

A SYSTEM AND METHOD FOR DETERMINING A CHARGING SCHEDULE FOR A PLURALITY OF VEHICLES

TECHNICAL FIELD

[0001] Various aspects of this disclosure relate to a system for determining a charging schedule for a plurality of vehicles, affiliated with a charging station, a control device for said system, and a method of operating the system for determining the charging schedule.

BACKGROUND

[0002] The following discussion of the background art is intended to facilitate an understanding of the present disclosure only. It should be appreciated that the discussion is not an acknowledgement or admission that any of the material referred to was published, known or is part of the common general knowledge of the person skilled in the art in any jurisdiction as of the priority date of the disclosure.

[0003] Electrification of the transport sector provides a sustainable alternative to the use of fossil fuels, e.g. petrol, and many economies have been adopting the use of electric vehicles (EVs) for transportation. However, the increasing penetration of EVs and their uncoordinated charging thereof at a particular charging station places immense pressure on existing energy infrastructure, leading to peak loads, excessive charging costs, and power outages.

[0004] In addition, the availability of a relatively limited number of charging facilities at a charging station is an unavoidable infrastructural limitation, and in many instances, leads to congestion of the charging facilities at certain periods.

[0005] Another problem associated with the use of EVs is driver range anxiety regarding the available electrical energy required for the driver to reach a destination. This leads to inaccurate energy levels at the end of a charging cycle, e.g. undercharging or overcharging, and often, the deterioration of the EV's battery capacity.

[0006] Further, an imbalance related to the customer requests and the availability of on-demand EVs leads to disruption in service level agreements.

[0007] Accordingly, there exists a need for an improved system that seeks to address at least one of the aforementioned problems.

SUMMARY

[0008] The disclosure was conceptualized to provide an improved system to determine an optimal electrical charging schedule for a plurality of vehicles, which in some embodiments may be operated by an on-demand vehicle provider, each vehicle being affiliated with a particular charging station. To this end, the improved system considers various parameters such as the state of health (SOH) of the electrochemical cell, e.g. battery; a state of energy (SOE), i.e. stored energy level of the electrochemical cell; a forecasted customer demand to the on-demand service provider for accessing the vehicles, and operational constraints of the electrochemical cells and the charging station, to obtain a control signal, e.g. required energy exchange instruction between the electrochemical cells and the charging station suitable for servicing the transportation requirements, e.g. demand requests of the users. In addition, the improved system utilizes the SOH and SOE of the batteries to develop charging strategies that mitigates degradation of the capacity of the said electrochemical cells. The improved system also manages uncertainty in demand prediction through an iterative sliding horizon approach for future demand satisfaction. Accordingly, the improved system provides a charging schedule that achieves, an immediate objective of the minimization of electricity cost under a dynamic electricity pricing structure, and long-term objectives of reducing electrochemical cell replacement, minimizing the electrochemical cells' replacement costs, maximizing the number of available vehicles by considering a predicted demand of the vehicles, and performing peak load shaving at the charging station.

[0009] According to a first aspect of the disclosure, there is provided a system for determining, over a predetermined time horizon, a charging schedule for a plurality of vehicles, which may be operated by an on-demand vehicle provider, and affiliated with a charging station, e.g. a source charging station, the system comprising a processor, the processor configured to: obtain, a first parameter indicative of SOH of an electrochemical cell of at least one vehicle among the plurality of vehicles; obtain, a second parameter indicative of a SOE of the electrochemical cell of the at least one vehicle among the plurality of vehicles; obtain, a third parameter indicative of a demand, over the predetermined time horizon, of the at least one vehicle among the plurality of vehicles, the at least one vehicle having an energy level greater than or equal to a threshold energy level; obtain, a fourth parameter indicative of an operational capacity of the charging station; and determine, for the at least one vehicle among the plurality of vehicles, a control signal related to the charging schedule, the control signal determined based on, at least one of the first parameter, the second parameter, the third parameter and/or

the fourth parameter. In some embodiments, the processor may be further configured to obtain, a sixth parameter indicative of a state of charge (SOC) of the electrochemical cell of the at least one vehicle among the plurality of vehicles, and to further determine the control signal based on, at least one of the first parameter, the second parameter, the third parameter, the fourth parameter, and/or the sixth parameter. The first aspect of the disclosure provides an improved system that minimizes electricity costs under a dynamic electricity pricing structure, reduces the requirement for electrochemical cell replacement, minimizes the electrochemical cells' replacement costs, maximizes the number of available vehicles, and provides peak load shaving at the charging station.

[0010] In various embodiments, the plurality of vehicles comprises at least one en route vehicle, and the processor is further configured to obtain, a fifth parameter indicative of an estimated arrival time of the en route vehicle at the charging station; and determine, for the at least one en route vehicle among the plurality of vehicles, the control signal related to the charging schedule, based on, at least one of the first parameter, the second parameter, the third parameter, the fourth parameter, the fifth parameter and/or the sixth parameter. Said embodiment may provide means for determining the SOE for the electrochemical cells' of en route vehicles, for determining an optimal charging strategy to mitigate degradation of the vehicles' electrochemical cells.

[0011] In various embodiments, the first parameter indicative of the SOH of the electrochemical cell comprises, at least one of a degradation of the electrochemical cell, and/or an age of the electrochemical cell. The consideration of first parameter may allow the improved system to develop optimal charging strategies that mitigates degradation of the capacity of the vehicles' electrochemical cells.

[0012] In various embodiments, the plurality of vehicles further comprises at least one idle vehicle, and wherein the second parameter indicative of the SOE of the electrochemical cell comprises, an initial energy level of the idle vehicle, and/or an estimated energy level of the en route vehicle at the estimated arrival time of the en route vehicle at the charging station. The consideration of second parameter for idle and en route vehicles, may allow the improved system to develop optimal charging strategies that mitigates degradation of the capacity of the vehicles' electrochemical cells.

[0013] In various embodiments, the fifth parameter indicative of the estimated arrival time of the en route vehicle at the charging station comprises, at least one of a departure time of the

en route vehicle from the charging station; a traffic data indicative of a traffic condition related to the en route vehicle; a weather data related to the en route vehicle; a road network data indicative of road network information related to the en route vehicle; and/or a performance data indicative of a performance condition of the en route vehicle. The consideration of the fifth parameter may provide means for determining the SOE for the electrochemical cells' of en route vehicles, for determining an optimal charging strategy to mitigate degradation of the vehicles' electrochemical cells.

[0014] In various embodiments, the estimated energy level of the en route vehicle at the estimated arrival time comprises, at least one of the departure time, the road network data, and/or the fifth parameter indicative of the estimated arrival time of the en route vehicle. The consideration of the estimated energy level of the en route vehicle at the estimated arrival time, may allow the determination of an optimal charging strategy to mitigate degradation of the vehicles' electrochemical cells.

[0015] In various embodiments, the third parameter indicative of the demand of the at least one vehicle having the energy level greater than or equal to the threshold energy level, further comprises a trip information, and wherein the third parameter comprises, at least one of: a historical supply data, of the at least one vehicle having the energy level greater than or equal to the threshold energy level; a historical demand data, of the at least one vehicle having the energy level greater than or equal to the threshold energy level, the historical demand comprising a historical trip information of said vehicle; a historical weather data related to the historical demand data and historical supply data of the at least one vehicle having the energy level greater than or equal to the threshold energy level; a forecasted weather data over the predetermined time horizon; and/or a forecasted supply data, indicative of an estimated supply of the at least one vehicle or another vehicle, having the energy level greater than or equal to the threshold energy level. Said embodiment may provide means for predicting the demand of available vehicles, and managing uncertainty in demand prediction for future demand satisfaction.

[0016] In various embodiments, the fourth parameter indicative of the operational capacity of the charging station comprises, at least one of a total number of units of available energy at the charging station; a cost per unit of the available energy at the charging station; a total number of charging ports available at the charging station; and/or a various number of charging modes for each charging port among the total number of charging ports available at the

charging station. The consideration of the fourth parameter may allow the determination of an optimal control signal related to the charging schedule of the improved system.

[0017] In various embodiments, the control signal related to the charging schedule comprises at least one of a required energy, such that the energy level of the at least one vehicle is greater than or equal to, the threshold energy level; a required charge duration, the required charge duration based on the required energy and a charging rate of the electrochemical cell; and a required charging mode among the various number of charging modes, for an allocated charging port among the total number of charging ports available, wherein the required charging mode is based on the required energy, the required charge duration and/or a desired duration, and the third parameter. The control signal related to the charging schedule of the improved system may minimize electricity costs under a dynamic electricity pricing structure, reduce the requirement for electrochemical cell replacement, minimize the electrochemical cells' replacement costs, maximize the number of available vehicles, and provide peak load shaving at the charging station.

[0018] In various embodiments, the processor is further configured to determine the control signal based on, at least one of: a charging rate of the electrochemical cell of the at least one vehicle; the second parameter indicative of the SOE of the electrochemical cell of the at least one vehicle over the predetermined time horizon. The control signal related to the charging schedule of the improved system may minimize electricity costs under a dynamic electricity pricing structure, reduce the requirement for electrochemical cell replacement, minimize the electrochemical cells' replacement costs, maximize the number of available vehicles, and provide peak load shaving at the charging station.

[0019] In various embodiments, the processor is further configured to transmit, the control signal to another processor of the at least one vehicle. Said embodiment provides the implementation of the control signal related to the charging schedule so as to achieve the objectives of the improved system.

[0020] According to a second aspect of the disclosure, there is provided a control device comprising a processor for determining, over a predetermined time horizon, a charging schedule for a plurality of vehicles affiliated with a charging station, the processor being in data communication with a memory having instructions stored therein, the instructions, when executed by the processor, causes the processor to: obtain, a first parameter indicative of a SOH of an electrochemical cell of at least one vehicle among the plurality of vehicles; obtain, a

second parameter indicative of a SOE of the electrochemical cell of the at least one vehicle among the plurality of vehicles; obtain, a third parameter indicative of a demand, over the predetermined time horizon, of the at least one vehicle among the plurality of vehicle, the at least one vehicle having an energy level greater than or equal to a threshold energy level; obtain, a fourth parameter indicative of an operational capacity of the charging station; and determine, for the at least one vehicle among the plurality of vehicles, a control signal related to the charging schedule, the control signal determined based on, at least one of the first parameter, the second parameter, the third parameter and/or the fourth parameter. In some embodiments, the processor may further obtain, a sixth parameter indicative of a SOC of the electrochemical cell of the at least one vehicle among the plurality of vehicles, and to further determine the control signal based on, at least one of the first parameter, the second parameter, the third parameter, the fourth parameter, and/or the sixth parameter. The second aspect of the disclosure provides a control device, including instructions that when executed on a processor, allows the determination of a charging schedule for a plurality of vehicles, that minimizes electricity costs under a dynamic electricity pricing structure, reduces the requirement for electrochemical cell replacement, minimizes the electrochemical cells' replacement costs, maximizes the number of available vehicles, and provides peak load shaving at the charging station.

[0021] In various embodiments, the plurality of vehicles comprises at least one en route vehicle, and the processor of the control device is further configured to obtain, a fifth parameter indicative of an estimated arrival time of the en route vehicle at the charging station; and determine, for the at least one en route vehicle among the plurality of vehicles, the control signal related to the charging schedule, based on, at least one of the first parameter, the second parameter, the third parameter, the fourth parameter, the fifth parameter and/or the sixth parameter. Said embodiment may provide means for determining the SOE for the electrochemical cells' of en route vehicles, for determining an optimal charging strategy to mitigate degradation of the vehicles' electrochemical cells.

[0022] According to a third aspect of the disclosure, there is provided a method for determining, over a predetermined time horizon, a charging schedule for a plurality of vehicles affiliated with a charging station, the method comprising providing a processor for: obtaining, a first parameter indicative of a SOH of an electrochemical cell of at least one vehicle among the plurality of vehicles; obtaining, a second parameter indicative of a SOE of the

electrochemical cell of the at least one vehicle among the plurality of vehicles; obtaining, a third parameter indicative of a demand, over the predetermined time horizon, of the at least one vehicle among the plurality of vehicle, the at least one vehicle having an energy level greater than or equal to a threshold energy level; obtaining, a fourth parameter indicative of an operational capacity of the charging station; and determining, for the at least one vehicle among the plurality of vehicles, a control signal related to the charging schedule, the control signal determined based on, at least one of the first parameter, the second parameter, the third parameter and/or the fourth parameter. In some embodiments, the processor may further obtain, a sixth parameter indicative of a SOC of the electrochemical cell of the at least one vehicle among the plurality of vehicles, and to further determine the control signal based on, at least one of the first parameter, the second parameter, the third parameter, the fourth parameter, and/or the sixth parameter. The third aspect of the disclosure provides an improved method that minimizes electricity costs under a dynamic electricity pricing structure, reduces the requirement for electrochemical cell replacement, minimizes the electrochemical cells' replacement costs, maximizes the number of available vehicles, and provides peak load shaving at the charging station.

[0023] In various embodiments, the plurality of vehicles comprises at least one en route vehicle, and the processor further obtains, a fifth parameter indicative of an estimated arrival time of the en route vehicle at the charging station; and determines, for the at least one vehicle among the plurality of vehicles, the control signal related to the charging schedule, based on, at least one of the first parameter, the second parameter, the third parameter, the fourth parameter, the fifth parameter and/or the sixth parameter. Said embodiment may provide means for determining the SOE for the electrochemical cells' of en route vehicles, for determining an optimal charging strategy to mitigate degradation of the vehicles' electrochemical cells.

[0024] In various embodiments, the first parameter indicative of the SOH of the electrochemical cell comprises, at least one of a degradation of the electrochemical cell, and/or an age of the electrochemical cell. The consideration of first parameter may allow the improved method to develop optimal charging strategies that mitigates degradation of the capacity of the vehicles' electrochemical cells.

[0025] In various embodiments, the plurality of vehicles further comprises at least one idle vehicle, and the second parameter indicative of the SOE of the electrochemical cell comprises, an initial energy level of the idle vehicle, and/or an estimated energy level of the en route

vehicle at the estimated arrival time of the en route vehicle at the charging station. The consideration of second parameter for idle and en route vehicles, may allow the improved method to develop optimal charging strategies that mitigates degradation of the capacity of the vehicles' electrochemical cells.

[0026] In various embodiments, the fifth parameter indicative of the estimated arrival time of the en route vehicle at the charging station comprises, at least one of a departure time of the en route vehicle from the charging station; a traffic data indicative of a traffic condition related to the en route vehicle; a weather data related to the en route vehicle; a road network data indicative of road network information related to the en route vehicle; and/or a performance data indicative of a performance condition of the en route vehicle. The consideration of the fifth parameter may provide means for determining the SOE for the electrochemical cells' of en route vehicles, for determining an optimal charging strategy to mitigate degradation of the vehicles' electrochemical cells.

[0027] In various embodiments, the estimated energy level of the en route vehicle at the estimated arrival time comprises, at least one of the departure time, the road network data, and/or the fifth parameter indicative of the estimated arrival time of the en route vehicle. The consideration of the estimated energy level of the en route vehicle at the estimated arrival time, may allow the determination of an optimal charging strategy to mitigate degradation of the vehicles' electrochemical cells.

[0028] In various embodiments, the third parameter indicative of the demand of the at least one vehicle having the energy level greater than or equal to the threshold energy level, further comprises a trip information, and wherein the third parameter comprises, at least one of: a historical supply data, of the at least one vehicle having the energy level greater than or equal to the threshold energy level; a historical demand data, of the at least one vehicle having the energy level greater than or equal to the threshold energy level, the historical demand comprising a historical trip information of said vehicle; a historical weather data related to the historical demand data and historical supply data of the at least one vehicle having the energy level greater than or equal to the threshold energy level; a forecasted weather data over the predetermined time horizon; and/or a forecasted supply data, indicative of an estimated supply of the at least one vehicle or another vehicle, having the energy level greater than or equal to the threshold energy level. Said embodiment may provide means for predicting the demand of

available vehicles, and managing uncertainty in demand prediction for future demand satisfaction.

[0029] In various embodiments, the fourth parameter indicative of the operational capacity of the charging station comprises, at least one of a total number of units of available energy at the charging station; a cost per unit of the available energy at the charging station; a total number of charging ports available at the charging station; and/or a various number of charging modes for each charging port among the total number of charging ports available at the charging station. The consideration of the fourth parameter may allow the determination of an optimal control signal related to the charging schedule of the improved method.

[0030] In various embodiments, the control signal related to the charging schedule comprises at least one of a required energy, such that the energy level of the at least one vehicle is greater than or equal to, the threshold energy level; a required charge duration, the required charge duration based on the required energy and a charging rate of the electrochemical cell; and a required charging mode among the various number of charging modes, for an allocated charging port among the total number of charging ports available, wherein the required charging mode is based on the required energy, the required charge duration and/or a desired duration, and the third parameter. The control signal related to the charging schedule of the improved method may minimize electricity costs under a dynamic electricity pricing structure, reduce the requirement for electrochemical cell replacement, minimize the electrochemical cells' replacement costs, maximize the number of available vehicles, and provide peak load shaving at the charging station.

[0031] In various embodiments, the processor is further configured to determine the required energy based on, at least one of a charging rate of the electrochemical cell of the at least one vehicle; the second parameter indicative of the SOE of the electrochemical cell of the at least one vehicle over the predetermined time horizon. The control signal related to the charging schedule of the improved method may minimize electricity costs under a dynamic electricity pricing structure, reduce the requirement for electrochemical cell replacement, minimize the electrochemical cells' replacement costs, maximize the number of available vehicles, and provide peak load shaving at the charging station.

[0032] According to a fourth aspect of the disclosure, there is provided a computer readable medium comprising instructions, which when executed by the processor, causes the processor to perform the method according to the third aspect. The fourth aspect of the disclosure

provides a medium, including instructions that when executed on a processor, allows the determination of a charging schedule for a plurality of vehicles, that minimizes electricity costs under a dynamic electricity pricing structure, reduces the requirement for electrochemical cell replacement, minimizes the electrochemical cells' replacement costs, maximizes the number of available vehicles, and provides peak load shaving at the charging station.

[0033] In various embodiments of the first to fourth aspects, each vehicle among the plurality of vehicles may be an EV. In some embodiments, the vehicle may be a hybrid vehicle.

BRIEF DESCRIPTION OF THE DRAWINGS

[0034] The disclosure will be better understood with reference to the detailed description when considered in conjunction with the non-limiting examples and the accompanying drawings, in which:

- FIG. 1 shows an exemplary schematic of a system 100 including a processor 150 for determining a charging schedule, over a predetermined time horizon, for a plurality of vehicles 110 affiliated with a charging station 102;
- FIG. 2 shows an exemplary schematic of a system 200 including the processor 150 for obtaining an estimated arrival time 124, and the second parameter 154 indicative of the SOE 122 of the electrochemical cell 116 of the en route vehicle 114;
- FIG. 3 shows an example of a performance measurement of the estimated arrival time 124 according to embodiments of the disclosure;
- FIG. 4A shows an example of a performance measurement of the SOE 122 of the en route vehicle 114, and FIG. 4B shows a graphical representation of an actual vs. predicted energy usage of the en route vehicle 114, according to embodiments of the disclosure;
- FIGS. 5A, 5B, 5C and 5D show exemplary graphical representations of the identified electrochemical cell 116 parameters, according to embodiments of the disclosure;
- FIG. 6 shows a system 600 for obtaining the third parameter 156 indicative of the customer demand 130 over the predetermined time horizon, for a plurality of vehicles 110 with a requirement of having an energy level greater than or equal to the threshold energy level required for servicing a demand request.
- FIG. 7A shows a graphical representation of an actual vs. forecasted demand 130 using the DeepAR machine learning algorithm, and FIG. 7B shows a graphical representation

of an actual vs. seasonal naïve forecasted demand 130, according to embodiments of the disclosure;

- FIGS. 8A, 8B, 8C, and 8D show graphical representations of the predicted 802 vs. measured 804 responses of the terminal voltages, e.g. $v^{ev}[k]$, of the electrochemical cell 116 at different SOC 123 levels, according to embodiments of the disclosure;
- FIG. 9 shows an exemplary schematic illustration of a control device 900 comprising a processor 920 configured to determine, over a predetermined time horizon, a charging schedule for a plurality of vehicles affiliated with a charging station, in accordance with another aspect of the disclosure;
- FIG. 10 shows an exemplary flowchart of a method 1000 for determining over a predetermined time horizon, a charging schedule for a plurality of vehicles affiliated with a charging station, in accordance with another aspect of the disclosure;
- FIGS. 11A and 11B show comparisons between the total energy consumption of a simulation for a plurality of vehicles, determined based on conventional algorithms, and algorithms of the system, control device and/or methods according to various aspects and embodiments of the disclosure;
- FIGS. 12A and 12B show comparisons between the electricity costs of a simulation for a plurality of vehicles, determined based on conventional algorithms, and algorithms of the system, control device and/or methods according to various aspects and embodiments of the disclosure;
- FIGS. 13A and 13B show comparisons between the electrochemical cell 116 degradation costs and energy consumption, of a simulation for a plurality of vehicles, determined based on conventional algorithms, and algorithms of the system, control device and/or methods according to various aspects and embodiments of the disclosure;
- FIGS. 14A and 14B show comparisons between the SOE levels of a plurality of vehicles over time, based on a simulation for said plurality of vehicles, determined based on conventional algorithms, and algorithms of the system, control device and/or methods according to various aspects and embodiments of the disclosure. FIGS. 14C and 14D show the terminal voltages of selected vehicles among the plurality of vehicles over time.

DETAILED DESCRIPTION

[0035] The following detailed description refers to the accompanying drawings that show, by way of illustration, specific details and embodiments in which the disclosure may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the disclosure. Other embodiments may be utilized and structural, and logical changes may be made without departing from the scope of the disclosure. The various embodiments are not necessarily mutually exclusive, as some embodiments can be combined with one or more other embodiments to form new embodiments.

[0036] Features that are described in the context of an embodiment may correspondingly be applicable to the same or similar features in the other embodiments. Features that are described in the context of an embodiment may correspondingly be applicable to the other embodiments, even if not explicitly described in these other embodiments. Furthermore, additions and/or combinations and/or alternatives as described for a feature in the context of an embodiment may correspondingly be applicable to the same or similar feature in the other embodiments.

[0037] In the context of various embodiments, the articles “a”, “an” and “the” as used with regard to a feature or element include a reference to one or more of the features or elements. As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

[0038] In the context of various embodiments, the terms “first”, “second”, “third”, “fourth” are merely used as notations to denote the order of the features or elements as they appear in the disclosure for clarity, and do not necessarily infer priority.

[0039] Throughout the description, the term “charging schedule”, as used herein, refers to a charging coordination arrangement, plan or strategy for a plurality, i.e. fleet of vehicles, each vehicle may be affiliated with a particular charging station. The charging schedule may include a set of control signals, and each one of the control signals may be the charging plan for the plurality of vehicles. In some embodiments, the charging schedule may be determined for the particular charging station, e.g. source charging station, and may be provided to the plurality of vehicles.

[0040] Throughout the description, the term “affiliated”, as used herein, refers to a relationship or association between each vehicle of the plurality of vehicle and a particular, e.g. source charging station. In some embodiments, a vehicle may be associated with a particular charging station, e.g. a source charging station near (i.e. within a predetermined distance) their place of residence or place of business. In some other embodiments, a vehicle may be

associated with more than one charging stations, e.g. source charging stations within a particular district or location.

[0041] Throughout the description, the term “vehicle(s)”, as used herein, refers broadly to any transportation means for transporting people, goods, crop, e.g. agricultural vehicles and/or animals, e.g. farm vehicles. The vehicles of the disclosure may be particularly suitable for transport on land, and in some embodiments may include vehicles such as cars, buses, lorries, trucks and/or motorcycles. It is contemplated that the vehicle may be a vehicle suitable for transport via rail, e.g. trains; air, e.g. aircrafts; or water, e.g. hovercrafts, ships.

[0042] Throughout the description, the term “idle vehicle”, as used herein, refers to a vehicle not in motion, and situated at the charging station. For example, the idle vehicle may be parked, and the engine of the idle vehicle may not be running. Accordingly, energy may not be drained from the electrochemical cell of the idle vehicle. In some embodiments, the idle vehicle may not or yet to be connected to a charging port, and the energy level of the electrochemical cell may be lower than a threshold energy level. In some other embodiments, the electrochemical cell of the idle vehicle may have an energy level equal to or greater than, the threshold energy level.

[0043] Throughout the description, the term “en route vehicle”, as used herein, refers a vehicle that has disconnected from a charging port of a charging station, e.g. source charging station. The en route vehicle may not be connected to a charging port, and energy may be drained from the electrochemical cell of the en route vehicle while it is in motion. This includes time periods where the en route may be stationary while having its engine running, e.g. at a red-light junction, parked outside a business or residence for a temporary period. In some embodiments, the en route vehicle may depart and return to the same charging station, e.g. source charging station. In some other embodiments, the en route vehicle may depart from another charging station and may return to the source charging station for charging of the electrochemical cell for the vehicle.

[0044] Throughout the description, the term “estimated arrival time” of the en route vehicle, as used herein, may refer to a time or time interval when the en route vehicles arrives at the source charging station, and is to be connected to the charging port. In various embodiments, the estimated arrival time may refer to the specific time or time interval at which the electrochemical cell of the vehicle is to be connected to the charging port. Accordingly, the

term “departure time” of the en route vehicle, as used herein, refers to a time or time interval that the vehicle is disconnected from the charging port, e.g. after a charging session.

[0045] Throughout the description, the term “electrochemical cell”, as used herein, refers to a battery module of the vehicle, e.g. idle, en route vehicle, while it is not connected to the charging port. The electrochemical cell may be a stored energy supply for the vehicle. In various embodiments, the electrochemical cell may be a rechargeable battery suitable for an electric vehicle (EV). In the description, the electrochemical cell may be defined by one or more parameters such as but not limited to, SOH, SOE, a charging efficiency, a charging rate, a maximum charge capacity.

[0046] Throughout the description, the term “obtain”, as used herein, refers to the processor which actively obtains, or passively receives information, e.g. parameters or data, from one and/or sensors. The processor may also obtain various data types from another processor or a communication interface, e.g. a user interface. The processor may also receive or obtain the various data types via a memory, a register, and/or an analog-to-digital port.

[0047] Throughout the description, the term “processor”, refers to a circuit, including analog circuits or components, digital circuits or components, hybrid circuits or components. Any other kind of implementation of the respective functions which will be described in more detail below may also be understood as a “circuit” in accordance with an alternative embodiment. A digital circuit may be understood as any kind of logic implementing entity, which may be a special purpose circuitry or a processor executing software store in a memory, or a firmware. The processor may also include a single stand-alone computer, a single dedicated server, multiple dedicated servers, and/or a virtual server running on a larger network of servers and/or cloud-based service. In various embodiments, the processor may be a controller or part thereof, the controller used to determine and control the charging schedule for the plurality of vehicles.

[0048] FIG. 1 shows an exemplary schematic of a system 100 including a processor 150 for determining a charging schedule, over a predetermined time horizon, for a plurality of vehicles 110 affiliated with a charging station 102. Each of the plurality of vehicles 110 is affiliated to the charging station 102, and may use the facilities of the charging station 102 to charge an electrochemical cell 116 of said vehicle 110. In various embodiments, the plurality of vehicles 110 may be operated by an on-demand vehicle provider, which may be affiliated to the charging

station 102. The charging station 102 may also be referred to as a source charging station 102 in the description.

[0049] In various embodiments, the predetermined time horizon may include a period of 24 hours, 12 hours, 6 hours, 3 hours, 1 hour, or 30 mins. It is contemplated that other predetermined time horizon may include 3 days, 5 day or one week.

[0050] In various embodiments, each of the plurality of vehicles 110 may be suitable for transport on land, and in some embodiments, may be an EV powered by one or more electric motors drawing its energy from an electrochemical cell 116 situated in the EV. In some embodiments, the vehicle 110 may include hybrid vehicles, drawing its energy from an electrochemical cell 116, and/or a fossil fuel source, e.g. petrol or diesel.

[0051] In various embodiments, the plurality of vehicles 110 may include at least one idle vehicle 112 situated at the charging station 102 and/or at least one en route vehicle 114. The engine of the idle vehicle 112 may be not running and energy may not be depleted from the electrochemical cell 116. Conversely, the engine of the en route vehicle 114 may be running and energy from the electrochemical cell 116 may be depleted.

[0052] Referring to FIG. 1, the system 100 includes a processor 150, configured to obtain parameters related to the electrochemical cell 116. The processor 150 obtains: a first parameter 152 indicative of a SOH 120 of the electrochemical cell 116; and a second parameter 154 indicative of a SOE 122 of the electrochemical cell 116, of the idle 112 or en route 114 vehicles amongst the plurality of vehicles 110.

[0053] In some embodiments, the processor 150 may be further configured to obtain for the en route vehicle 114, a fifth parameter 160 indicative of an estimated arrival time 124 of said en route vehicle 114 at the charging station 102, and may use the fifth parameter 160 to obtain the SOE 122 for the en route vehicle 114. In some embodiments, the processor 150 may be further configured to obtain a sixth parameter 162 indicative of an SOC 123 of the electrochemical cell 116, of the idle 112 or en route 114 vehicles amongst the plurality of vehicles 110.

[0054] The processor 150 is further configured to obtain: a third parameter 156 indicative of a demand 130, over the predetermined time horizon, of a vehicle among the plurality of vehicles 110, with a requirement of having an energy level greater than or equal to a threshold energy level; and a fourth parameter 158 indicative of an operational capacity of the charging station 102. In various embodiments, the demand 130 may refer to customer demands, of, e.g.

hosted by, the on-demand vehicle provider, for use of a vehicle among the plurality of vehicles 110.

[0055] In various embodiments, the threshold energy level may refer an energy level required for servicing a customer's demand request, e.g. transportation requirements of user. A demand request may include a time or time interval of use, one or more trip information, a departure time of the en route vehicle 114 from the charging station, and a user-defined estimated time of arrival, at which the en route vehicle 114 returns to be charged. In some embodiments, the threshold energy level may refer to a maximum energy capacity of the electrochemical cell 116, e.g. a fully charged battery.

[0056] The processor 150 is further configured to determine, e.g. calculate, for each vehicle amongst the plurality of vehicles 110, a control signal 170 related to the charging schedule based on, at least one of the first parameter 152, the second parameter 154, the third parameter 156, and/or the fourth parameter 158. In some embodiments, the control signal 170 may further be based on, the sixth parameter 162 indicative of the SOC 123 of the electrochemical cell 116. In various embodiments, for en route vehicles 114, the processor 150 may be configured to determine, e.g. calculate, the control signal 170 for the en route vehicle 114 based on, at least one of the first parameter 152, the second parameter 154, the third parameter 156, the fourth parameter 158, the fifth parameter 160, and/or the sixth parameter 162.

[0057] The processor 150 may be further be configured to transmit, the control signal 170 to another processor, e.g. on-board controller of the vehicle 110.

[0058] FIG. 2 shows an exemplary schematic of a system 200 including the processor 150 for obtaining an estimated arrival time 124, and the second parameter 154 indicative of the SOE 122 of the electrochemical cell 116 of the en route vehicle 114. FIG. 3 shows an example of a performance measurement of the estimated arrival time 124 according to embodiments of the disclosure. FIG. 4A shows an example of a performance measurement of the SOE 122 of the en route vehicle 114, and FIG. 4B shows a graphical representation of an actual vs. predicted energy usage of the en route vehicle 114, according to embodiments of the disclosure.

[0059] Referring to FIGS. 1 and 2, the second parameter 122 indicative of the SOE 122 of the electrochemical cell 116 of the idle vehicle 112 may include an initial energy level. The initial energy level may refer to the energy stored in electrochemical cell 116 prior to charging. For example, the idle vehicle 112 may have returned from a journey and is parked at and needs

to be charged. The SOE 122 of the idle vehicle 112 may be measured by one or more sensors on the idle vehicle 112, and may be transmitted to the processor 150.

[0060] Referring to FIG. 2, the processor 150 may be configured to obtain the estimated arrival time 124 (time or time interval for connecting to a charging port) of the en route vehicle 114 at the charging station 102.

[0061] The processor 150 may be configured to obtain a departure time 202, e.g. time or time interval the en route vehicle 114 disconnects from the charging port, of the en route vehicle 114 from the charging station 102.

[0062] The processor 150 may be configured to obtain a road network data 204 indicative of the road network information related to the en route vehicle 114. The road network data 204 may include an origin and a destination information of one or more trips of the en route vehicle 114, and the shortest distance from the origin to the destination of the one or more trips. The road network data 204 may be stored in a memory of the processor 150 or an external server, and may be updated periodically, e.g. when road network information changes. The road network data 204 may be transmitted to the processor 150.

[0063] The processor 150 may be configured to obtain a traffic data 206 indicative of the traffic condition related to the en route vehicle 114. The traffic data 206 may include a location information, a calendar date, a day of the week, a time of the day, congestion data at said location, and/or road closure information. The traffic data 206 may be obtained from one or more other processors, e.g. global positioning system and/or a clock, located on the en route vehicle 114; and/or an external server, e.g. real-time or near real-time congestion data, road closure information. The traffic data 206 may be transmitted to the processor 150.

[0064] The processor 150 may be configured to obtain a weather data 208, e.g. rain, snow, hail conditions, related to the en route vehicle 114 at the location it is situated at. The weather data 208 may be obtained from an external server providing real-time weather data 208 from one or more satellites.

[0065] The processor 150 may be configured to obtain a performance data 210 indicative of a performance condition of the en route vehicle 114. The performance data 210 may refer to vehicle dynamics data associated with the motion of the en route vehicle 114. Non-limiting examples of the performance data 210 include data associated with the jerk of the en route vehicle 114, i.e. rate of acceleration changes with respect to time (acceleration jerk), and the temperature of the engine of the en route vehicle 114. It is contemplated that other vehicle

dynamics data may include drive, train, braking system and tires; geometry of the suspension, steering and chassis; mass distribution; aerodynamics data; and/or vehicle behavior data, e.g. yaw, pitch, critical speed.

[0066] Referring to FIGS. 2 and 3, the processor 150 may obtain the fifth parameter 160 of the estimated arrival time 124 of the en route vehicle 114 based on the aforementioned departure time 202, road network data 204, traffic data 206, weather data 208 and/or performance data 210. In various embodiments, the fifth parameter 160 may be calculated using one or more trained predicted or estimated arrival time 124 machine learning algorithms, and in an embodiment, may be calculated using the XGBoost machine learning algorithm. Referring to the confusion matrix of FIG. 3, an overall accuracy of 0.74 may be obtained. In addition, it was observed that the best classification performance was for trips that were 10 mins to 30 mins in duration. It is contemplated that another parameter for obtaining the fifth parameter 160 of the estimated arrival time 124 may include data regarding a driver's style or pattern.

[0067] Referring to FIG. 2, the processor 150 may be further configured to obtain the second parameter 154 indicative of the SOE 122 of the en route vehicle 114 at the estimated arrival time 124 of the en route vehicle 114 at the charging station 102. In other words, the SOE 122 prior to charging of the en route vehicle 114 may be obtained.

[0068] The processor 150 may obtain the SOE 122 of the en route vehicle 114 by calculating an energy usage, based on the departure time 202, estimated arrival time 124 and the road network data 204, e.g. origin and destination information. For example, the processor 150 may calculate an average speed of the en route vehicle 114 based on the aforementioned parameters. Accordingly, the processor 150 may calculate the SOE 122 based on an initial energy of the en route vehicle 114, e.g. energy level at departure time 202, and the energy usage of the en route vehicle 114.

[0069] Referring to FIGS. 2, 4A and 4B, the second parameter 154 of the SOE 122 of the en route vehicle 114 may be obtained using one or more trained SOE 122 machine learning algorithms, and in an embodiment, calculated using the XGBoost and/or a support vector regression machine learning algorithms. As may be seen from the confusion matrix shown in FIG. 4A, an overall accuracy of 0.83 may be obtained using the XGBoost algorithm, and the best classification performance may be obtained for 0 % to 10 % energy usage. In addition, as may be seen from FIG. 4B, a coefficient of determination (R^2 score) was 0.86, and the root

mean square error (RMSE) was 0.99. It is further contemplated that the estimated SOE 122 for the en route vehicle 114 may include other parameters such as the mapping of the vehicle's SOH 120, e.g. first parameter 152, to the energy usage profile for the en route vehicle 114.

[0070] In some embodiments, the fifth parameter 160 and the second parameter 154 may be determined by another processor on the en route vehicle 114, or on an external server, and may be transmitted to the processor 150.

[0071] Referring to FIGS. 1 and 2, the first parameter 152 indicative of the SOH 120 of the electrochemical cell 116 may include, a parameter indicative of a degradation of the electrochemical cell 116, and/or an age of the electrochemical cell 116. Repeated charging and discharging cycles may lead to capacity fading, cyclic and/or calendric degradation of the electrochemical cell 116, leading to deterioration of the SOH 120 of the electrochemical cell 116. In addition, the SOH 120 of the electrochemical cell 116 may deteriorate with age, e.g. lifetime of electrochemical cell 116.

[0072] In various embodiments, the processor 150 may obtain the SOH 120 of the electrochemical cell 116, based on a mathematical, e.g. state-space or equivalent circuit model which mimics the electrochemical behavior of the electrochemical cell 116. In particular, the model includes parameters such as internal resistance, and capacitance to capture the non-linear behavior of the electrochemical cell 116, for determining the SOH 120. In various embodiments, the equivalent circuit model may be represented by Equations (1) and (2):

$$\varepsilon_c^{ev}[k+1] = \varepsilon_c^{ev}[k] + \eta^{ev} \frac{i^{ev}[k]\Delta t}{Q^{ev}} \quad \text{Equation (1); and}$$

$$x^{ev}[k+1] = A^{ev}x^{ev}[k] + B^{ev}u^{ev}[k] \quad \text{Equation (2),}$$

where

$$x^{ev}[k] = \begin{bmatrix} \varepsilon_c^{ev}[k] \\ e^{ev}[k] \\ i_R^{ev}[k] \end{bmatrix}; \quad A^{ev} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & A_R^{ev} \end{bmatrix}; \quad B^{ev} = \begin{bmatrix} \frac{\eta^{ev}\Delta t}{Q^{ev}} \\ \frac{\eta^{ev}v_{OC}[k]\Delta t}{Q} \\ B_R^{ev} \end{bmatrix}; \quad u^{ev}[k] = i^{ev}[k];$$

$$i_R^{ev}[k] = \begin{bmatrix} i_{R_1}^{ev}[k] \\ i_{R_2}^{ev}[k] \\ \vdots \end{bmatrix}; \quad A_R^{ev} = \begin{bmatrix} \exp(-\frac{\Delta t}{R_1^{ev}C_1^{ev}}) & 0 & \dots \\ 0 & \exp(-\frac{\Delta t}{R_2^{ev}C_2^{ev}}) & \dots \\ \vdots & \dots & \ddots \end{bmatrix};$$

$$\mathbf{B}_R^{ev} = \begin{bmatrix} 1 - \exp\left(-\frac{\Delta t}{R_1^{ev} C_1^{ev}}\right) \\ 1 - \exp\left(-\frac{\Delta t}{R_2^{ev} C_2^{ev}}\right) \\ \vdots \end{bmatrix}, \text{ and where } ev \text{ refers to the vehicle 110 index; } R_n^{ev}, C_n^{ev} \text{ refers to}$$

the transient components associated with resistance and capacitance of the electrochemical cell 116; i^{ev} refers to a current, e.g. decision variable of the electrochemical cell 116; Q^{ev} refers to the capacity of the electrochemical cell 116; $\mathbf{A}^{ev}, \mathbf{B}^{ev}$ are state transition matrices; $\mathbf{x}^{ev}$ refers to a state vector; η^{ev} refers to the charging efficiency; v_{oc} refers to the open circuit voltage; R_0 refers to the internal resistance of the electrochemical cell 116; ε_c^{ev} refers to an SOC 123 of the electrochemical cell 116, i.e. sixth parameter 162; k refers to the time index; Δt refers to a sampling interval; and e^{ev} refers to the SOE 122 of the electrochemical cell 116, e.g. the stored energy level in an idle 112 or en route 114 vehicle.

[0073] FIGS. 5A, 5B, 5C and 5D show exemplary graphical representations of the identified electrochemical cell 116 parameters, according to embodiments of the disclosure. FIG. 5A shows an exemplary open circuit voltage (v_{oc}); FIG. 5B shows an exemplary internal resistance (R_0); FIG. 5C shows an exemplary transient resistance (R_1); and FIG. 5D shows an exemplary time constant of ($R_1 C_1$), at varying SOC 123 levels. FIGS. 5A to 5D represents parameters in Equations (1) and (2), and reflects the SOH 120 of the electrochemical cell 116.

[0074] In various embodiments, the processor 150 may further obtain the sixth parameter 162 indicative of the SOC 123 of the electrochemical cell 116. In some embodiments, for an idle vehicle 112, the SOC 123 of the electrochemical cell 116 may be measured, in real-time or near real-time, using one or more sensors of the idle vehicle 112, and may be transmitted to the processor 150. In some other embodiments, for an en route vehicle 114, the SOC 123 of the electrochemical cell 116 may be derived from the second parameter 154 indicative of the SOE 122 of the electrochemical cell 116.

[0075] FIG. 6 shows a system 600 for obtaining the third parameter 156 indicative of the demand 130, e.g. customer demand, over the predetermined time horizon, for use of a vehicle 110 with a requirement of having an energy level greater than or equal to the threshold energy level required for servicing a demand request. FIG. 7A shows a graphical representation of an actual vs. forecasted demand 130 using a DeepAR machine learning algorithm, and FIG. 7B shows a graphical representation of an actual vs. seasonal naïve forecasted demand 130, according to embodiments of the disclosure.

[0076] The forecasted demand 130 may include a trip information, and the trip information and may include one or more origins and one or more destinations.

[0077] Referring to FIG. 6, the third parameter 156 may include a historical supply data 602 of a vehicle 110 having an energy level required for servicing the demand request. In some embodiments, the historical supply data 602 may relate to a supply of vehicles 110, each vehicle having a maximum energy level, e.g. fully charged battery. The historical supply data 602 may include vehicles 110 affiliated with the charging station 102. It is contemplated that vehicles 110 affiliated with another charging station, e.g. not using the charging station 102 facilities, and may historically be supplied to the charging station 102 on a need basis.

[0078] The third parameter 156 may include a historical demand data 604 of the vehicle 110 having the energy level required for servicing the demand request. The historical demand data 604 may include a historical trip information for the vehicle 110, and may include one or more historical origins and one or more historical destinations.

[0079] The third parameter 156 may include a historical weather data 606 related to the historical demand data 602 and historical supply data 604 of the vehicle 110 having said energy level. For example, there may be a correlation between the historical weather data 606 and the historical demand 602 and supply 604 data. For instance, an increase in historical demand data 602 may be observed during wet weather.

[0080] The third parameter 156 may include a forecasted weather data 608 over the predetermined time horizon.

[0081] The third parameter 156 may also include a forecasted supply data 610 indicative of an estimated supply of vehicles 110 having said energy level required for servicing the demand request. The forecasted supply data 610 may include the number of idle vehicles 112 having said energy level requirements and ready to service the demand request, the number of en route vehicles 114 having said energy level requirement and ready to service the demand request upon return to the charging station 102, e.g. based on the estimated SOE 122 of the en route vehicle 114 during the predetermined time horizon. The forecasted supply data 610 may also include the number of en route vehicles 114 that will return to the charging station 102 during the predetermined time horizon, having said energy level requirements after a charging duration within the predetermined time horizon. It is contemplated that the forecasted supply data 610 may further include another vehicle, not affiliated to the charging station 102, and

having said energy level requirements to service the demand request. For example, other vehicles may be deployed from another charging station 102 on a need basis.

[0082] The historical supply data 602, historical demand data 604 and historical weather data 606 may be stored in a memory of the processor 150, or may be transmitted to the processor 150 from an external server. The forecasted weather data 608 may be transmitted to the processor 150 from one or more weather forecasting sources, and the forecasted supply data 610 may be transmitted to the processor 150 from an external server, in real-time or near real-time.

[0083] The third parameter 156 may therefore be a forecasted customer demand 130 for use of vehicles 110 with a requirement of having said energy level required for servicing the demand request, thereby providing for a number of vehicles 110 ready to service one or more demand requests.

[0084] The third parameter 156 may be obtained based on one or more trained machine learning algorithms. Referring to FIGS. 6 and 7A, an average RMSE between a predicted 702 and actual 704 forecasted demand 130 was observed to be 1.09 over 182 hours, and the full RMSE to be 1.63, using the DeepAR prediction algorithm.

[0085] Referring to FIGS. 6 and 7B, an average RMSE between a predicted 712 and actual 714 forecasted demand 130 over the same 182 hours was observed to be 1.57, and a full RMSE observed to be 2.07, based on the average seasonal naïve forecast.

[0086] In various embodiments, the third parameter 156 indicative of the demand 130, e.g. customer demand of use of vehicles 110, may be represented by Equation (3):

$$N(e^{ev} \geq e_{req}^{ev})[k] \geq N_R[k] \quad \text{Equation (3);}$$

where

$N(e^{ev} \geq e_{req}^{ev})[k]$ is an embodiment of the third parameter 156, and refers to the number of vehicles 110 with the energy level greater than or equal to the threshold, e.g. required energy level; N_R refers to the number of requests; and k refers to the time index.

[0087] Referring to FIG. 1, the fourth parameter 158 indicative of the operational capacity of the charging station 102 may include, a total number of units of available energy at the charging station 102, at the predetermined time horizon. The total number of units of available energy may be measured, in real-time or near real-time, using one or more sensors at the charging station 102, and may be transmitted to the processor 150.

[0088] The fourth parameter 158 may include a cost per unit of the available energy. The available energy may be procured under a dynamic price scheme where the cost per unit of available energy may be different over various time horizons. The cost per unit of available energy may be obtained in real-time or near real-time, from an external server, and transmitted to the processor 150.

[0089] The fourth parameter 158 may include a total number of charging ports available at the charging station 102, and the various number of charging modes for each charging port. For example, a charging port may include a fast charging mode and a normal charging mode. The total number of charging ports and modes thereof may be stored in a memory of the processor 150.

[0090] The fourth parameter 158 indicative of the operational capacity of the charging station 102 may be expressed using a set of mathematical equations which model the operational constraints of the charging station 102. In various embodiments, the operational capacity of the charging station 102 may be represented by Equations (4) to (9):

$$\sum_{s \in OM} \delta_s^{ev} [k] \leq 1 \quad \text{Equation (4);}$$

$$\delta_s^{ev} [k] - \delta_s^{ev} [k - 1] \leq \delta_s^{ev} [\tau_s^{ev}], \tau_s^{ev} = k, k + 1, \dots, \min(k + T_s^{ev} - 1, H) \quad \text{Equation (5);}$$

$$\underline{i}_s^{ev} \delta_s^{ev} [k] \leq i_s^{ev} [k] \leq \bar{i}_s^{ev} \delta_s^{ev} [k], \forall s \in OM \quad \text{Equation (6);}$$

$$\underline{v}^{ev} \leq v^{ev} [k] \leq \bar{v}^{ev} \quad \text{Equation (7);}$$

$$\sum_{ev \in V} i^{ev} [k] = \sum_{ev \in V} \sum_{s \in OM} i_s^{ev} [k] \leq \bar{I} [k] \quad \text{Equation (8); and}$$

$$e^{ev} [T_{dep}^{ev}] \geq e_{req}^{ev}, \forall ev \in V = \{1, \dots, EV\} \quad \text{Equation (9);}$$

where

$OM = \{OFF, CM1, CM2, DM\}$ refers to the set of operational states; $V = \{1, \dots, EV\}$ refers to the set of the plurality of vehicles 110 in the charging station 102; ev refers to the vehicle 110 index; $CM1$ refers to the normal charging mode; $CM2$ refers to the fast charging mode; DM refers to the discharging mode; $\delta_1 \in \{0,1\}$ refers to the binary variable denoting the OFF condition; $\delta_2 \in \{0,1\}$ refers to the binary variable denoting the normal charging condition; $\delta_3 \in \{0,1\}$ refers to the binary variable denoting the fast charging condition; $\delta_4 \in \{0,1\}$ refers to the binary variable denoting the discharging condition; $T_s^{ev}, ev \in V, s \in OM$ refers to the minimum state layover time; H refers to the prediction horizon, e.g. predetermined time horizon; i_s^{ev} refers to the input or output current in state $s \in OM$ of $ev \in V$; and T_{dep}^{ev} refers to a time of departure, e.g. of a vehicle 110 ready to service a demand request. While Equations

(4) to (9) are denoted with reference to 2 charging modes, e.g. *CM1*, *CM2*, the embodiments of the disclosure are not limited thereto, and a plurality of charging modes may be customized according to the requirements of, and the availability of charging modes available at a charging station 102.

[0091] As shown in FIG. 1, the processor 150 determines the control signal 170 for the vehicle 110 based on the first 152, second 154, third 156, and/or fourth 158 parameters. In some embodiments, the control signal 170 may further be determined based on the sixth parameter 162 indicative of the SOC 123 of the electrochemical cell 116. In various embodiments, the processor 150 may determine the control signal 170 for the en route vehicle 114 based on the first 152, second 154, third 156, fourth 158, the fifth 160 parameters and/or the sixth parameter 162.

[0092] The control signal 170 related to the charging schedule may include a required energy such that the energy level of the electrochemical cell 116 of the vehicle 110 is greater than or equal to the threshold energy level, for servicing one or more demand requests. In some embodiments, the required energy may be the energy required for the electrochemical cell 116 to obtain a maximum capacity, e.g. fully charged battery.

[0093] In various embodiments, the required energy may be expressed as a function of the terminal voltage $v^{ev}[k]$ of the electrochemical cell 116. The terminal voltage $v^{ev}[k]$ may be represented by Equation (10):

$$v^{ev}[k] = v_{oc}^{ev}(\varepsilon_c^{ev})[k] + \sum_j i_R^{ev}[k] R_j^{ev} + R_0^{ev}, \forall ev \in V = \{1, \dots, EV\} \quad \text{Equation (10);}$$

where $V = \{1, \dots, EV\}$ refers to the set of the plurality of vehicles 110 in the charging station 102; ev refers to the vehicle 110 index; $v^{ev}[k]$ refers to the terminal voltage of the electrochemical cell; v_{oc}^{ev} refers to the open circuit voltage; ε_c^{ev} refers to SOC 123 of the electrochemical cell 116; k refers to the time index; i^{ev} refers to a current, e.g. decision variable, of the electrochemical cell 116; $R_j^{ev}, j = 1, 2, \dots$ refers to resistances associated with the transient response of the electrochemical cell 116; and R_0^{ev} refers to an internal resistance of the electrochemical cell 116.

[0094] The control signal 170 may include a required charge duration, which may be based on the required energy and/or the charging rate of the electrochemical cell 116. The processor 150 may be further configured to determine, e.g. calculate the required charge duration accordingly.

[0095] The control signal 170 may include an allocated charging port in the charging station 102, and a required charging mode for that allocated charging port. For example, a user may select a normal charging mode, e.g. *CM1*, or a fast charging mode, e.g. *CM2*. In various embodiments, the processor 150 may determine the required charging mode based on the required energy, the required charge duration and/or the third parameter 156 of the demand 130.

[0096] In some embodiments, a user may define a desired duration, e.g. input via a user interface of the processor 150, and the processor 150 may determine the charging mode based on the required energy, the desired charge duration and/or the third parameter 156 of the demand 130. For example, the processor 150 may determine a fast charging mode, e.g. *CM2*, if a desired duration is shorter than the required charge duration.

[0097] Accordingly, the control signal 170 related to the charging schedule, for the vehicle 110 may be determined by optimizing the cost function of the electricity cost, while considering the first 152, second 154, third 156, fourth 158, fifth 160 parameters, and/or the sixth parameter 162. In various embodiments, the optimization of the cost function in the form of minimizing the electricity costs may be represented by Equation (11):

$$\min_{i^{ev}[k], \forall ev \in V, \forall k \text{ in } H} \sum_{ev \in V} \sum_{k \in H} C_{elec}^{ev}[k] + C_{loss}^{ev}[k] \quad \text{Equation (11);}$$

s.t. Equations (1) to (10);

where,

$C_{elec}^{ev}[k]$ is the cost of electricity represented by Equation (12):

$$C_{elec}^{ev}[k] = p[k] \cdot (e^{ev}[k] - e^{ev}[k-1]) \quad \text{Equation (12);}$$

where $p[k]$ refers to the unit energy price at time instant k ;

$C_{loss}^{ev}[k]$ is the cost of capacity loss represented by Equation (13):

$$C_{loss}^{ev}[k] = p_{man} \cdot C_{loss, cycle}^{ev}[k] \quad \text{Equation (13);}$$

where p_{man} refers to the cost of manufacturing an electrochemical cell 116 of unit capacity; and $C_{loss, cycle}^{ev}[k]$ refers the electrochemical cell's 116 capacity, degraded due to a charging cycle;

[0098] FIGS. 8A, 8B, 8C, and 8D show graphical representations of the predicted 802 vs. measured 804 responses of the terminal voltages, e.g. $v^{ev}[k]$, of the electrochemical cell 116 at different SOC 123 levels. The predicted 802 response, expressed as the terminal voltage $v^{ev}[k]$ may be determined in accordance with Equation (10) as defined above, and based on the identified electrochemical cell 116 parameters as shown in FIGS. 5A to 5D.

[0099] In FIGS. 8A to 8D, the x-axis may be time (in seconds), and the y-axis may be the terminal voltage. Referring to FIGS. 8A to 8D, it may be seen that the predicted 802 response closely follows that of the measured 804 response, in particular for a SOC 123 of 58.26 % (FIG. 8C). In addition, the overall RMSE was observed to be in the range of 5 % to 7 %.

[00100] Repeated charging and discharging cycles may lead to capacity fading, and may reduce the capacity of the electrochemical cell 116 over time. In other words, the SOH 120 of the electrochemical cell 116 may deteriorate due to capacity fading.

[00101] In various embodiments, the processor 150 may be configured to determine the control signal 170, based on the charging rate of the electrochemical cell 116 of the vehicle 110, and the SOE 122, e.g. second parameter 154, of the electrochemical cell 116, over the predetermined time horizon.

[00102] The processor 110 may determine the control signal 170 by considering the cyclic faded capacity cost function represented by Equations (14) to (16):

$$C_{loss}[k] = (k_1^{ev} \varepsilon_{dev}^{ev}[k] + k_2^{ev} \varepsilon_{avg}^{ev}[k] + k_3^{ev} i^{ev}[k] \Delta t) \quad \text{Equation (14);}$$

where

$$\varepsilon_{avg}^{ev}[k] = \frac{1}{i^{ev}[k] \Delta t} \int_0^{i^{ev}[k] \Delta t} (\varepsilon_c^{ev}[k] + \eta^{ev} \frac{i^{ev} \Delta t}{Q^{ev}}) d(i^{ev} \Delta t) \quad \text{Equation (15);}$$

where, $\varepsilon_{avg}^{ev}[k]$ represents the average SOE 122 during a time interval of k and $k+1$; and

$$\varepsilon_{dev}^{ev}[k] = \sqrt{\frac{1}{i^{ev}[k] \Delta t} \int_0^{i^{ev}[k] \Delta t} (\varepsilon_c^{ev}[k] + \eta^{ev} \frac{i^{ev} \Delta t}{Q^{ev}} - \varepsilon_{avg}^{ev}[k])^2 d(i^{ev} \Delta t)} \quad \text{Equation (16);}$$

where $\varepsilon_{dev}^{ev}[k]$ represents the SOE 122 deviation during the time interval of k and $k+1$; where k refers to the time index; Δt refers to a sampling interval; i^{ev} refers to the current of the electrochemical cell 116; η^{ev} refers to a charging efficiency of the electrochemical cell 116; and Q^{ev} refers to the capacity of the electrochemical cell 116.

[00103] The control signal 170 which considers the cyclic faded capacity cost function represented by Equations (14) to (16), may avoid excessive charging and discharging of the electrochemical cell 116, to minimize the capacity fading effect and degradation of the electrochemical cell 116. Accordingly, degradation of the electrochemical cell 116 may be reduced, and the SOH 120 of the electrochemical cell 116 may be preserved.

[00104] FIG. 9 shows an exemplary schematic illustration of a control device 900 comprising a processor 920 configured to determine, over a predetermined time horizon, a charging schedule for a plurality of vehicles affiliated with a charging station, in accordance with another

aspect of the disclosure. The control device 900 may be configured for the system 100, 200, 600 described with reference to FIGS. 1 to 8D of the disclosure, and repeated descriptions are omitted for brevity.

[00105] Referring to FIG. 9, the control device 900 includes a processor 920 in data communication with a memory 910 having instructions stored therein, the instructions, when executed by the processor 920, causes the processor 920 to: obtain, a first parameter indicative of a SOH of an electrochemical cell of at least one vehicle among the plurality of vehicles (step 922); obtain, a second parameter indicative of a SOE of the electrochemical cell of the at least one vehicle among the plurality of vehicles (step 924); obtain, a third parameter indicative of a demand, over the predetermined time horizon, of the at least one vehicle among the plurality of vehicle, the at least one vehicle having an energy level greater than or equal to a threshold energy level (step 926); obtain, a fourth parameter indicative of an operational capacity of the charging station (step 928); and determine, for the at least one vehicle among the plurality of vehicles, a control signal related to the charging schedule, the control signal determined based on, at least one of the first parameter, the second parameter, the third parameter and/or the fourth parameter (step 930). In some embodiments, the processor 920 may further obtain a sixth parameter indicative of the SOC of the electrochemical cell of the at least one vehicle among the plurality of vehicles (step 929), and may further determine the control signal related to the charging schedule based on, at least one of the first parameter, the second parameter, the third parameter, the fourth parameter and/or the sixth parameter (step 932).

[00106] In various embodiments, when the plurality of vehicles include at least one en route vehicle, the processor 920 may be further configured to: obtain, a fifth parameter indicative of an arrival time of the en route vehicle at the charging station (step 940); and determine, for the at least one en route vehicle among the plurality of vehicles, the control signal related to the charging schedule, based on, at least one of the first parameter, the second parameter, the third parameter, fourth parameter and/or the fifth parameter. In some embodiments, the control signal related to the charging schedule may be further based on, at least one of the first parameter, the second parameter, the third parameter, the fourth parameter, the fifth parameter and/or the sixth parameter indicative of the SOC of the electrochemical cell (step 942).

[00107] In various embodiments, the processor 920 may be configured to execute steps 922 to 942 in accordance with the processor 150 described in relation to the system 100, 200, 600 of FIGS. 1 to 8D. In FIG. 9, the arrows between steps 922 to 930, steps 922 to 932, and steps

922 to 942 do not necessarily infer a sequential order or priority. For example, the processor 920 may be configured to execute any one of steps 922 to 929, and 940 in a parallel order.

[00108] FIG. 10 shows an exemplary flowchart of a method 1000 for determining over a predetermined time horizon, a charging schedule for a plurality of vehicles affiliated with a charging station, in accordance with another aspect of the disclosure. The method 1000 may be configured for operating the system 100, 200, 600 described with reference to FIGS. 1 to 8D and repeated descriptions will be omitted for brevity.

[00109] Referring to FIG. 10, method 1000 includes providing a processor for executing the following steps of: obtaining, a first parameter indicative of a SOH of an electrochemical cell of at least one vehicle among the plurality of vehicles (step 1002); obtaining, a second parameter indicative of a SOE of the electrochemical cell of the at least one vehicle among the plurality of vehicles (step 1004); obtaining, a third parameter indicative of a demand, over the predetermined time horizon, of the at least one vehicle among the plurality of vehicle, the at least one vehicle having an energy level greater than or equal to a threshold energy level (step 1006); obtaining, a fourth parameter indicative of an operational capacity of the charging station (step 1008); and determining, for the at least one vehicle among the plurality of vehicles, a control signal related to the charging schedule, the control signal determined based on, at least one of the first parameter, the second parameter, the third parameter and/or the fourth parameter (step 1010). In some embodiments, the processor may further execute the steps of: obtaining, a sixth parameter indicative of the SOC of the electrochemical cell of the at least one vehicle among the plurality of vehicles (step 1009); and determining, the control signal related to the charging schedule based on, at least one of the first parameter, the second parameter, the third parameter and/or the fourth parameter, and the sixth parameter (step 1012).

[00110] In various embodiments, the plurality of vehicles may include at least one en route vehicle, and the processor may be further configured to execute the steps of: obtaining, a fifth parameter indicative of an estimated arrival time of the en route vehicle at the charging station (step 1020); and determining, for the at least one en route vehicle among the plurality of vehicles, the control signal related to the charging schedule, based on, at least one of the first parameter, the second parameter, the third parameter, the fourth parameter and/or the fifth parameter. In some embodiments, determining the control signal related to the charging schedule may be further based on, at least one of the first parameter, the second parameter, the third parameter, the fourth parameter, the fifth parameter and/or the sixth parameter indicative

of the SOC of the electrochemical cell (step 1022). In FIG. 10, the arrows between steps 1002 to 1010, steps 1002 to 1012, and steps 1002 to 1022 do not necessarily infer a sequential order or priority. For example, the processor may be configured to execute any one of steps 1002 to 1009, and 1020 in a parallel order.

[00111] In various embodiments of method 1000, the first parameter indicative of the SOH of the electrochemical cell may include, at least one of a degradation of the electrochemical cell, and/or an age of the electrochemical cell.

[00112] In various embodiments of method 1000, the plurality of vehicles may further include at least one idle vehicle, and the second parameter indicative of the SOE of the electrochemical cell may include, an initial energy level of the idle vehicle, and/or an estimated energy level of the en route vehicle at the estimated arrival time of the en route vehicle at the charging station.

[00113] In various embodiments of method 1000, the fifth parameter indicative of the estimated arrival time of the en route vehicle at the charging station may include, at least one of a departure time of the en route vehicle from the charging station; a traffic data indicative of a traffic condition related to the en route vehicle; a weather data related to the en route vehicle; a road network data indicative of road network information related to the en route vehicle; and/or a performance data indicative of a performance condition of the en route vehicle.

[00114] In various embodiments of method 1000, the estimated energy level of the en route vehicle at the estimated arrival time may include, at least one of the departure time, the road network data, and/or the fifth parameter indicative of the estimated arrival time of the en route vehicle.

[00115] In various embodiments of method 1000, the third parameter indicative of the demand of the at least one vehicle with a requirement of having the energy level greater than or equal to the threshold energy level, may further include a trip information. The third parameter may include, at least one of a historical supply data, of the at least one vehicle having the energy level greater than or equal to the threshold energy level; a historical demand data, of the at least one vehicle having the energy level greater than or equal to the threshold energy level, the historical demand comprising a historical trip information of said vehicle; a historical weather data, related to the historical demand data and historical supply data of the at least one vehicle having the energy level greater than or equal to the threshold energy level; a forecasted weather data, over the predetermined time horizon; and/or a forecasted supply data, indicative

of an estimated supply of the at least one vehicle or another vehicle, having the energy level greater than or equal to the threshold energy level.

[00116] In various embodiments of method 1000, the fourth parameter indicative of the operational capacity of the charging station may include, at least one of a total number of units of available energy at the charging station; a cost per unit of the available energy at the charging station; a total number of charging ports available at the charging station; and/or a various number of charging modes for each charging port among the total number of charging ports available at the charging station.

[00117] In various embodiments of method 1000, the control signal related to the charging schedule may include at least one of a required energy, such that the energy level of the at least one vehicle is greater than or equal to, the threshold energy level; a required charge duration, the required charge duration based on the required energy and a charging rate of the electrochemical cell; and a required charging mode among the various number of charging modes, for an allocated charging port among the total number of charging ports available, wherein the required charging mode is based on the required energy, the required charge duration and/or a desired duration, and the third parameter.

[00118] In various embodiments of method 1000, the processor may be configured to determine the control signal based on, at least one of the charging rate of the electrochemical cell of the at least one vehicle; and/or the second parameter indicative of the SOE of the electrochemical cell of the at least one vehicle over the predetermined time horizon.

[00119] Another aspect of the disclosure relates to a computer readable medium comprising instructions, which when executed by the processor, causes the processor to perform the various embodiments of method 1000.

[00120] FIGS. 11A to 14D show exemplary graphical representations of a simulation to determine a charging schedule for a plurality of vehicles affiliated to a charging station. The charging schedule may include a control signal for each of the plurality of vehicles, which may be determined in accordance with any one of Equations (1) to (15) of the disclosure. The simulation may be based on system 100, 200, 600 described with reference to FIGS. 1 to 8D; may be executed by the processor 920 of control device 900 described with reference to FIG. 9, and/or may be executed by a processor of method 1000 for operating system 100, 200, 600, the method described with reference to FIG. 10.

[00121] FIG. 11A to 14D show comparisons between the total energy consumption (FIGS. 11A and 11B); electricity cost (FIGS. 12A and 12B); electrochemical cell 116 degradation costs and energy consumption (FIGS. 13A and 13B); SOE levels of vehicles over time (FIGS. 14A and 14B); and terminal voltages of vehicles over time (FIGS. 14C and 14D), determined based on conventional algorithms, and that using algorithms of the system, control device and/or methods according to various aspects and embodiments of the disclosure. The conventional systems and methods may refer to the conventional methods, based on fixed charging rate, and where said vehicle starts charging once it is connected to the charging port.

[00122] The simulation may be based on a predetermined time horizon of 4 hours, for a plurality of 20 vehicles, of which includes idle and en route vehicles, and a sampling time of 10 minutes. While the simulation is based on the aforementioned parameters, embodiments of the disclosure are not limited thereto, and the predetermined time horizon, number of vehicles and sampling time may be change and may be user-specific.

[00123] FIG. 11A shows the total energy consumption, including market electricity prices per kWatt-hour 1102, and the energy consumption of the plurality of vehicles 1104, according to conventional algorithms; and FIG. 11B shows the total energy consumption, including market electricity prices per kWatt-hour 1112, and the energy consumption of the plurality of vehicles 1114, according to algorithms of the disclosure. FIG. 12A shows the electricity costs, including market electricity prices per kWatt-hour 1202, and the energy consumption of the plurality of vehicles 1204, according to conventional algorithms; and FIG. 12B shows the electricity costs, including market electricity prices per kWatt-hour 1212, and the energy consumption of the plurality of vehicles 1214, according to algorithms of the disclosure. As shown in FIGS. 11A to 12B, a lower peak-to-average ratio may be observed for the total energy consumption (FIG. 11B) and electricity costs (FIG. 12B) associated with the plurality of vehicles, and determined according to algorithms of the disclosure. In addition, a total energy cost savings of 15.58 % was determined for the plurality of vehicles.

[00124] FIG. 13A shows the electrochemical cell 116 degradation costs and energy consumption, including the cost associated with degradation 1302, and the energy consumption of the plurality of vehicles 1304, according to conventional algorithms; and FIG. 13B shows the electrochemical cell 116 degradation costs and energy consumption, including the cost associated with degradation 1312, and the energy consumption of the plurality of vehicles 1314, according to algorithms of the disclosure. From FIGS. 13A and 13B, it was observed

that cost savings of 60.89 % was achieved based on the charging schedule, determined in accordance with algorithms of the disclosure.

[00125] FIG. 14A shows the SOE levels of 4 randomly selected vehicles, vehicle 1402, 1404, 1408, 1410 among the plurality of vehicles, according to conventional algorithms; and FIG. 14B shows the SOE levels of the same 4 randomly selected vehicles, vehicle 1402, 1404, 1408, 1410 among the plurality of vehicles, according to algorithms of the disclosure. FIGS. 14C and 14D show the terminal voltages over time for 2 randomly selected vehicles among vehicles 1402, 1404, 1408 and 1410, for example, vehicle 1408 (FIG. 14C) and 1410 (FIG. 14D), which may be based on FIG. 14B. From FIGS. 14A to 14D, it may be seen that the charging schedule of vehicles 1402, 1404, 1408, 1410 (FIG. 14B) may be spaced over a longer time period, so as to avoid peak loads at the charging station. Further, exemplary vehicles 1408 and 1410 may obtain sufficient terminal voltages for servicing incoming demand requests, while minimizing the costs associated with the charging of the electrochemical cells 116 for said exemplary vehicles 1408, 1410, under a dynamic electricity pricing structure.

[00126] Various embodiments of the disclosure thus provide an improved system, and method thereof for determining, over the predetermined time horizon, an optimized electrical charging schedule for a plurality of vehicles, which may be operated by an on-demand vehicle provider, each vehicle being affiliated with a charging station. The disclosure considers, in particular, the SOH and SOE of the vehicle's electrochemical cell 116 to minimize the capacity fading effect by prevent excessive charging and discharging of the electrochemical cell 116, thereby mitigation degradation of the electrochemical cell 116, and maintaining the SOH and lifetime of the electrochemical cell 116. This may lead to cost savings for the user as the replacement costs of such electrochemical cells 116 may be high. This improved system therefore provides for an improved charge strategy, which achieves the immediate objective of the minimization of electricity cost under a dynamic electricity pricing structure. In addition, the improved strategy achieves the long-term objectives of minimizing the electrochemical cells' replacement costs, maximizing the number of available vehicles by considering a predicted demand of the vehicles, and performing peak load shaving at the charging station.

[00127] While the disclosure has been particularly shown and described with reference to specific embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the disclosure as defined by the appended claims. The scope of the disclosure is thus indicated by

the appended claims and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced.

CLAIMS

1. A system for determining, over a predetermined time horizon, a charging schedule for a plurality of vehicles affiliated with a charging station, the system comprising a processor, the processor configured to

obtain, a first parameter indicative of a state of health (SOH) of an electrochemical cell of at least one vehicle among the plurality of vehicles;

obtain, a second parameter indicative of a state of energy (SOE) of the electrochemical cell of the at least one vehicle among the plurality of vehicles;

obtain, a third parameter indicative of a demand, over the predetermined time horizon, of the at least one vehicle among the plurality of vehicles, the at least one vehicle having an energy level greater than or equal to a threshold energy level;

obtain, a fourth parameter indicative of an operational capacity of the charging station; and

determine, for the at least one vehicle among the plurality of vehicles, a control signal related to the charging schedule, the control signal determined based on, at least one of the first parameter, the second parameter, the third parameter and/or the fourth parameter.

2. The system of claim 1, wherein the processor is further configured to

obtain, a sixth parameter indicative of a state of charge (SOC) of the electrochemical cell of the at least one vehicle among the plurality of vehicles; and

determine, for the at least one vehicle among the plurality of vehicles, a control signal related to the charging schedule, the control signal determined based on, at least one of the first parameter, the second parameter, the third parameter, the fourth parameter, and/or the sixth parameter.

3. The system of claim 1 or claim 2, wherein the plurality of vehicles comprises at least one en route vehicle, and wherein the processor is further configured to

obtain, a fifth parameter indicative of an estimated arrival time of the en route vehicle at the charging station; and

determine, for the at least one en route vehicle among the plurality of vehicles, the control signal related to the charging schedule, based on, at least one of the first parameter, the

second parameter, the third parameter, the fourth parameter, the fifth parameter and/or the sixth parameter.

4. The system of any one of claims 1 to 3, wherein the first parameter indicative of the SOH of the electrochemical cell comprises, at least one of a degradation of the electrochemical cell, and/or an age of the electrochemical cell.

5. The system of claim 3 or claim 4, wherein the plurality of vehicles further comprises at least one idle vehicle, and wherein the second parameter indicative of the SOE of the electrochemical cell comprises,

an initial energy level of the idle vehicle, and/or

an estimated energy level of the en route vehicle at the estimated arrival time of the en route vehicle at the charging station.

6. The system of claim 5, wherein the fifth parameter indicative of the estimated arrival time of the en route vehicle at the charging station comprises, at least one of

a departure time of the en route vehicle from the charging station;

a traffic data indicative of a traffic condition related to the en route vehicle;

a weather data related to the en route vehicle;

a road network data indicative of road network information related to the en route vehicle; and/or

a performance data indicative of a performance condition of the en route vehicle.

7. The system of claim 6, wherein the estimated energy level of the en route vehicle at the estimated arrival time comprises, at least one of the departure time, the road network data, and/or the fifth parameter indicative of the estimated arrival time of the en route vehicle.

8. The system of any one of claims 1 to 7, wherein the third parameter indicative of the demand of the at least one vehicle having the energy level greater than or equal to the threshold energy level, further comprises a trip information, and

wherein the third parameter comprises, at least one of

a historical supply data, of the at least one vehicle having the energy level greater than or equal to the threshold energy level;

a historical demand data, of the at least one vehicle having the energy level greater than or equal to the threshold energy level, the historical demand comprising a historical trip information of said vehicle;

a historical weather data, related to the historical demand data and historical supply data of the at least one vehicle having the energy level greater than or equal to the threshold energy level;

a forecasted weather data, over the predetermined time horizon; and/or

a forecasted supply data, indicative of an estimated supply of the at least one vehicle or another vehicle, having the energy level greater than or equal to the threshold energy level.

9. The system of any one of claims 1 to 8, wherein the fourth parameter indicative of the operational capacity of the charging station comprises, at least one of

a total number of units of available energy at the charging station;

a cost per unit of the available energy at the charging station;

a total number of charging ports available at the charging station; and/or

a various number of charging modes for each charging port among the total number of charging ports available at the charging station.

10. The system of claim 9, wherein the control signal related to the charging schedule comprises at least one of

a required energy, such that the energy level of the at least one vehicle is greater than or equal to, the threshold energy level;

a required charge duration, the required charge duration based on the required energy and a charging rate of the electrochemical cell; and

a required charging mode among the various number of charging modes, for an allocated charging port among the total number of charging ports available,

wherein the required charging mode is based on the required energy, the required charge duration and/or a desired duration, and the third parameter.

11. The system of claim 10, wherein the processor is further configured to determine the control signal based on, at least one of
 - the charging rate of the electrochemical cell of the at least one vehicle;
 - the second parameter indicative of the SOE of the electrochemical cell of the at least one vehicle over the predetermined time horizon.
12. The system of any one of claims 1 to 11, wherein the processor is further configured to transmit, the control signal to another processor of the at least one vehicle.
13. The system of any one of claims 1 to 12, wherein the plurality of vehicles each comprise an electric vehicle.
14. A control device comprising a processor for determining, over a predetermined time horizon, a charging schedule for a plurality of vehicles affiliated with a charging station,
 - the processor being in data communication with a memory having instructions stored therein, the instructions, when executed by the processor, causes the processor to
 - obtain, a first parameter indicative of a SOH of an electrochemical cell of at least one vehicle among the plurality of vehicles;
 - obtain, a second parameter indicative of a SOE of the electrochemical cell of the at least one vehicle among the plurality of vehicles;
 - obtain, a third parameter indicative of a demand, over the predetermined time horizon, of the at least one vehicle among the plurality of vehicle, the at least one vehicle having an energy level greater than or equal to a threshold energy level;
 - obtain, a fourth parameter indicative of an operational capacity of the charging station; and
 - determine, for the at least one vehicle among the plurality of vehicles, a control signal related to the charging schedule, the control signal determined based on, at least one of the first parameter, the second parameter, the third parameter and/or the fourth parameter.
15. A method for determining, over a predetermined time horizon, a charging schedule for a plurality of vehicles affiliated with a charging station, the method comprising
 - providing a processor for

obtaining, a first parameter indicative of a SOH of an electrochemical cell of at least one vehicle among the plurality of vehicles;

obtaining, a second parameter indicative of a SOE of the electrochemical cell of the at least one vehicle among the plurality of vehicles;

obtaining, a third parameter indicative of a demand, over the predetermined time horizon, of the at least one vehicle among the plurality of vehicle, the at least one vehicle having an energy level greater than or equal to a threshold energy level;

obtaining, a fourth parameter indicative of an operational capacity of the charging station; and

determining, for the at least one vehicle among the plurality of vehicles, a control signal related to the charging schedule, the control signal determined based on, at least one of the first parameter, the second parameter, the third parameter and/or the fourth parameter.

16. The method of claim 15, wherein the processor further

obtains, a sixth parameter indicative of a SOC of the electrochemical cell of the at least one vehicle among the plurality of vehicles; and

determine, for the at least one vehicle among the plurality of vehicles, a control signal related to the charging schedule, the control signal determined based on, at least one of the first parameter, the second parameter, the third parameter, the fourth parameter, and/or the sixth parameter.

17. The method of claim 15 or claim 16, wherein the plurality of vehicles comprises at least one en route vehicle, and

wherein the processor further

obtains, a fifth parameter indicative of an estimated arrival time of the en route vehicle at the charging station; and

determines, for the at least one en route vehicle among the plurality of vehicles, the control signal related to the charging schedule, based on, at least one of the first parameter, the second parameter, the third parameter, the fourth parameter, the fifth parameter and/or the sixth parameter.

18. The method of any one of claims 15 to 17, wherein the first parameter indicative of the SOH of the electrochemical cell comprises, at least one of a degradation of the electrochemical cell, and/or an age of the electrochemical cell.
19. The method of any one of claims 15 to 18, wherein the control signal related to the charging schedule comprises at least one of
 - a required energy, such that the energy level of the at least one vehicle is greater than or equal to, the threshold energy level;
 - a required charge duration, the required charge duration based on the required energy and a charging rate of the electrochemical cell; and
 - a required charging mode among the various number of charging modes, for an allocated charging port among the total number of charging ports available,wherein the required charging mode is based on the required energy, the required charge duration and/or a desired duration, and the third parameter.
20. A computer readable medium comprising instructions, which when executed by the processor, causes the processor to perform the method of any one of claims 15 to 19.