile devices, road sensors, cameras, and third-party traffic data providers. The cloud server processes, aggregates, and compresses this raw information into usable datasets for navigation (e.g., congestion levels, road closures, rainfall along a route). The navigation unit 106 connects to the cloud server through the vehicle's connectivity module or a paired device, Built-in modem (Telematics Control Unit – TCU), cellular network (3G, 4G, 5G, Long-Term-Evolution vehicle to anything, LTE-V2X), Smartphone tethering via Bluetooth, Wi-Fi, or USB, Head unit with Wi-Fi connects to hotspot or external network.

[0049] The navigation unit 106 communicates with the cloud sever via standard internet protocols - HTTP/HTTPS, REpresentational State Transfer, REST, APIs for periodic updates; Message Queuing Telemetry Transport (MQTT), WebSockets for real-time updates. Data is typically encoded in JSON or XML format.

[0050] The navigation unit 106 requests weather and traffic layers from the cloud server based on Current location (from GNSS/GPS), Destination & route (map-matching). The cloud responds with relevant data. The navigation unit 108 merges this with map data and recalculates routes, distance to a destination etc.

[0051] The navigation unit 106 retrieves the set destination or the home location, computes the distance and travel time to the set destination or the home location, considering the route conditions, traffic conditions, weather conditions, terrain conditions etc. from a cloud server and sends all the navigation data to the charging controller 112.

[0052] The SoC prediction module 304 predicts required SoC to reach the set destination or the home location based on the navigation data and the historical driving data comprising energy consumption per unit distance for different conditions. A safety buffer is added to the required SoC and this value is set as required SoC.

[0053] The SoC is predicted/computed based on: (i) route energy estimate to the set destination or the home location, determined from distance to travel, real-time traffic data, weather data, terrain data etc. (ii) an energy/km model trained on historical driving data stored in the navigation unit 106; and (iii) a safety buffer.

[0054] The prediction of required SoC comprises below steps:

Obtaining navigation data.

Predicting route energy requirement E_route = f(navigation data, historical driving data).

Required SoC (in percentage of battery capacity) = (E_route + E_buffer)/C_bat × 100%.

[0055] E_route is the predicted energy consumption for the route, determined from the navigation data and historical driving data.

[0056] E_buffer is a safety buffer, expressed either as a fixed percentage of E_route or as a dynamic margin determined by environmental factors such as predicted weather (e.g., headwinds, temperature) or anticipated congestion.

[0057] C_bat is the usable capacity of the vehicle battery 114.

[0058] The prediction of SoC may be continuously updated during the charging session as updated navigation or environmental data becomes available, ensuring that the predicted SoC remains accurate and conservative.

Safety Buffer Calculation

[0059] The safety buffer may be implemented in multiple modes:

[0060] Static mode: A fixed percentage (e.g., X% of route energy) added to cover unforeseen conditions. Example, if the traffic is high or unpredictable, the safety buffer may be dynamically set as 30% of energy/km model. If the traffic is low or predictable, the safety buffer may be dynamically set as 20% of energy/km. Similarly if the terrain gradient is high a certain factor for safety buffer is set. Based on the travel time to the charging station and weather conditions, certain factor for safety buffer is set.

[0061] Dynamic mode: Variable buffer determined by route-specific uncertainties. For example, a higher buffer is applied for mountainous terrain, adverse weather, or congested traffic.

[0062] Adaptive learning mode: Buffer adjusted based on historical driving data/efficiency of the user, e.g., aggressive driving habits or past deviations from predicted energy use.

[0063] By incorporating a safety buffer, the system ensures the user is not left stranded even if energy consumption exceeds the baseline prediction.

[0064] Once the required SoC is computed, the required SoC is used as a trigger to generate at least one notification to the user. During the charging session, the required SoC is updated in real time using real time navigation data.

[0065] The monitoring module 302 continuously monitors over-current, over-voltage, short circuit, SoC, temperatures of AC-DC converter 120, DC-DC converter 118 and other components by reading the signals through the input output interfaces 204.

[0066] The monitoring module 302 continuously monitors the present SoC and the dynamically updated required SoC. Once the present SoC in the vehicle 100 equals or exceeds the required SoC, a notification is generated to the user, by the user interface module 306, indicating that the required SoC to reach the destination or the home location is reached. The notification may be on at least one of a dashboard of the vehicle 100, through lamps or on the registered mobile phone 128. Options are provided to the user to select the actions required. The options are: switch to slow charging, terminate fast charging or continue with fast charging. The user may select any one of these options by pressing on the displayed options on the dashboard or on the mobile phone 128 or through keys provided in the dashboard. The user interface module 306 receives the user input and executes accordingly.

[0067] If the user selects option of continuing the fast charging, the fast charging continues till a predefined maximum SoC threshold is reached. The predefined maximum SoC threshold may be pre-stored in memory 202. Once predefined maximum SoC threshold is reached the charging is changed to slow charging by the charging controller 112 or by the charging station 101.

[0068] If the user selects option of switching to slow charging, the user interface module 306 requests the charging station 101 to switch to slow charging. In an embodiment the charging controller 112 and charging station 101 exchange data, via protocols like CCS or CHAdeMO, SAE J1772 or IEC 61851 to negotiate charging speed, voltage, and current threshold for fast and slow charging. In an embodiment, the EV 100 switches to slow charging mode by limiting the current using the current limiting component. In an embodiment the control module 308 limits the charging current for slow charging using the current limiting components which are not shown.

[0069] If the user selects option to terminate the fast charging, the control module 308 sends a command to the charging station 101 to terminate the charging. The charging unit 101 stops charging. The control module 308 opens the fail-safe relay 124 to isolate the battery 114 from the charging station 101.

[0070] If there is any malfunction like over-voltage, over-current, excessive battery temperature, during charging, the charging is terminated. Terminating the charging is done by opening the fail-safe relay 124 by the charging controller 112 through the input output interfaces 204 and the power electronics driver circuits 206.

[0071] The charging controller 112 comprises machine learning model 310, which comprises machine learning algorithm and models, trained on historical driving data/patterns, navigation data like traffic data, terrain data, weather data and energy usage to improve prediction accuracy of required SoC. Over time, this enables more precise prediction of required SoC.

[0072] In an embodiment, prior to charging and during a charging session, the SoC prediction module 304 continuously predicts the required SoC. In an embodiment, the required SoC is dynamically computed by applying a machine learning (ML) model 310 that accounts for the vehicle's historical driving data/patterns and real-time navigation data.

[0073] Machine Learning (ML) Model 310 Architecture

[0074] The ML model 310 may comprise at least one of a regression model, neural network, and gradient boosting algorithm trained to predict energy consumption per unit distance under varying conditions. Input features to the ML model 310 may comprise navigation data and historical driving data, Current vehicle weight/load, Road gradient (from GPS and map data), Real-time traffic congestion level, Ambient temperature and weather forecast, Battery temperature and state-of-health (SoH) etc.

[0075] Regression Model: Learns linear/nonlinear mapping between route conditions and energy consumption per km.

[0076] Neural Network: Captures nonlinear dependencies (e.g., effect of slope + congestion + temperature).

[0077] Gradient Boosting Trees (e.g., eXtreme Gradient Boostin, XGBoost, Light Gradient Boosting Machine, LightGBM): Handles mixed feature inputs and outputs, high accuracy in prediction.

[0078] This comprises the below steps.

[0079] Training Data Collection

[0080] The vehicle's control unit and/or the navigation unit 106, continuously collects historical driving data/pattern, comprising Average and peak energy consumption (Wh/km), Vehicle speed and acceleration patterns, Driving terrain (flat, hilly, mountainous), Ambient temperature and weather effects, Battery aging and degradation trends, Traffic conditions encountered (slow traffic, stop-and-go vs. highway). These data sets are periodically uploaded to a local or cloud-based ML training module. The ML model 310 uses these data sets for predicting required SoC.

[0081] Real-Time Prediction

[0082] Prior to charging session and during a charging session, the control module 308 invokes the ML model 310 to predict/compute the SoC required to reach the set destination or the home location.

[0083] The ML model 310 outputs an estimated energy consumption (kWh) value per unit distance, which includes adjustments for real-time traffic, terrain, weather etc. Based on the energy estimated energy consumption value, the distance to the set destination or the home location, the required S0C is predicted.

[0084] A safety buffer is added to the predicted SoC to account for uncertainty.

[0085] Required SoC Computation

[0086] The predicted SoC plus the safety buffer is set as required SoC to trigger a user notification.

[0087] Dynamic Updating

[0088] As traffic, route, or weather conditions change, the ML model 310 re-predicts the required SoC in real time. The required SoC is dynamically updated during charging session, ensuring that even if conditions worsen, the vehicle 100 always charges enough energy to reach the set destination or the home location.

[0089] . The firmware modules are implemented as firmware or in combination with the hardware.

[0090] The navigation interface module 300 is implemented as combination of firmware and hardware. The hardware part may comprise configuring the CAN bus and exchanging the requests and commands for navigation data on the CAN bus with the navigation unit 108.

[0091] The SoC prediction module 304 interacts with the machine learning model 310 to predict the required SoC.

[0092] The user interface module 306, generates notifications for the user. The notifications may be at least one of visual and audio outputs, buzzers, lamps etc. The notifications indicate the status of the charging. The user interface module 306 is implemented as combination of firmware and hardware. The hardware part comprises the output ports of the processor unit 200 and sending signals through the input output interfaces 204 to the notification unit 108.

[0093] The control module 308 controls and monitors the charging unit 110. The control module 308 is implemented as combination of firmware and hardware. The hardware part comprises the output ports of the processor unit and sending signals through the input output interfaces 204 to the Power electronics driver circuits 206.

[0094] The fail-safe handling module 309 monitors for any fault conditions and immediately disconnects the battery 114 of the vehicle 100 from the charging station 101 by opening the fail-safe relay 124. The fail-safe handling module 309 is implemented as combination of firmware and hardware. The hardware part comprises the output ports of the processor unit and sending signals through the input output interfaces 204 and power electronics driver circuits 206 to the fail-safe relay 124.

[0095] The firmware modules may be implemented using various languages like, C, Embedded C, C++, JAVA etc.

[0096] Given below are some examples how the modules for communicating through Bluetooth modules are developed for Android devices like Internet of Things (IoT) devices and mobile phones, for example between the charging controller 112 and the mobile phone 128.

[0097] Tools and technologies used:

The tools used may comprise, Android Studio, Java or Kotlin programming language, Android Software Development Kit, Android Native Development Kit, Wi-Fi or Bluetooth module, Message Queuing Telemetry Transport, MQTT broker etc.

[0098] Android SDK: Software development kit for tools and libraries for developing Android apps.

[0099] Android NDK: a software development kit that provides tools and libraries for developing native code for Android apps.

[0100] MQTT, Message Queuing Telemetry Transport: A messaging protocol for IoT devices.

[0101] Different Application Programming Interface, APIs, like Nearby Connections API may be used to search, establish connection and transfer data between Android devices. Within the Nearby Connections API, the function startDiscovery () function may be used to discover other devices like system 100. Once other devices are discovered, the function requestConnection () is used to request a connection. The connection request is accepted through acceptConnection () or rejected through rejectConnection () by devices. Once the connection is accepted, the charging controller 112 and the mobile phone 128 can exchange data. Also the JAVA APIs like navigator.bluetooth.requestDevice may be used to discover, connect and transfer data between IoT devices and mobile phones, for example the charging controller 112 and the mobile phone 128.

[0102] Figure 4 illustrates a method 400 for Predictive Charging of a vehicle 100. The method 400 is performed by the charging controller 112. The method starts with step 402.

[0103] Step 402 discloses detecting start of fast charging of the battery 114 of the electric vehicle 100.

[0104] Step 404 disclose receiving set destination or home location, navigation data from the navigation unit 106.

[0105] Step 406 discloses predicting required SoC for the battery 114 to reach the set destination or the home location, based on the navigation data.

[0106] Step 408 discloses monitoring the SoC of the battery 114 during the fast charging.

[0107] Step 410 discloses generating at least one notification to a user when the monitored SoC reaches or exceeds the required SoC, the notifications providing options for the user to continue fast charging, to terminate fast charging or to switch to slow charging.

[0108] Step 412 discloses controlling the charging unit 110 and/or communicating appropriate messages to the charging station 101, to execute the option selected by the user. The appropriate messages comprise request to switch to slow charging, terminate fast charging, communicating a predetermined current threshold to the charging station 101 etc.

[0109] The subject matter provides various technical advantages. Some are listed below, for example.

[0110] Battery life extension: By reducing unnecessary time spent for fast charging which uses high current charging, once the required SoC is reached, the charging controller 112 minimizes degradation due to lithium plating, high temperature rise, and accelerated cell aging, by switching to slow charging.

[0111] Improved charging efficiency: Fast charging typically becomes inefficient at higher SoC levels due to tapering. By notifying the user early, the charging sessions are shortened, improving station throughput.

[0112] User control and flexibility: Instead of relying solely on automated cut-offs, the charging controller 112 empowers the user to make an informed decision based on travel needs and battery preservation.

[0113] Grid load management: Allowing users to switch to slow charging after achieving the required SoC reduces instantaneous demand on the charging infrastructure, supporting grid stability during peak demand periods.

[0114] Fallback to home location: Even when no navigation destination is set, the charging controller 112 provides a reliable benchmark by using the stored home address, ensuring predictive control is always available.

Reference numerals and their description:

100	Vehicle
101	Charging station
102	Charging system
104	Communication unit
106	Navigation unit
108	Notification unit
110	Charging unit
112	Charging controller
114	Battery
116	Battery management system
118	DC-DC converter
120	AC-DC converter
122	Protection circuits
124	Fail-safe relay
126	Connector
128	Mobile phone
200	Processor unit
202	Memory unit
204	Input output interfaces
206	Power electronics driver circuits
208	Navigation interface
300	Navigation interface module
302	Monitoring module
304	SoC prediction module
306	User interface module
308	Control module
309	Fail-safe handling module 309
310	Machine learning models

We claim:

1. A method (400) for predictive charging of an electric vehicle (100), the method (400) comprising:

   detecting (402) start of fast charging of a battery (114) of the electric vehicle (100);

   receiving (404) navigation data, from a navigation unit (106) of the electric vehicle (100), the navigation data comprising:
   a distance to a set destination or a distance to a predefined home location when no destination is set; and
   predicted travel time, traffic data, terrain data, weather data on the route to the set destination or the home location, distance to the set destination or the home location, historical driving data;

   predicting (406) a required state of charge (SoC) for the battery (114) for reaching the set destination or the home location, based on the navigation data, the prediction including a safety buffer;

   monitoring (408) the SoC of the battery (114) during the fast charging;

   generating (410) at least one notification to a user when the monitored SoC reaches or exceeds the required SoC, the notifications presenting one or more selectable options for:
   termination of the fast charging;
   switching from fast charging to slow charging; and
   continuation of the fast charging; and
   and
   controlling (412) a charging unit (110) to execute the option selected by the user.

2. The method (400) as claimed in claim 1, wherein controlling the charging unit (110) to execute the option selected by the user comprises at least one of:
   sending a message to the charging station (101) to terminate the charging, and opening a safety-relay (124); and
   sending a message to the charging unit (101) to switch to slow charging,

   based on the user selected option.

3. The method (400) as claimed in claim 1, comprises dynamically computing the safety buffer based on real time navigation data.

4. The method (400) as claimed in claim 1, wherein generating at least one notification comprises generating notification via at least one of: a vehicle dashboard display, on a registered mobile phone linked to the electric vehicle (100), or an audio output on an infotainment device of the electric vehicle (100).

5. The method (400) as claimed in claim 1, wherein switching from fast charging to slow charging comprises at least one of:
   reducing a charging current supplied to the battery (114) below a predetermined current threshold; or
   communicating the predetermined current threshold to the charging station (101).

6. The method (400) as claimed in claim 1, further comprising terminating the charging session by opening the fail-safe relay (124), if no user input is received within a predetermined time after the notification is generated.

7. The method (400) as claimed in claim 1, comprising continuing the fast charging till a pre-defined maximum SoC threshold, on user selecting the option to continue fast charging.

8. The method (400) as claimed in claim 1, wherein terminating the fast charging comprises sending a message to the charging station (101) to terminate the charging; and opening the safety-relay (124);

9. The method (400) as claimed in claim 1, wherein predicting the required SoC, further comprises applying a machine learning model (310) trained on historical driving data of the electric vehicle (100) to predict power consumption based on real time navigation data, wherein the machine learning models comprise at least one of a regression model, neural network, or gradient boosting algorithm trained to predict power consumption per unit distance under varying conditions.

10. The method (400) as claimed claim 1, wherein terminating the charging session further comprises opening the fail-safe relay (124) to electrically isolate the battery (114) of the electric vehicles (100).

11. The method (400) as claimed claim 1, comprising dynamically adjusting the safety buffer based on at least one of: ambient temperature, battery health state and historical variance in energy prediction accuracy.

12. A predictive charging controller (112) for an electric vehicle (100), the predictive charging controller (112) comprising:

a detection unit (210) to detect start of a fast charging of a battery (114) of the electric vehicle (100);

a navigation interface (208) to receive, from a navigation unit (106) of the electric vehicle (100), the navigation data comprising:
a distance to a set destination or a distance to a predefined home location when no destination is set; and
predicted travel time, traffic data, terrain data, weather data on the route to the set destination or the home location, distance to the set destination or the home location, historical driving data;

a state-of-charge, SoC, prediction module (304) to predict a required state of SoC to reach the set destination or the home location, based on the navigation data, the prediction including a safety buffer;

a monitoring module (302) to monitor the SoC of a battery (114) of the electric vehicle (100) during the fast charging;

a user interface module (306) to generate at least one notification to a user when the current SoC reaches or exceeds the required SoC, the notification presenting selectable options comprising at least one of:
termination of the fast charging;
switching from fast charging to slow charging; and
continuation of fast charging;
and
a control module (308) to control a charging unit (110) to execute the option selected by the user.

13. The predictive charging controller (112) as claimed in claim 12, wherein the control module (308) is configured to control the charging unit (110) to execute the option selected by the user by, at least one of:
sending a message to the charging station (101) to terminate the charging, and opening a safety-relay (124); and
sending a message to the charging unit (101) to switch to slow charging,

based on the user selected option.

14. The predictive charging controller (112) as claimed in claim 12, wherein the predefined home location is retrieved from a user profile stored in the electric vehicle (100).

15. The predictive charging controller (112) as claimed in claim 12, wherein the safety buffer is dynamically computed according to real time navigation data comprising at least one of terrain data, weather data and traffic data.

16. The predictive charging controller (112) as claimed in claim 12, wherein the control module (308) is configured to reduce charging current below a predetermined threshold when switching from fast charging to slow charging.

17. The predictive charging controller (112) as claimed in claim 12, wherein the control module is configured to send a message to the charging station to switch from fast charging to slow charging.

18. The predictive charging controller (112) as claimed in claim 12, wherein the notification is presented via at least one of a vehicle dashboard display, on a registered mobile phone (128) and a voice assistant.

19. The predictive charging controller (112) as claimed in claim 12, configured to terminate fast charging if no user input is received within a predetermined time after the notification.

20. The predictive charging controller (112) as claimed in claim 12, comprising machine learning model (310) to predict required SoC, the machine learning model (310) trained on historical driving data of the electric vehicle (100) to predict power consumption under current traffic, weather and terrain conditions, wherein the machine learning model (310) comprises at least one of a regression model, neural network, or gradient boosting algorithm trained to predict power consumption per unit distance under varying conditions.

21. The predictive charging controller (112) as claimed in claim 12, comprising Navigation interface module 300, Monitoring module 302, SoC prediction module 304, User interface module 306, Control module 308 and a Fail-safe handling module 309.

Prakash Balekundri
Patent Agent
IN/PA Number: 1935

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ABSTRACT

TITLE: Predictive charging controller and a method thereof

The subject matter discloses a predictive charging controller 112 and a method 400 for controlling predictive charging of an electric vehicle 100. The predictive charging controller 112 detects initiation of fast charging, receives navigation data including distance to a set destination or, when no destination is set, distance to a predefined home location. Based on this data, a required SoC including a safety buffer is computed. The SoC of the battery is monitored continuously. When the monitored SoC of the vehicle battery 114 reaches or exceeds the required SoC, a notification is generated for the user. The notification provides selectable options comprising terminating charging, switching from fast to slow charging, or continuing fast charging. The predictive charging controller 112 executes the option selected by the user.

To be published with figure 1