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Systems for optimizing battery charging and discharging

Abstract

A method includes accessing historic five-minute electricity data for a predetermined number of previous days, determining, using the historic five-minute electricity data for the predetermined number of previous days, a maximum charge price for the predetermined number of previous days, and determining, using the historic five-minute electricity data for the predetermined number of previous days, a minimum discharge price for the predetermined number of previous days. The method further includes determining a current amount of charge of a battery, accessing live five-minute electricity data for a current day, and communicating one or more instructions to discharge a battery when a next live five-minute electricity price is greater than the determined minimum discharge price and the current amount of charge of the battery is greater than zero. The method further includes communicating one or more instructions to charge the battery when the next live five-minute electricity price is less than the determined maximum charge price and the current amount of charge of the battery is greater than a maximum charge amount of the battery.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application is a continuation of U.S. application Ser. No. 17/206,850, filed Mar. 19, 2021, entitled “SYSTEMS FOR OPTIMIZING BATTERY CHARGING AND DISCHARGING” which claims the benefit of U.S. Provisional

Application 62/992,640 filed Mar. 20, 2020, the entire disclosures of which are incorporated herein by reference.

TECHNICAL FIELD

(1) This disclosure generally relates to batteries, and more particularly to systems for optimizing battery charging and discharging.

BACKGROUND

(2) Energy storage devices such as batteries are used by various individuals, businesses, and organizations to store power from the electric grid or other power sources (e.g., wind or solar power plants). The stored power may then be used to provide needed electrical power. As one example, an individual may install a battery in their home that stores power from the electric grid and discharges the stored power for use in their home or electric vehicle. As another example, a business may install a large backup battery that stores power in case of a power outage. In these and other examples, the unused power stored in a battery may be discharged and sold back to the electric grid.

SUMMARY OF PARTICULAR EMBODIMENTS

(3) In some embodiments, a system includes one or more processors and one or more computer-readable non-transitory storage media coupled to one or more of the processors. The one or more computer-readable non-transitory storage media comprises instructions operable when executed by one or more of the processors to cause the system to access historic five-minute electricity data for a predetermined number of previous days, determine, using the historic five-minute electricity data for the predetermined number of previous days, a maximum charge price for the predetermined number of previous days, and determine, using the historic five-minute electricity data for the predetermined number of previous days, a minimum discharge price for the predetermined number of previous days. The instructions are further operable when executed by one or more of the processors to cause the system to determine a current amount of charge of a battery, access live five-minute electricity data for a current day, communicate one or more instructions to discharge a battery when a next live five-minute electricity price is greater than the determined minimum discharge price and the current amount of charge of the battery is greater than zero, and communicate one or more instructions to charge the battery when the next live five-minute electricity price is less than the determined maximum charge price and the current amount of charge of the battery is greater than a maximum charge amount of the battery.

(4) In one embodiment, a method includes accessing historic five-minute electricity data for a predetermined number of previous days, determining, using the historic five-minute electricity data for the predetermined number of previous days, a maximum charge price for the predetermined number of previous days, and determining, using the historic five-minute electricity data for the predetermined number of previous days, a minimum discharge price for the predetermined number of previous days. The method further includes determining a current amount of charge of a battery, accessing live five-minute electricity data for a current day, and communicating one or more instructions to discharge a battery when a next live five-minute electricity price is greater than the determined minimum discharge price and the current amount of charge of the battery is greater than zero. The method further includes communicating one or more instructions to charge the battery when the next live five-minute electricity price is less than the determined maximum charge price and the current amount of charge of the battery is greater than a maximum charge amount of the battery.

(5) In some embodiments, one or more computer-readable non-transitory storage media includes software that is operable when executed to access historic five-minute electricity data for a predetermined number of previous days, determine, using the historic five-minute electricity data for the predetermined number of previous days, a maximum charge price for the predetermined number of previous days, and determine, using the historic five-minute electricity data for the

predetermined number of previous days, a minimum discharge price for the predetermined number of previous days. The software is further operable when executed to determine a current amount of charge of a battery, access live five-minute electricity data for a current day, communicate one or more instructions to discharge a battery when a next live five-minute electricity price is greater than the determined minimum discharge price and the current amount of charge of the battery is greater than zero, and communicate one or more instructions to charge the battery when the next live five-minute electricity price is less than the determined maximum charge price and the current amount of charge of the battery is greater than a maximum charge amount of the battery.
(6) The embodiments disclosed herein are only examples, and the scope of this disclosure is not limited to them. Particular embodiments may include all, some, or none of the components, elements, features, functions, operations, or steps of the embodiments disclosed herein. Embodiments according to the invention are in particular disclosed in the attached claims directed to a method, a storage medium, a system and a computer program product, wherein any feature mentioned in one claim category, e.g. method, can be claimed in another claim category, e.g. system, as well. The dependencies or references back in the attached claims are chosen for formal reasons only. However any subject matter resulting from a deliberate reference back to any previous claims (in particular multiple dependencies) can be claimed as well, so that any combination of claims and the features thereof are disclosed and can be claimed regardless of the dependencies chosen in the attached claims. The subject-matter which can be claimed comprises not only the combinations of features as set out in the attached claims but also any other combination of features in the claims, wherein each feature mentioned in the claims can be combined with any other feature or combination of other features in the claims. Furthermore, any of the embodiments and features described or depicted herein can be claimed in a separate claim and/or in any combination with any embodiment or feature described or depicted herein or with any of the features of the attached claims.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) For a more complete understanding of the particular embodiments, and the advantages thereof, reference is now made to the following written description taken in conjunction with the accompanying drawings, in which:
(2) FIG. **1** illustrates an example power generation and distribution system, according to some embodiments;
(3) FIG. **2** illustrates a quantile-quantile plot of electricity prices, according to some embodiments;
(4) FIG. **3** illustrates a histogram of five-minute electricity prices for a particular node of FIG. **1**, according to some embodiments;
(5) FIG. **4** illustrates monthly five-minute electricity price histograms for a particular node of FIG. **1**, according to some embodiments;
(6) FIG. **5** illustrates a graphical representation of an optimal strike price for a battery, according to some embodiments;
(7) FIG. **6** illustrates a method for determining an optimal price to charge/discharge a battery based on a comparison of live five-minute pricing data with a matrix of maximum charge and minimum discharge price combinations for the previous N days, according to some embodiments; and
(8) FIG. **7** illustrates an example computer system, according to some embodiments.
DESCRIPTION OF EXAMPLE EMBODIMENTS
(9) Energy storage devices such as batteries are used by various individuals, businesses, and organizations to store power from the electric grid or other power sources (e.g., wind or solar power plants). The stored power may then be used to provide needed electrical power. As one

example, an individual may install a battery in their home that stores power from the electric grid and discharges the stored power for use in their home or electric vehicle. As another example, a business may install a large backup battery that stores power in case of a power outage. In these and other examples, the unused power stored in a battery may be discharged and sold back to the electric grid. However, determining optimal times to charge and discharge a battery to the grid throughout a day is typically not known or addressed.

(10) To address these and other problems with existing systems, the embodiments of the disclosure provide systems and methods for optimizing battery charging and discharging to an electric grid. More specifically, some embodiments of the disclosure determine optimal times throughout a day to discharge stored electrical power in a battery to an electric grid. Similarly, some embodiments of the disclosure determine optimal times throughout a day to charge a battery using electrical power from an electric grid.

(11) FIG. **1** is a block diagram illustrating an example power generation and distribution system **100**, according to certain embodiments. Power generation and distribution system **100** includes power generation unit **110**, electric grid **120**, and nodes **130**. Power generation unit **100** generates megawatts of power for transmission over electric grid **120** for use at nodes **130**. Each node **130** includes residential and commercial structures that may each include a battery **140**. Battery **140** may store electrical power from electric grid **120** (or from other power generation sources such as solar/wind power sources) and may discharge stored power back to electric grid **120**. In some embodiments, battery **140** may be a stand-alone battery that is not associated with any residential or commercial structure.

(12) In general, a battery such as battery **140** has the payoff structure of a physical call option. In some electric grids **120** (e.g., the Texas Interconnection electric grid operated by Electric Reliability Council of Texas (ERCOT)), electricity is priced in five-minute segments in a continuous, 24 hour/365 day market. Battery **140** can be discharged multiple times per day, following the 5-minute nodal price signals of electric grid **120**. For example, a battery **140** with a one megawatt (MW) capacity can be discharged over twelve five-minute joint or disjoint periods. TABLE 1 below illustrates example five-minute nodal pricing for a particular node **130** for a two-hour window of a particular day.

(13) TABLE-US-00001 TABLE 1

TIME	PRICE/MWh
6:00:00	$1207.95
6:05:00	$1208.28
6:10:00	$1208.30
6:15:00	$1208.33
6:20:00	$1208.63
6:25:00	$1208.74
6:30:00	$1208.73
6:35:00	$1208.80
6:40:00	$21.40
6:45:00	$21.38
6:50:00	$21.21
6:55:00	$1208.46
7:00:00	$1208.65
7:05:00	$1208.79
7:10:00	$1208.68
7:15:00	$1208.77
7:20:00	$1208.71
7:25:00	$1208.81
7:30:00	$1208.69
7:35:00	$21.29
7:40:00	$21.48
7:45:00	$21.34
7:50:00	$21.40
7:55:00	$21.42
8:00:00	$21.30

(14) Unlike traditional financial options, whose strike prices are set at purchase, a daily strike price of battery **140** (e.g., the fixed price at which power of battery **140** is sold or bought) can be set at the discretion of its owner or operator. Leaving aside physical parameters such as the battery degradation cost per charging cycle, the challenge for the owner or operator is to set a daily discharge strike price for battery **140** which maximizes the battery's opportunity to capture the day's highest 5-minute nodal prices, up to the limit of the physical capacity of battery **140**. Similarly, the challenge for the owner or operator of battery **140** is to set a daily charging strike price for battery **140** which maximizes the battery's opportunity to capture the day's lowest 5-minute nodal prices, up to the limit of the physical capacity of battery **140**. For discharging battery **140**, the discharge strike price of battery **140** cannot be so high that a discharge algorithm only looks for the highest prices and cannot be so low that battery **140** discharges before the appearance of extreme prices.

(15) The highly volatile and random nature of five-minute nodal prices is problematic for statistical/machine learning predictive methods. Weather and its effect on renewable generation, generation outages, and transmission constraints are all reflected in the five-minute market. Price

prediction reduces to weather and constraint prediction, without an increase in tractability. Predicting optimal battery dispatch times and prices is therefore of limited use.

(16) The highly volatile and skewed nature of nodal five-minute prices is shown in the quantile-quantile plot of FIG. **2**, which plots quantiles from a normal distribution vs. quantiles of actual prices. Normally distributed data points would fall on the line. As illustrated in this figure, nodal power data is highly skewed to the upside.

(17) The histogram illustrated in FIG. **3** also gives insight into the problem. Predictive methods are more likely to capture the mass of the distribution around zero. Battery sale price optimization, however, requires the capture of the majority of rare but extreme prices, out to $10,000/MW, for example.

(18) Despite the volatile and unpredictable nature of five-minute nodal power prices, some patterns do emerge. For example, FIG. **4** illustrates monthly price histograms for a particular node **130**. This figure illustrates how the daily distribution of the highest twelve five-minute nodal prices of the particular node **130** follows a seasonal pattern. As illustrated in this figure, shoulder and winter months generally follow bi-modal distributions with high prices in both the morning and evening. On the contrary, May through September high prices are concentrated in the afternoon.

(19) To address the problems and limitations of typical predictive methods, and to address the desire of charging and discharging battery **140** at a majority of optimal prices of node **130**, certain embodiments of the disclosure provide strike price optimization for battery **140** using a model that learns and adjusts to seasonality through recent prices (e.g., charge and discharge price combinations of the previous N days). A graphical representation of the optimal strike price **510** for battery **140** is illustrated in FIG. **5**, which illustrates how the optimal strike **510** over any particular time period for a particular node **130** is the highest y-axis/lowest x-axis combination on a graph of the average price of the first twelve five-minute daily sales. In some embodiments, battery **140** is controlled to charge and discharge based on a comparison of live five-minute pricing data with a matrix of maximum charge and minimum discharge price combinations for the previous N days. A particular embodiment that optimizes battery **140** using such an algorithm is illustrated below in reference to FIG. **6**.

(20) FIG. **6** illustrates an example method **600** for determining optimal price (e.g., price **510**) to charge/discharge battery **140** based on a comparison of live five-minute pricing data with a matrix of maximum charge and minimum discharge price combinations for the previous N days. In this example embodiment and throughout this disclosure, the set number of five-minute periods is twelve, which corresponds to a 1 MW battery (i.e., a 1 MW battery will be completely discharged over twelve five-minute periods). However, any other set number of five-minute periods may be used (e.g., 24 five-minute periods per day for a 2 MW battery **140**, 48 five-minute periods per day for a 4 MW battery, etc.)

(21) At step **610**, method **600** accesses historical five-minute pricing data for the previous N days. For example, method **600** may access five-minute pricing data for the previous three days. N may be any appropriate integer number of previous days. In some embodiments, the five-minute pricing data accessed in step **610** may be five-minute nodal pricing for a particular node **130** for a particular 24-hour period as illustrated above in TABLE 1.

(22) At step **620**, method **600** determines maximum charge and minimum discharge prices for the previous N days. For example, TABLE 2 below illustrates the twelve five-minute periods in which battery **140** was discharged over the past two days, with the minimum discharge price for each day being underlined for emphasis:

(23) TABLE-US-00002 TABLE 2 1 Day Prior 2 Days Prior TIME PRICE/MWh TIME PRICE/MWh 6:00:00 $1208.95 6:05:00 $1208.90 7:10:00 $1208.28 6:10:00 $1208.92 7:15:00 <u>$1202.30</u> 8:15:00 $1209.30 9:15:00 $1208.33 8:25:00 $1208.30 10:20:00 $1208.63 10:25:00 <u>$1204.71</u> 10:25:00 $1208.74 10:30:00 $1208.77 10:30:00 $1228.73 10:35:00 $1218.73 10:35:00 $1228.8 10:40:00 $1218.80 10:55:00 $1218.46 11:55:00 $1228.46 11:00:00 $1238.65

12:00:00 $1228.65 12:05:00 $1218.79 12:05:00 $1228.79 13:10:00 $1208.68 12:10:00 $1238.68

(24) Similarly, TABLE 3 below illustrates the twelve five-minute periods in which battery **140** was charged over the past two days:

(25) TABLE-US-00003 TABLE 2 1 Day Prior 2 Days Prior TIME PRICE/MWh TIME PRICE/MWh 1:00:00 $12.95 2:05:00 $12.90 1:10:00 $12.28 2:15:00 $12.92 1:15:00 $12.30 2:30:00 $12.30 2:15:00 $12.33 3:15:00 $12.30 2:20:00 $20.63 4:25:00 $12.71 2:25:00 $20.74 4:35:00 $12.77 2:30:00 $22.73 4:40:00 $21.73 2:35:00 $22.80 4:50:00 $21.80 2:55:00 $21.46 4:55:00 $25.46 3:00:00 $25.65 5:00:00 $22.65 3:05:00 $21.79 5:05:00 $22.79 3:10:00 $20.68 5:10:00 $23.68

(26) In this example, the maximum charge price over the previous two days as determined in step **620** was $25.65 (which occurred one day prior at 3:00) and the minimum discharge price was $1204.71 (which occurred two days prior at 10:25). In some embodiments, the maximum charge price is set in step **620** to the highest maximum charge price over the previous N days (i.e., $25.65 in this example) and the minimum discharge price is set in step **620** to the lowest minimum discharge price over the previous N days (i.e., $1204.71 in this example). In other embodiments, the maximum charge price is set in step **620** to the average of the maximum charge prices over the previous N days (i.e., ($25.65+$25.46)/2=$25.56 in this example) and the minimum discharge price is set in step **620** to the average of the minimum discharge prices over the previous N days (i.e., ($1204.71+$1202.30)/2=$1203.51 in this example). In some embodiments, step **620** includes choosing the maximum charge price/minimum discharge price combination that gives the optimal charge price and optimal discharge price. In these embodiments, a matrix of possible maximum charge/minimum discharge prices is created and tested against the historical five-minute pricing data for the previous N days of step **610**. In some embodiments, the combination that gives the highest net revenue is selected as the optimal charge price and optimal discharge price combination.

(27) At step **630**, method **600** accesses live five-minute pricing data for the current day. In some embodiments, the live five-minute pricing data is electricity pricing data that is provided by a manager of an electricity grid. For example, ERCOT publishes in real time the electricity price per MWh for the upcoming next five-minute time period of the day.

(28) At step **640**, method **600** compares the live five-minute pricing data of step **630** with the optimal minimum discharge price determined in step **620**. If the next live five-minute electricity price is greater than or equal to the optimal minimum discharge price determined in step **620** and the amount of current charge of battery **140** is greater than zero (i.e., there is at least some charge remaining in battery **140**), method **600** moves to step **650** where instructions are sent to discharge battery **140** during the next five-minute time period. If the next live five-minute electricity price (i.e., the next upcoming live five-minute electricity price) is not greater than or equal to the optimal minimum discharge price determined in step **620** or the amount of current charge of battery **140** is not greater than zero, method **600** moves to step **660**.

(29) In some embodiments, step **640** analyzes predictive conditions in addition to the minimum discharge price determined in step **620** and the amount of current charge of battery **140**. For example, method **600** may move to step **650** only when the following three conditions are met: 1) the next live five-minute electricity price is greater than or equal to the optimal minimum discharge price determined in step **620**, 2) the amount of current charge of battery **140** is greater than zero, and 3) one or more predictive conditions are met. Similarly, method **600** may move to step **660** if any of the above three conditions are not met. In some embodiments, the predictive conditions include utilizing a classification method and/or a price forecast method. The classification method may define future time periods as one of a predefined category (e.g., high, medium, or low price) based on historical market conditions and forecasted conditions. The price forecast method may be based on the relationships between historical data and historical price, with forecasted market data input and future price output. Example predictive models and algorithms that may be utilized by

step **640** are discussed in more detail below.
(30) In some embodiments, XGBoost (also known as extreme gradient boosting) may be utilized in step **640**. XGBoost is a machine learning algorithm which falls under the category of distributed and ensemble machine learning. This algorithm is useful because of its high speed and high model efficiency. XGBoost supports parallelization by creating decision trees and converts weak learners to strong learners by adjusting the weight of weak-learners which reduces the bias from the model and improves accuracy.
(31) In some embodiments, a classification predictive model may be utilized in step **640**. In general, classification predictive modeling is the process of approximating a mapping function (f) from input variables (X) to discrete output variables (y). This is a supervised learning model where the data is labeled with the correct classes. In some embodiments, this model classifies and groups the data into three categories: high, medium and low (1, 0, −1) making it a multi-class classification predictive model. A high output value indicates that the next 15-minute value is in a high zone, which is, for example, 10% of the highest historical price values. A medium output value represents that the next 15-minute value is in a medium zone, which is, for example, 80% of the medium historical price values. A low output value represents that the next 15-minute value is in a low zone, which is, for example, 10% of the lowest historical price values.
(32) In some embodiments, a regression predictive model may be utilized in step **640**. In general, regression predictive modeling is the process of approximating a mapping function (f) from input variables (X) to continuous output variables (y). This is a supervised learning model where the input is the true historical electricity prices along with other variables and the output is a continuous value which represents the predicted price of the electricity in 15-minute interval. The predicted output values from the regression algorithm provides the magnitude of the prices which are expected in the next 24-hour period.
(33) At step **660**, method **600** compares the live five-minute pricing data of step **630** with the optimal maximum charge price determined in step **620**. If the next live five-minute electricity price is less than or equal to the optimal maximum charge price determined in step **620** and the amount of current charge of battery **140** is less than the maximum charge amount (i.e., there is at least some charge space remaining in battery **140**), method **600** moves to step **670** where instructions are sent to charge battery **140** during the next five-minute time period. If the next live five-minute electricity price is not less than or equal to the optimal maximum charge price determined in step **620** or the amount of current charge of battery **140** is not less than the maximum charge amount, method **600** moves to step **680** where no charging or discharging is performed on battery **140**. After step **680**, method **600** may proceed back to step **640**.
(34) At step **685**, method **600** determines if battery **140** has been completely discharged (e.g., a 1 MW battery **140** has already been discharged over twelve five-minute time periods). If so, method **600** may end. Otherwise, method **600** may proceed to step **640**.
(35) In some embodiments, method **600** may analyze one or more customer constraints in steps **640** and **660** before deciding to charge or discharge battery **140** in steps **650** and **670**. For example, some customers may place a constraint that their battery may not be discharged to the grid during certain portions of the day (e.g., battery **140** may not be discharged between the hours of 8 AM-10 PM). As another example, some customers may place a constraint that their battery may not be discharged below a certain percentage (e.g., battery **140** may not be ever be discharged below 20% of capacity). As yet another example, some customers may place certain charge/discharge price constraints on their battery (e.g., battery **140** may not be ever be discharged below a certain price or charged above a certain price). Method **600** may analyze such customer constraints to ensure that battery **140** is not charged or discharged in violation of any such constraints.
(36) Although this disclosure describes and illustrates particular steps of the method of FIG. **6** as occurring in a particular order, this disclosure contemplates any suitable steps of the method of FIG. **6** occurring in any suitable order. Moreover, although this disclosure describes and illustrates

an example method for determining an optimal price to charge/discharge battery **140** based on a comparison of live five-minute pricing data with a matrix of maximum charge and minimum discharge price combinations for the previous N days including the particular steps of the method of FIG. **6**, this disclosure contemplates any suitable method for determining an optimal price to charge/discharge battery **140** based on a comparison of live five-minute pricing data with a matrix of maximum charge and minimum discharge price combinations for the previous N days including any suitable steps, which may include all, some, or none of the steps of the method of FIG. **6**, where appropriate. Furthermore, although this disclosure describes and illustrates particular components, devices, or systems carrying out particular steps of the method of FIG. **6**, this disclosure contemplates any suitable combination of any suitable components, devices, or systems carrying out any suitable steps of the method of FIG. **6**, including computer system **800** described below.

(37) FIG. **7** illustrates an example computer system **700**. In particular embodiments, one or more computer systems **700** perform one or more steps of one or more methods described or illustrated herein. In particular embodiments, one or more computer systems **700** provide functionality described or illustrated herein. In particular embodiments, software running on one or more computer systems **700** performs one or more steps of one or more methods described or illustrated herein or provides functionality described or illustrated herein. Particular embodiments include one or more portions of one or more computer systems **700**. Herein, reference to a computer system may encompass a computing device, and vice versa, where appropriate. Moreover, reference to a computer system may encompass one or more computer systems, where appropriate. In some embodiments, computer system **700** may be integrated with battery **140**. In other embodiments, computer system **700** is separate from battery **140**. In some embodiments, one computer system **700** is integrated with battery **140** and communicates with another computer system **700** via one or more computer/communications networks.

(38) This disclosure contemplates any suitable number of computer systems **700**. This disclosure contemplates computer system **700** taking any suitable physical form. As example and not by way of limitation, computer system **700** may be an embedded computer system, a system-on-chip (SOC), a single-board computer system (SBC) (such as, for example, a computer-on-module (COM) or system-on-module (SOM)), a desktop computer system, a laptop or notebook computer system, an interactive kiosk, a mainframe, a mesh of computer systems, a mobile telephone, a personal digital assistant (PDA), a server, a tablet computer system, an augmented/virtual reality device, or a combination of two or more of these. Where appropriate, computer system **700** may include one or more computer systems **700**; be unitary or distributed; span multiple locations; span multiple machines; span multiple data centers; or reside in a cloud, which may include one or more cloud components in one or more networks. Where appropriate, one or more computer systems **700** may perform without substantial spatial or temporal limitation one or more steps of one or more methods described or illustrated herein. As an example and not by way of limitation, one or more computer systems **700** may perform in real time or in batch mode one or more steps of one or more methods described or illustrated herein. One or more computer systems **700** may perform at different times or at different locations one or more steps of one or more methods described or illustrated herein, where appropriate.

(39) In particular embodiments, computer system **700** includes a processor **702**, memory **704**, storage **706**, an input/output (I/O) interface **708**, a communication interface **710**, and a bus **712**. Although this disclosure describes and illustrates a particular computer system having a particular number of particular components in a particular arrangement, this disclosure contemplates any suitable computer system having any suitable number of any suitable components in any suitable arrangement.

(40) In particular embodiments, processor **702** includes hardware for executing instructions, such as those making up a computer program. As an example and not by way of limitation, to execute

instructions, processor **702** may retrieve (or fetch) the instructions from an internal register, an internal cache, memory **704**, or storage **706**; decode and execute them; and then write one or more results to an internal register, an internal cache, memory **704**, or storage **706**. In particular embodiments, processor **702** may include one or more internal caches for data, instructions, or addresses. This disclosure contemplates processor **702** including any suitable number of any suitable internal caches, where appropriate. As an example and not by way of limitation, processor **702** may include one or more instruction caches, one or more data caches, and one or more translation lookaside buffers (TLBs). Instructions in the instruction caches may be copies of instructions in memory **704** or storage **706**, and the instruction caches may speed up retrieval of those instructions by processor **702**. Data in the data caches may be copies of data in memory **704** or storage **706** for instructions executing at processor **702** to operate on; the results of previous instructions executed at processor **702** for access by subsequent instructions executing at processor **702** or for writing to memory **704** or storage **706**; or other suitable data. The data caches may speed up read or write operations by processor **702**. The TLBs may speed up virtual-address translation for processor **702**. In particular embodiments, processor **702** may include one or more internal registers for data, instructions, or addresses. This disclosure contemplates processor **702** including any suitable number of any suitable internal registers, where appropriate. Where appropriate, processor **702** may include one or more arithmetic logic units (ALUs); be a multi-core processor; or include one or more processors **702**. Although this disclosure describes and illustrates a particular processor, this disclosure contemplates any suitable processor.

(41) In particular embodiments, memory **704** includes main memory for storing instructions for processor **702** to execute or data for processor **702** to operate on. As an example and not by way of limitation, computer system **700** may load instructions from storage **706** or another source (such as, for example, another computer system **700**) to memory **704**. Processor **702** may then load the instructions from memory **704** to an internal register or internal cache. To execute the instructions, processor **702** may retrieve the instructions from the internal register or internal cache and decode them. During or after execution of the instructions, processor **702** may write one or more results (which may be intermediate or final results) to the internal register or internal cache. Processor **702** may then write one or more of those results to memory **704**. In particular embodiments, processor **702** executes only instructions in one or more internal registers or internal caches or in memory **704** (as opposed to storage **706** or elsewhere) and operates only on data in one or more internal registers or internal caches or in memory **704** (as opposed to storage **706** or elsewhere). One or more memory buses (which may each include an address bus and a data bus) may couple processor **702** to memory **704**. Bus **712** may include one or more memory buses, as described below. In particular embodiments, one or more memory management units (MMUs) reside between processor **702** and memory **704** and facilitate accesses to memory **704** requested by processor **702**. In particular embodiments, memory **704** includes random access memory (RAM). This RAM may be volatile memory, where appropriate. Where appropriate, this RAM may be dynamic RAM (DRAM) or static RAM (SRAM). Moreover, where appropriate, this RAM may be single-ported or multi-ported RAM. This disclosure contemplates any suitable RAM. Memory **704** may include one or more memories **704**, where appropriate. Although this disclosure describes and illustrates particular memory, this disclosure contemplates any suitable memory.

(42) In particular embodiments, storage **706** includes mass storage for data or instructions. As an example and not by way of limitation, storage **706** may include a hard disk drive (HDD), a floppy disk drive, flash memory, an optical disc, a magneto-optical disc, magnetic tape, or a Universal Serial Bus (USB) drive or a combination of two or more of these. Storage **706** may include removable or non-removable (or fixed) media, where appropriate. Storage **706** may be internal or external to computer system **700**, where appropriate. In particular embodiments, storage **706** is non-volatile, solid-state memory. In particular embodiments, storage **706** includes read-only memory (ROM). Where appropriate, this ROM may be mask-programmed ROM, programmable

ROM (PROM), erasable PROM (EPROM), electrically erasable PROM (EEPROM), electrically alterable ROM (EAROM), or flash memory or a combination of two or more of these. This disclosure contemplates mass storage **706** taking any suitable physical form. Storage **706** may include one or more storage control units facilitating communication between processor **702** and storage **706**, where appropriate. Where appropriate, storage **706** may include one or more storages **706**. Although this disclosure describes and illustrates particular storage, this disclosure contemplates any suitable storage.

(43) In particular embodiments, I/O interface **708** includes hardware, software, or both, providing one or more interfaces for communication between computer system **700** and one or more I/O devices. Computer system **700** may include one or more of these I/O devices, where appropriate. One or more of these I/O devices may enable communication between a person and computer system **700**. As an example and not by way of limitation, an I/O device may include a keyboard, keypad, microphone, monitor, mouse, printer, scanner, speaker, still camera, stylus, tablet, touch screen, trackball, video camera, another suitable I/O device or a combination of two or more of these. An I/O device may include one or more sensors. This disclosure contemplates any suitable I/O devices and any suitable I/O interfaces **708** for them. Where appropriate, I/O interface **708** may include one or more device or software drivers enabling processor **702** to drive one or more of these I/O devices. I/O interface **708** may include one or more I/O interfaces **708**, where appropriate. Although this disclosure describes and illustrates a particular I/O interface, this disclosure contemplates any suitable I/O interface.

(44) In particular embodiments, communication interface **710** includes hardware, software, or both providing one or more interfaces for communication (such as, for example, packet-based communication) between computer system **700** and one or more other computer systems **700** or one or more networks. As an example and not by way of limitation, communication interface **710** may include a network interface controller (NIC) or network adapter for communicating with an Ethernet or other wire-based network or a wireless NIC (WNIC) or wireless adapter for communicating with a wireless network, such as a WI-FI network. This disclosure contemplates any suitable network and any suitable communication interface **710** for it. As an example and not by way of limitation, computer system **700** may communicate with an ad hoc network, a personal area network (PAN), a local area network (LAN), a wide area network (WAN), a metropolitan area network (MAN), or one or more portions of the Internet or a combination of two or more of these. One or more portions of one or more of these networks may be wired or wireless. As an example, computer system **700** may communicate with a wireless PAN (WPAN) (such as, for example, a BLUETOOTH WPAN), a WI-FI network, a WI-MAX network, a cellular telephone network (such as, for example, a Global System for Mobile Communications (GSM) network), or other suitable wireless network or a combination of two or more of these. Computer system **700** may include any suitable communication interface **710** for any of these networks, where appropriate. Communication interface **710** may include one or more communication interfaces **710**, where appropriate. Although this disclosure describes and illustrates a particular communication interface, this disclosure contemplates any suitable communication interface.

(45) In particular embodiments, bus **712** includes hardware, software, or both coupling components of computer system **700** to each other. As an example and not by way of limitation, bus **712** may include an Accelerated Graphics Port (AGP) or other graphics bus, an Enhanced Industry Standard Architecture (EISA) bus, a front-side bus (FSB), a HYPERTRANSPORT (HT) interconnect, an Industry Standard Architecture (ISA) bus, an INFINIBAND interconnect, a low-pin-count (LPC) bus, a memory bus, a Micro Channel Architecture (MCA) bus, a Peripheral Component Interconnect (PCI) bus, a PCI-Express (PCIe) bus, a serial advanced technology attachment (SATA) bus, a Video Electronics Standards Association local (VLB) bus, or another suitable bus or a combination of two or more of these. Bus **712** may include one or more buses **712**, where appropriate. Although this disclosure describes and illustrates a particular bus, this disclosure

contemplates any suitable bus or interconnect.
(46) Herein, a computer-readable non-transitory storage medium or media may include one or more semiconductor-based or other integrated circuits (ICs) (such, as for example, field-programmable gate arrays (FPGAs) or application-specific ICs (ASICs)), hard disk drives (HDDs), hybrid hard drives (HHDs), optical discs, optical disc drives (ODDs), magneto-optical discs, magneto-optical drives, floppy diskettes, floppy disk drives (FDDs), magnetic tapes, solid-state drives (SSDs), RAM-drives, SECURE DIGITAL cards or drives, any other suitable computer-readable non-transitory storage media, or any suitable combination of two or more of these, where appropriate. A computer-readable non-transitory storage medium may be volatile, non-volatile, or a combination of volatile and non-volatile, where appropriate.
(47) Herein, “or” is inclusive and not exclusive, unless expressly indicated otherwise or indicated otherwise by context. Therefore, herein, “A or B” means “A, B, or both,” unless expressly indicated otherwise or indicated otherwise by context. Moreover, “and” is both joint and several, unless expressly indicated otherwise or indicated otherwise by context. Therefore, herein, “A and B” means “A and B, jointly or severally,” unless expressly indicated otherwise or indicated otherwise by context.
(48) The scope of this disclosure encompasses all changes, substitutions, variations, alterations, and modifications to the example embodiments described or illustrated herein that a person having ordinary skill in the art would comprehend. The scope of this disclosure is not limited to the example embodiments described or illustrated herein. Moreover, although this disclosure describes and illustrates respective embodiments herein as including particular components, elements, feature, functions, operations, or steps, any of these embodiments may include any combination or permutation of any of the components, elements, features, functions, operations, or steps described or illustrated anywhere herein that a person having ordinary skill in the art would comprehend. Furthermore, reference in the appended claims to an apparatus or system or a component of an apparatus or system being adapted to, arranged to, capable of, configured to, enabled to, operable to, or operative to perform a particular function encompasses that apparatus, system, component, whether or not it or that particular function is activated, turned on, or unlocked, as long as that apparatus, system, or component is so adapted, arranged, capable, configured, enabled, operable, or operative. Additionally, although this disclosure describes or illustrates particular embodiments as providing particular advantages, particular embodiments may provide none, some, or all of these advantages.

Claims

1. A system comprising: a battery; one or more processors; and one or more computer-readable non-transitory storage media coupled to one or more of the processors and comprising instructions operable when executed by one or more of the processors to cause the system to: access historic five-minute electricity data for a predetermined number of previous days; determine, using the historic five-minute electricity data for the predetermined number of previous days, a matrix of maximum charge price and minimum discharge price combinations for the predetermined number of previous days, the matrix including a respective set number of maximum charge prices and minimum discharge prices for each of the predetermined number of previous days, the set number determined by a number of five-minute periods for the battery to be completely discharged; determine, using the matrix of maximum charge price and minimum discharge price combinations for the predetermined number of previous days, a minimum discharge price for the predetermined number of previous days; determine that a current amount of charge of the battery is greater than zero; access live five-minute electricity data for a current day; determine that an upcoming next live five-minute electricity price is greater than the determined minimum discharge price using a price prediction model; in response to the determining that the amount of charge of the battery is

greater than zero and that the electricity price is greater than the determined minimum discharge price, electronically communicate to the battery, across a communications network, instructions to discharge the battery during a next five-minute period; wherein the battery is configured, in response to electronically receiving the instructions across the communications network, to discharge during the next five-minute period.
2. The system of claim 1, wherein determining the minimum discharge price for the predetermined number of previous days comprises determining a lowest minimum discharge price for the predetermined number of previous days.
3. The system of claim 1, wherein determining the minimum discharge price for the predetermined number of previous days comprises: determining a plurality of minimum prices for the predetermined number of previous days, wherein each minimum price of the plurality of minimum prices is a minimum price at which the battery was discharged for a particular day of the predetermined number of previous days; and calculating an average of the plurality of minimum prices.
4. The system of claim 1, wherein communicating the instructions to discharge the battery are further based on one or more customer constraints.
5. The system of claim 4, wherein the one or more customer constraints include a requirement that the battery be discharged to an electrical grid during one or more designated periods during a day.
6. The system of claim 4, wherein the one or more customer constraints include a requirement that the battery may not be discharged to an electrical grid below a specified percentage of its capacity.
7. The system of claim 1, wherein the price prediction model is a machine learning model based on ensemble of decision trees.
8. A system comprising: a battery; one or more processors; and one or more computer-readable non-transitory storage media coupled to one or more of the processors and comprising instructions operable when executed by one or more of the processors to cause the system to: access historic five-minute electricity data for a predetermined number of previous days; determine, using the historic five-minute electricity data for the predetermined number of previous days, a matrix of maximum charge price and minimum discharge price combinations for the predetermined number of previous days, the matrix including a respective set number of maximum charge prices and minimum discharge prices for each of the predetermined number of previous days, the set number determined by a number of five-minute periods for the battery to be completely discharged; determine, using the matrix of maximum charge price and minimum discharge price combinations for the predetermined number of previous days, a maximum charge price for the predetermined number of previous days; determine that a current amount of charge of the battery is less than a maximum charge amount of the battery; access live five-minute electricity data for a current day; determine that an upcoming next live five-minute electricity price is less than the determined maximum charge price using a price prediction model; in response to the determining that the amount of charge of the battery is less than the maximum charge amount of the battery and that the electricity price is less than the determined maximum charge price, electronically communicate to the battery, across a communications network, instructions to charge the battery during the next five-minute period; wherein the battery is configured, in response to electronically receiving the instructions across the communications network, to charge during the next five-minute period.
9. The system of claim 8, wherein determining the maximum charge price for the predetermined number of previous days comprises determining a highest maximum charge price for the predetermined number of previous days.
10. The system of claim 8, wherein determining the maximum charge price for the predetermined number of previous days comprises: determining a plurality of maximum prices for the predetermined number of previous days, wherein each maximum price of the plurality of maximum prices is a maximum price at which the battery was charged for a particular day of the predetermined number of previous days; and calculating an average of the plurality of maximum

prices.
11. The system of claim 8, wherein the price prediction model is a machine learning model based on ensemble of decision trees.
12. The system of claim 8, wherein the price prediction model utilizes classification predictive modeling that defines future time periods as one of a plurality of defined categories based on historical market conditions and forecasted conditions.
13. The system of claim 8, wherein the price prediction model is a regression predictive model to forecast expected prices.
14. A method comprising: by a computing device, accessing historic five-minute electricity data for a predetermined number of previous days; by the computing device, determining, using the historic five-minute electricity data for the predetermined number of previous days, a matrix of maximum charge price and minimum discharge price combinations for the predetermined number of previous days, the matrix including a respective set number of maximum charge prices and minimum discharge prices for each of the predetermined number of previous days, the set number determined by a number of five-minute periods for a battery to be completely discharged; by the computing device, determining, using the matrix of maximum charge price and minimum discharge price combinations for the predetermined number of previous days, at least one of: a maximum charge price, a minimum discharge price, or combination thereof for the predetermined number of previous days; by the computing device, determining a current amount of charge of the battery; by the computing device, accessing live five-minute electricity data for a current day using a price prediction model; by the computing device, electronically communicating to the battery, across a communications network, instructions to at least one of: (i) discharging the battery during a next five-minute period, in response to the determining that an amount of charge of the battery is greater than zero and that electricity price is greater than the determined minimum discharge price; (ii) charging the battery during the next five-minute period, in response to the determining that the amount of charge of the battery is less than the maximum charge amount of the battery and that the electricity price is less than the determined maximum charge price; and charge the battery during the next five-minute period; or (iii) combination thereof; and by the computing device, executing corresponding to the instructions at least one of: discharging the battery during the next five-minute period, charging the battery during the next five-minute period, or combination thereof.
15. The method of claim 14, wherein determining the maximum charge price for the predetermined number of previous days comprises determining a highest maximum charge price for the predetermined number of previous days.
16. The method of claim 14, wherein determining the minimum discharge price for the predetermined number of previous days comprises determining a lowest minimum discharge price for the predetermined number of previous days.
17. The method of claim 14, wherein determining the maximum charge price for the predetermined number of previous days comprises: determining a plurality of maximum prices for the predetermined number of previous days, wherein each maximum price of the plurality of maximum prices is a maximum price at which the battery was charged for a particular day of the predetermined number of previous days; and calculating an average of the plurality of maximum prices.
18. The method of claim 14, wherein determining the minimum discharge price for the predetermined number of previous days comprises: determining a plurality of minimum prices for the predetermined number of previous days, wherein each minimum price of the plurality of minimum prices is a minimum price at which the battery was discharged for a particular day of the predetermined number of previous days; and calculating an average of the plurality of minimum prices.
19. The method of claim 14, wherein electronically communicating the instructions to discharge the battery are further based on one or more customer constraints comprising at least one of: a

requirement that the battery be discharged to an electrical grid during one or more designated periods during a day; a requirement that the battery may not be discharged to the electrical grid below a specified percentage of its capacity; a requirement that the battery may not be discharged below a certain electricity price; a requirement that the battery may not be charged above a certain electricity price; or combination thereof.

20. The method of claim 14, wherein the price prediction model is a machine learning model based on ensemble of decision trees.