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ENERGY CONTROL UTILIZING A VIRTUAL POWER PLANT

Abstract

A power distribution system includes an electrical utility and at least one virtual power plant. The virtual power plant can be utilized and controlled in order to support the operations of the electrical utility. Upon determining an electrical need, the utility instructs the virtual power plant to make an energy adjustment by a scheduled time. The virtual power plant allocates the energy adjustment among the distributed energy resources of its fleet in order to achieve the energy adjustment by the scheduled time.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation of U.S. application Ser. No. 17/464,032, filed Sep. 1, 2021, which claims the benefit of U.S. Application No. 63/111,580 filed on Nov. 9, 2020, the disclosures of which are hereby incorporated by reference in their entireties. To the extent appropriate a claim of priority is made to each of the above-disclosed applications.

BACKGROUND

[0002] The levels of energy demand and energy generation at sites connected to a power grid vary throughout the day. For example, in homes connected to the power grid, there will be peak times of energy usage when heating or cooling occurs. For example, in the middle of a hot day, many homes will be running an air conditioner at the same time. When multiple sites connected to the grid are using a higher level of energy simultaneously, this can strain the ability of electric utilities to provide adequate power throughout the grid. It can also increase the cost of generating and purchasing energy. Events such as inclement weather, including thunderstorms, high wind, and even forest fires, can also cause reliability issues with the grid that can cause a grid to be unable to supply enough power or cause complete outages in certain areas. Further, forecasted events can also result in planned outages during which at least some consumers cannot obtain power from the utility.

[0003] More commonly power grids can also connect to alternative energy sources in addition to the power plants operated by electric utilities. Examples of these energy generators include solar and wind generators. These generators can also strain the power grid if there is excessive generation at one time. For example, during a clear bright day, solar generators may be able to produce more energy than the grid can safely handle. As a result, there is a need for electric utilities to have greater control of the grid to better respond to times of high demand, as well as to handle times when excess power is available.

[0004] Virtual power plants provide power generation and storage capabilities that can support the power grid. A virtual power plant includes a plurality of distributed energy resources, that can be distributed across multiple different sites. A centralized control system manages the operations of the virtual power plant and associated distributed energy resources.

SUMMARY

[0005] In general terms, this disclosure is directed to energy control utilizing a virtual power plant. In some embodiments, and by non-limiting example, a virtual power plant comprises a plurality of distributed energy resources. The virtual power plant can respond to an energy control request by a platform operator and/or entity, to support the power grid, such as by controlling the virtual power plant to achieve an energy target by a scheduled time.

[0006] One aspect is a method of controlling a fleet of distributed energy resources, the method comprising: receiving an energy control request including an energy target and a scheduled time to achieve the energy target; determining an energy adjustment needed across the fleet to achieve the energy target; determining an allocation of the energy adjustment among the distributed energy resources of the fleet; and instructing the distributed energy resources of the fleet to make energy adjustments according to allocations to cause the fleet of distributed energy resources to achieve the energy target by the scheduled time.

[0007] Another aspect is a system for controlling a fleet of distributed energy resources, the system comprising: at least one computing device; and at least one computer-readable storage device storing data instructions that, when executed by the at least one computing device, cause the at least one computing device to: receive an energy control request including an energy target and a scheduled time to achieve the energy target; determine an energy adjustment needed across the fleet to achieve the energy target; determine an allocation of the energy adjustment among the distributed energy resources of the fleet; and instruct the distributed energy resources of the fleet to make energy adjustments according to allocations to cause the fleet of distributed energy resources to achieve the energy target by the scheduled time.
[0008] A further aspect is a method of controlling a virtual power plant, the method comprising: predicting by an electrical utility an electrical need; determining an energy adjustment to be made by a virtual power plant to respond to the need; determining a scheduled time to achieve the energy adjustment; and instructing the virtual power plant to make the energy adjustment by the scheduled time.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0009] FIG. **1** is a schematic block diagram illustrating an example power distribution system.
[0010] FIG. **2** is a flow chart illustrating an example method of controlling a fleet of distributed energy resources.
[0011] FIG. **3** is a flow chart illustrating an example method of controlling a fleet of distributed energy resources.
[0012] FIG. **4** is a schematic block diagram illustrating an example of the distributed energy optimization and control system, shown in FIG. **1**.
[0013] FIG. **5** is a schematic block diagram illustrating an example the fleet of distributed energy resources, shown in FIG. **1**, and corresponding virtual model of the fleet.
[0014] FIG. **6** is a schematic block diagram illustrating an example of various target energy adjustments for the distributed energy resources shown in virtual representations of battery systems as shown in the virtual model of FIG. **5**.
[0015] FIG. **7** is a graphical representation of a group of distributed energy resources charging to an energy target by a scheduled time.
DETAILED DESCRIPTION
[0016] Various embodiments will be described in detail with reference to the drawings, wherein like reference numerals represent like parts and assemblies throughout the several views. Reference to various embodiments does not limit the scope of the claims attached hereto. Additionally, any examples set forth in this specification are not intended to be limiting and merely set forth some of the many possible embodiments for the appended claims.
[0017] The present disclosure describes an example power distribution system involving an electrical utility and at least one virtual power plant. The virtual power plant can be utilized and controlled in order to support the operations of the electrical utility. For example, upon determining an electrical need, the utility instructs the virtual power plant to make an energy adjustment by a scheduled time. The energy adjustment can include charging or discharging. The virtual power plant allocates the energy adjustment among the distributed energy resources of its fleet in order to achieve the energy adjustment by the scheduled time.
[0018] FIG. **1** is a schematic block diagram illustrating an example power distribution system **100**. In this example, the power distribution system **100** includes an electric utility **102** and a virtual power plant (“VPP”) **104**. The example electric utility **102** includes a power plant **110**, a distribution grid **112**, and a grid operations control center **114** having a utility computing device

116 operated by a platform operator O. The platform operator O is an operator associated with utility **102** in this example. However, the platform operator O may be associated with different entities including energy service providers, generator retailers, and/or another entity that wishes to execute an energy control request. While a utility will be discussed herein, the discussion applies to other entities that may execute an energy control request. The example virtual power plant **104** includes a distributed energy optimization and control system **120**, and a fleet **122** of distributed energy resources ("DERs") across a plurality of sites. In the illustrated example, site 1 includes DER 1, site 2 includes DER 2, and site 3 includes DER 3. The example distributed energy optimization and control system **120** includes a computing device **130**, a VPP status monitor **132**, and an energy control objective engine **134**. Portions of the power distribution system **100** can communicate across a data communication network **140**.

[0019] A reliable power distribution system **100** is critical for modern societies, which rely on the power distribution system **100** to supply a consistent source of electricity for an endless variety of electrical needs. Several examples of systems that utilize electrical power include refrigeration systems, lighting, heating and air conditioning systems, computers and portable electronics, and electric motors.

[0020] An electric utility **102** is one possible source of electrical power, and traditionally has been the primary source of power through the grid. A power plant **110** generates electricity and distributes the energy across the distribution grid **112**. Although a single power plant is illustrated and described in the example, the electric utility **102** can have multiple power plants, and each power plant can generate power from various sources of energy. The distribution grid **112** can include many different components, but at its core, the distribution grid **112** includes transmission lines that conduct electricity from the power plant **110** to the consumer sites.

[0021] In the illustrated example, the utility **102** also includes a grid operations control center **114**, including a platform operator O, that is tasked with monitoring and controlling the grid operations in an effort to maintain a stable and reliable supply of electricity on the distribution grid **112**.

[0022] The grid operations control center **114** can utilize a variety of tools to not only monitor the real-time status of the distribution grid **112**, but also to forecast both supply and demand in the future. For example, the grid operations control center **114** may have one or more computerized models that take as inputs current operating conditions as well as various other data, such as weather forecasts, in order to make predictions about consumer demand in the future. By comparing the power plant **110** production capabilities and the predicted demand, the grid operations control center **114** can try to identify possible problems before they occur, in an effort to avoid power outages, voltage drops, or frequency variations.

[0023] As one example, one of the biggest consumers of electrical energy is air conditioning systems. On a particularly hot day, an entity such as a utility can see a significant increase in peak demand due to the simultaneous operation of numerous home and commercial air conditioning systems. Therefore, if the utility is not prepared or is not able to supply sufficient electrical energy at a time of peak demand, the utility may need to shut down portions of the grid in order to maintain adequate quality on the rest of the grid.

[0024] But it is not only meeting peak demand that the grid operations control center **114** must worry about. The growth of renewable energy sources (solar, wind, and the like) also presents challenges to the utility. Solar and wind generators provide variable amounts of energy depending on the conditions. During a clear bright day, a solar generator can supply maximum energy to the grid, but cloud cover or dark of night reduce or eliminate solar production. Similarly, wind speeds can vary the amount of production from wind generators. Therefore, utilities connected to substantial renewable energy sources may also have the opposite problem of having too much energy at times of peak production.

[0025] One of the advantages of the power distribution system **100** including the virtual power plant **104** is that the virtual power plant **104** can help to support the operations of the utility **102**. It can do this by supplying additional power to the grid during times of peak consumption and can also do this by drawing excess power from the grid during times of peak production.

[0026] The example virtual power plant **104** shown in FIG. **1** includes an example distributed energy optimization and control system **120**, and a fleet **122** of distributed energy resources.

[0027] The distributed energy resources can include a variety of resources including electrical generators (e.g., distributed generation systems) and storage systems (e.g., distributed energy storage systems). Examples of electrical generators include renewable energy sources, such as solar power (e.g., photovoltaics), wind power, geothermal power, small hydro, biomass, biogas, and the like. Examples of storage systems include battery, pumped hydro, compressed air, and thermal energy storage systems.

[0028] In the illustrated example, the virtual power plant **104** includes DERs that are distributed across a plurality of sites. Each site can have one or more DERs. For example, site 1 includes DER 1, site 2 includes DER 2, and site 3 includes DER 3. An example of the DER 1 is a solar generator **150** and battery storage system **152**. An example of the DER 2 is a wind power generator **154** and battery storage system **156**. An example of the DER 3 is a gas generator **158** and battery storage system **160**. DERs do not have to include a battery storage system, but each of the examples shown in FIG. **1** includes a similar battery storage system for ease of explanation.

[0029] The distributed energy optimization and control system **120** provides centralized control of the fleet of distributed energy resources of the virtual power plant **104**. In this example, the distributed energy optimization and control system **120** includes the computing device **130**, which operates the VPP status monitor **132**, and the energy control objective engine **134**. The VPP status monitor **132** monitors the status and operation of the fleet of DERs **122**. In some embodiments, the VPP status monitor **132** maintains a virtual model of the fleet of DERs **122**, as illustrated and described in more detail herein with reference to FIG. **5**.

[0030] Portions of the power distribution system **100**, such as the computing devices described herein, and the distributed energy resources, can communicate with one another across a data communication network **140**. The data communication network **140** can include one or more data communication networks, such as the Internet, cellular data communication networks, local area networks, and the like.

[0031] FIG. **2** is a flow chart illustrating an example method **220** of controlling a fleet of distributed energy resources. In this example, the method **220** includes operations **222**, **224**, **226**, and **228**.

[0032] The operation **222** is performed to predict, by an entity such as an electrical utility, an electrical need. For example, the prediction may be made by the grid operations control center **114** shown in FIG. **1**. This prediction may be made in response to a variety of factors, including a forecasted increase in energy consumption at a certain time, notice of a reliability event such as a feeder needing to shut down, and current pricing of electricity allowing distributed energy resources to charge inexpensively compared to times of peak demand. By predicting an electrical need, the electrical utility can identify and avoid possible problems such as power outages, voltage drops, or frequency variations.

[0033] The operation **224** is performed to determine an energy adjustment to be made by a virtual power plant to respond to the need. For example, the grid operations control center **114** of FIG. **1** may determine an energy adjustment to respond to the predicted need. In another example, the computing device **130** of FIG. **1** may determine an energy adjustment to respond to the predicted need. The energy adjustment can be a target energy level for the entire fleet of distributed energy resources need to meet. Distributed energy resources selected to be charged or discharged to achieve the energy adjustment.

[0034] The operation **226** is performed to determine a scheduled time to achieve the energy adjustment. For example, the grid operations control center **114** of FIG. **1** may determine a scheduled time to achieve the energy adjustment. In another example, the computing device **130** of

FIG. **1** may determine a scheduled time to achieve the energy adjustment. This scheduled time is the time that the energy adjustment must be made to avoid possible problems such as power outages, voltage drops, overloading the distribution grid **112** of FIG. **1**, or frequency variations. Distributed energy resources in the fleet of distributed energy resources, such as the fleet of distributed energy resources **122** shown in FIG. **1**, that are selected to achieve the energy adjustment by the scheduled time may have the same scheduled starting time or different starting times. Determining the starting times will be explained in more detail herein with reference to FIG. **4**.

[0035] The operation **228** is performed to instruct the virtual power plant to make the energy adjustment by the scheduled time. As shown in FIG. **1** for example, the electric utility **102** may instruct the virtual power plant **104** to make the energy adjustment by the scheduled time. The virtual power plant **104** can allocate the energy adjustment among the distributed energy resources of its fleet, such as the fleet of distributed energy resources **122** of FIG. **1**, in order to achieve the energy adjustment by the scheduled time.

[0036] FIG. **3** is a flow chart illustrating an example method **280** of controlling a fleet of distributed energy resources. In this example, the method **280** includes operations **282**, **284**, **286**, and **288**.

[0037] The operation **282** is performed to receive an energy control request including an energy target and a scheduled time to achieve the energy target. In FIG. **1**., for example, the utility **102** sends an energy control request to the distributed energy optimization and control system **120**. The energy target may be received in order to avoid potential problems that the distribution grid **112** could experience at or after the scheduled time.

[0038] The operation **284** is performed to determine an energy adjustment needed across the fleet to achieve the energy target. For example, the energy control objective engine **134** of FIG. **1** can determine the necessary adjustment needed to reach the energy target by calculating the difference between the current energy storage level of the fleet of distributed energy resources **122** and the energy target.

[0039] The operation **286** is performed to determine an allocation of the energy adjustment among the distributed energy resources of the fleet. For example, in FIG. **1** the distributed energy optimization and control system **120** can determine any number of distributed energy resources in the fleet of distributed energy resources **122**. In embodiments, each distributed energy resource in the fleet of distributed energy resources **122** has its own specific energy adjustment percentage to meet. As illustrated in FIG. **1**, DER 1, DER 2, and DER 3 have different target adjustments. Alternatively, it can be determined that each distributed energy resource should charge or discharge to the same storage percentage.

[0040] In certain embodiments, the allocation is determined by selecting the distributed energy resources that will reach the energy allocation with the lowest cost. For example, the allocation may include a distributed energy resource that produces energy with solar power and the energy allocation is occurring in the early afternoon when the sun is bright. The solar energy produced effectively costs nothing, so that included distributed energy resource keeps the cost of the energy allocation as low as possible. Therefore, the allocation may determine a first set of distributed energy resources with the lowest cost available to allocate to. If the first set of distributed energy resources is insufficient to fulfill the energy adjustment, a second set of distributed energy resources with the next lowest costs of allocating the energy adjustment will be selected and so on.

[0041] The operation **286** may also consider the effect the energy allocation has on the cost of energy in the power distribution system. For example, if the allocation included the distributed energy resource that produces energy with solar, it prevents the solar energy from being used on the rest of the distribution grid during the energy adjustment. Certain resources may need to stay connected to the grid to keep the cost of energy low. For example, if enough energy producing resources are not supporting the distribution grid, a utility may need to power up additional power plants to account for the lower energy production. Powering up additional power plants costs the utility money and makes energy more expensive in the distribution grid as a result.

[0042] The operation **288** is performed to instruct the distributed energy resources of the fleet to make energy adjustments according to allocations to cause the fleet of distributed energy resources to achieve the energy target by the scheduled time. In some embodiments, this scheduled time is determined to ensure that the distribution grid, such as the distribution grid **112** of FIG. **1**, can supply sufficient power during peak times of energy usage and can handle the energy generated during peak times of energy generation. The distributed energy optimization and control system **120** of FIG. **1** can monitor the energy adjustments made in real-time with the VPP status monitor **132** to ensure that the instructed adjustments will be sufficient to meet the energy target by the scheduled time, indicated by the energy control objective engine **134**. The VPP status monitor **132** may continuously monitor the VPP status in real-time or perform monitoring updates in predetermined intervals, such as every five minutes. If the distributed energy optimization and control system **120** determines that the current instructions are insufficient, it can update the instructions and establish different target adjustments for the fleet to make by the scheduled time. The objective monitor **428** will typically determine whether the current instructions are insufficient and will be explained in more detail herein with reference to FIG. **4**.

[0043] FIG. **4** is a schematic block diagram illustrating an example of the distributed energy optimization and control system **120**, shown in FIG. **1**. In this example, the VPP status monitor **132** includes a distributed energy resource communication engine **410** and a distributed energy resource modelling engine. The energy control objective engine **134** of FIG. **1** includes a utility communication engine **420**, allocation engine **422**, scheduling engine **424**, distributed energy resource communication engine **426**, and an objective monitor **428**.

[0044] As explained above with reference to FIG. **1**, the VPP status monitor **132** monitors the status and operation of the fleet of DERs **122** in FIG. **1**. The VPP status monitor **132** utilizes the distributed energy resource communication engine **410** to receive and monitor the status and operation of the fleet of DERs **122**. The distributed energy resource communication engine **410** can receive information about each distributed energy resource in the fleet of DERs **122** such as the current state of charge, storage capacity, rate of charge, rate of discharge, the assigned energy target, and the adjustment cost.

[0045] The distributed energy resource modelling engine **412** creates and maintains a virtual model of the fleet. For example, it can create a virtual model of the distributed energy resources in the fleet of DERs **122** in FIG. **1**, as illustrated and described in more detail herein with reference to FIG. **5**. The model can contain any desired information about the distributed energy resources in the fleet, including the current state of charge, storage capacity, rate of charge, rate of discharge, the assigned energy target, and the adjustment cost. The distributed energy resource modelling engine **412** can communicate with the energy control objective engine to receive information about the distributed energy resources, including the energy target for each distributed energy resource.

[0046] As explained above with reference to FIG. **1**, the energy control objective engine **134** can determine the necessary adjustment needed to reach the energy target. The utility communication engine **420** enables the energy control objective engine **134** to communicate with a utility, such as utility **102** in FIG. **1**. The utility communication engine **420** can receive instructions from the utility which includes an energy adjustment to reach an energy target by a scheduled time.

[0047] The allocation engine **422** enables the energy control objective engine **134** to determine how to allocate the energy adjustment among the distributed energy resources of its fleet in order to achieve the energy adjustment by the scheduled time. For example, the allocation engine **422** can allocate an energy adjustment between the distributed energy resources in the fleet of DERs **122** in FIG. **1**. The allocation engine **422**, for instance, may determine that DER 1 in the fleet should charge to ninety percent of its capacity, DER 2 should charge to sixty percent of its capacity, and DER 3 should charge to twenty-five percent of its capacity to meet the energy adjustment target.

The allocation engine **420** can utilize every distributed energy resource in the fleet or select a subgroup of the distributed energy resources. Additionally, the allocation engine can determine a specific energy level for each distributed energy resource or select a uniform energy level each distributed resource should meet.

[0048] The allocation engine **422** can communicate with the VPP status monitor **132** to obtain any information needed to allocate the energy adjustment. For example, the allocation engine **422** may receive the current state of charge, storage capacity, rate of charge, the rate of discharge, and the adjustment cost for each distributed energy resource in the fleet. In some embodiments, the allocation engine **422** receives this information from the virtual model created by the distributed energy resource modelling engine **412**. In other embodiments, the allocation engine **422** communicates with distributed energy resource communication engine **426** to receive the same information. This allows the energy control objective engine **134** to allocate the energy adjustment without communicating with the VPP status monitor **132**.

[0049] The allocation engine **422** may determine how to allocate the energy adjustment based on any of the characteristics of the distributed energy resources or based on a strategy defined by a utility, such as utility **102** as shown in FIG. **1**. In embodiments, the allocation engine **422** determines the allocation based on the adjustment costs associated with the distributed energy resources in the fleet. The desired strategy may be to accomplish the energy adjustment as inexpensively as possible. In embodiments, to accomplish the low-cost strategy, allocation engine **422** may identify a first group of distributed energy resources in the fleet with the lowest adjustment cost value. If the first group of distributed energy resources is insufficient to accomplish the energy adjustment, allocation engine **422** may identify additional groups of distributed energy resources with the next lowest adjustment costs until the energy adjustment can be met. In further embodiments, allocation engine **422** will determine which distributed energy resources to used based on the adjustment cost and other values. For example, if scheduled time is soon, the allocation engine **422** may determine a group of distributed energy resources with adequate rates of charge or rates of discharge that also keep the cost of meeting the energy adjustment low. The allocation engine **422** may also utilize distributed energy resources that already have a current state of charge near the target state of charge for the energy adjustment.

[0050] In other embodiments, allocation engine **422** will determine which distributed energy resources to use based on other qualities of the distributed energy resources. For example, allocation engine **422** may select distributed energy resources with a large capacity to limit the number of distributed energy resources used to meet the energy adjustment. In further embodiments, allocation engine may select distributed energy resources with a fast rate of charge or rate of discharge to meet the energy adjustment as quickly as possible. Any combination of the qualities of the distributed energy resources may be used.

[0051] In further embodiments, allocation engine **422** may select the distributed energy resources based on a predetermined strategy. In some embodiments, a utility, such as utility **102** shown in FIG. **1**, will establish the elements of the strategy. For example, a utility may wish for a predetermined group of distributed energy resources to be used to meet the energy adjustment. Allocation engine **422** will include these distributed energy resources in the allocation and select additional distributed energy resources if the energy adjustment cannot be met with predetermined group. If the energy adjustment does not require every distributed energy resource in the predetermined group, allocation engine **422** can select a subgroup from the predetermined group of distributed energy resources. In another example, the strategy may be to select distributed energy resources that are associated with a type of energy production, such as solar energy. Allocation engine **422** can exclusively select distributed energy resources that utilize solar energy production to meet the energy adjustment.

[0052] The scheduling engine **424** allows the energy control objective engine **134** to schedule the energy adjustment by the time specified by the utility. The scheduling engine **424** can communicate with the allocation engine **422** to determine which distributed energy resources require energy allocation scheduling and the energy target for each distributed energy resource. The scheduling engine **424** can also communicate with the VPP status monitor **132** to obtain any information needed to determine the schedule for each distributed energy resource in the fleet. For example, the scheduling engine may obtain the current state of charge, storage capacity, rate of charge, the rate of discharge, the energy target, and the adjustment cost for each distributed energy resource in the fleet. The scheduling engine **424** can receive this information from the virtual model created by the distributed energy resource modelling engine **412**. Alternatively, the scheduling engine **424** can communicate with distributed energy resource communication engine **426** to receive the same information. This allows the energy control objective engine **134** to schedule the energy adjustment without communicating with the VPP status monitor **132**.

[0053] For each distributed energy resource that has an assigned energy target, the scheduling engine **424** calculates the time each distributed energy resource needs to begin adjusting its energy level to meet its energy target by the scheduled time. In some embodiments, the scheduling engine **424** may schedule different start times for each distributed energy resource to adjust its energy level depending on factors such as the storage capacity, current energy level, rate of charge, and rate of discharge of each distributed energy resource. In examples, the factors used to schedule different start times for each distributed energy resource to adjust its energy level are referred to as adjustment rates. Thus, the storage capacity, current energy level, rate of charge, and rate of discharge of each distributed energy resource, or a combination thereof may be an adjustment rate that is used to determine the start time for each distributed energy resource. For example, for the fleet of DERs **122** in FIG. **1**, the scheduling engine may schedule the energy adjustment for DER 1 to being at 1 PM, the energy adjustment for DER 2 to begin at 1:45 PM, and the energy adjustment for DER 3 to begin at 12:10 PM.

[0054] Scheduling each distributed energy resource's start time based on the distributed energy resources properties can be advantageous to guarantee that the distributed energy resource meets its energy target right at the scheduled time. It can be advantageous to delay the energy level adjustment until the time the distributed energy resource will meet the target right at the scheduled time because it allows the distributed energy resource to continue passively functioning as long as possible. For example, by allowing a solar panel to passively function, energy usage will come from the energy produced by a solar panel rather than from energy produced by the utility. Waiting for the ideal energy adjustment start time for a distributed energy resource may allow the distributed energy resource to approach or even reach the energy adjustment before the scheduled start time without any intervention from the distributed energy optimization and control system **120**. The scheduling engine **424** may alternatively establish a uniform start time for the fleet of distributed energy resources.

[0055] The distributed energy resource communication engine **426** operates like the distributed energy resource communication engine **410** described above. The distributed energy resource communication engine **426** allows the energy control objective engine **134** to communicate with the fleet of distributed energy resources without communicating with the VPP status monitor **132**.

[0056] The objective monitor **428** tracks the status of the energy adjustment and can monitor the fleet of distributed energy resources in real-time to ensure that the energy target will be met by the scheduled time. The objective monitor can communicate with the distributed energy resource communication engine **426** or the VPP status monitor **132** to communicate with the fleet of distributed energy resources and receive information on the current energy level adjustments made by the distributed energy resources. In some embodiments, the objective monitor **428** receives this information from the virtual model created by the distributed energy resource modelling engine **412**. The objective monitor **428** may indicate that the current allocation and scheduling is insufficient to reach the energy target by the scheduled time. The allocation engine **422** can then reallocate the energy adjustment if necessary and scheduling engine **424** can reschedule the energy adjustment for each selected distributed energy resource if necessary. The distributed energy resource communication engine **426** can then instruct the distributed energy resources of the fleet to make energy adjustments according to the revised allocations and schedule. This will cause the fleet of distributed energy resource to achieve the energy target by the scheduled time.

[0057] The distributed energy optimization and control system **120** can additionally include other optimization and control functions **400**. In examples, the energy control objective engine **134** uses the other optimization and control functions **400** to control the virtual power plant **104**. The other optimization and control functions **400** may be implemented to accomplish a goal, such as increasing storage in the virtual power plant **104**, controlling demand response, power, reactive power, and so on. Examples of other optimization and control functions **400** include demand response, power, reactive power, power factor, primary reserve, and secondary reserve optimization and control functions. In an example, the demand response optimization and control function may be used to shift and/or reduce energy consumption from typical peak periods of consumption.

[0058] In an example, the power optimization and control function may be used to control the power available to the distribution grid, such as distribution grid **112** shown in FIG. **1**. In an example, the reactive power optimization and control function may be used to control the reactive power available to the distribution grid, such as distribution grid **112** shown in FIG. **1**.

[0059] In an example, the power factor optimization and control function may be used to control the ratio of real power to apparent power on the distribution grid, such as distribution grid **112** shown in FIG. **1**.

[0060] In an example, the primary reserve optimization and control function may be used to control the power stored on a primary reserve of a power distribution system, such as power distribution system **100** shown in FIG. **1**. In an example, the secondary reserve optimization and control function may be used to control the power stored on a secondary reserve of a power distribution system, such as power distribution system **100** shown in FIG. **1**.

[0061] FIG. **5** is a schematic block diagram illustrating an example of the fleet of distributed energy resources **122**, shown in FIG. **1**, and corresponding virtual model **500** of the fleet. In some embodiments the virtual model **500** is part of the VPP status monitor **132**, shown in FIG. **4**. As explained above, the distributed energy resource modelling engine **412** of FIG. **4** can create the virtual model **500**. The fleet of distributed energy resources **122** includes DER 1, DER 2, and DER 3 of FIG. **1**. Battery storage system model **552** is the virtual representation of battery storage system **152**. Battery storage system **556** is the virtual representation of battery storage system **156**. Battery storage system **560** is the virtual representation of battery storage system **160**.

[0062] The virtual model **500** stores any information related to the fleet of distributed energy resources **122**. This information can include capacity, current storage level, rate of charge, rate of discharge, the assigned energy target, the adjustment cost, and other operating points of each distributed energy resource. For example, the DER 1 model includes virtual battery storage system model **552**, a capacity of 13.5 kWh, a rate of charge of 3.3 kW, a rate of discharge of 5 kW, and an energy target of 55%. In some embodiments, the information in the virtual model can be updated by communicating with the distributed energy resource communication engine **410**, allocation engine **422**, scheduling engine **424**, and objective monitor **428** as shown in FIG. **4**.

[0063] The virtual model **500** can update in real-time to effectively model the current state of the fleet of distributed energy resources **122**. The virtual model **500** can be used to determine an energy adjustment needed across the fleet to achieve an energy target, determine an allocation of the energy adjustment among the distributed energy resources of the fleet, and provide real-time updates if monitoring of the energy control request occurs. For example, the allocation engine **422**, scheduling engine **424**, and objective monitor **428** as shown in FIG. **4** all may communicate with the distributed energy resource modelling engine **412** as shown in FIG. **4** to access the virtual model **500**.

[0064] The virtual model **500** can also be provided to a utility, such as utility **102** in FIG. **1**. The virtual model **500** can be leveraged to determine the cheapest and ideal method for the utility to achieve a goal. For example, a utility can use the virtual model **500** to determine that discharging DER 1 and DER 2 will be the cheapest way to provide energy to an energy consumer at a specific time. The virtual model **500** can also be used to forecast the state of the power distribution system, including energy levels of the distributed energy levels at future times.

[0065] FIG. **6** is a schematic block diagram illustrating an example of various target energy adjustments for the distributed energy resources shown in virtual representations of battery systems as shown in the virtual model **500** of FIG. **5**. FIG. **6** illustrates virtual representations of battery storage systems **602**, **604**, **606**, and **608**. In this example, the fleet of DERs includes DER 1, DER 2, DER 3, and DER 4. Only the virtual representations of battery systems for each DER are shown in this example. DER 1 includes virtual representation of battery storage system **602**. DER 2 includes virtual representation of battery storage system **604**. DER 3 includes virtual representation of battery storage system **606**. DER 4 includes virtual representation of battery storage system **608**. The target of the energy adjustments of the distributed energy resources can be strict or allow for certain levels of flexibility.

[0066] In certain embodiments, the distributed energy resource may be instructed to charge to a specific energy level and hold at that energy level when it is reached. For example, the distributed energy resource modeled by the virtual representation of battery storage system **602** may be instructed to reach the target energy level **610** and hold at that energy level until the scheduled time. In embodiments, once the distributed energy resource reaches the target energy level **610**, the distributed energy resource's power is set to zero to retain the energy level. The distributed energy resource can hold this energy level until the scheduled time. Alternatively, the distributed energy resource can hold this energy level for a period after the scheduled time.

[0067] In other embodiments, the distributed energy level may be instructed to reduce to a maximum energy level target and be allowed to continue discharging energy when meeting the maximum energy level target before the scheduled time is reached. For example, the distributed energy resource modeled by the virtual representation of battery storage system **604** may be instructed to reach the maximum target energy level **612** and be allowed to continue discharging past the maximum target energy level **612**.

[0068] In other embodiments, the distributed energy level may be instructed to reach a minimum energy level but be allowed to go over the target energy level and continue increasing the energy level before the scheduled time is reached. For example, the distributed energy resource modeled by the virtual representation of battery storage system **606** may be instructed to reach the minimum target energy level **614** and be allowed to continue charging past the minimum target energy level **614**.

[0069] The distributed energy resource can also be given a minimum target energy level and a maximum target energy level that it must meet but can fluctuate between the two levels before the scheduled time. For example, the distributed energy resource modeled by the virtual representation of battery storage system **608** may be instructed to reach the minimum target energy level **616** and not surpass the maximum target energy level **618**.

[0070] FIG. **7** is a graphical representation of a group of distributed energy resources charging to an energy target by a scheduled time. In this example, only batteries associated with the DER are included. Charging graph **700** illustrates the energy level over time of three DER batteries: B1, B2, and B3. Energy level **702** is the energy level of DER battery B1. Energy level **704** is the energy level of DER battery B2. Energy level **706** is the energy level of DER battery B3. In embodiments, the virtual model **500** as shown in FIG. **5** can provide graphical representations of a group of distributed energy resources such as the graphical representation of FIG. **7**. The graphical representations could be provided to a utility, such as utility **102** shown in FIG. **1**., for the utility to monitor the progress of reaching the energy adjustment.

[0071] Charging graph **700** illustrates the different start times that DER batteries may have when

meeting an energy adjustment **720**. Energy adjustment **720** is 40 kWh in this example. DER battery B1 begins charging at start time **710**, DER battery B2 begins charging at start time **712**, and DER battery B3 begins charging at start time **714**. The group of DERs meet the energy adjustment **720** at hold time **722**. In this example, the energy adjustment is strict and does not want the energy adjustment to go above or below the energy adjustment **720**. The DER batteries therefore hold their energy levels until end time **724**. The end time **724** is the scheduled time associated with the energy adjustment. In other embodiments, the energy adjustment **720** may be flexible and allow the group of DER batteries to go above a minimum target and below a maximum target.
[0072] As illustrated in FIG. **7**, the DER battery energy levels **702**, **704**, and **706** at end time **724** are unequal. In other embodiments, the energy levels **702**, **704**, and **706** may be instructed to reach the same state of charge. In further embodiments, the energy levels **702**, **704**, and **706** may be a level that corresponds to an equal percentage of the total storage capacity of each DER battery B1, B2, and B3. For example, DER battery B1 may have a storage capacity of 20 kWh, DER battery B2 may have a storage capacity of 10 kWh, and DER battery B3 may have a storage capacity of 50 kWh. The DER batteries B1, B2, and B3 may be instructed to charge or discharge, depending on the DER batteries' initial level of charge, to 50% of their storage capacity to reach the energy adjustment **720**. In this example, DER battery B1 could have an energy level of 10 kWh, DER battery B2 would have an energy level of 5 kWh, and DER battery B3 would have an energy level of 25 kWh. The group of DER batteries would therefore meet the illustrated energy adjustment **720** equal to 40 kWh.
[0073] In some embodiments, the start times for each DER battery could be the same. For example, DER batteries B1, B2, and B3 could all begin charging at start time **710**. Additionally, the DER batteries could reach the energy adjustment **720** exactly at end time **724**.
[0074] The various embodiments described above are provided by way of illustration only and should not be construed to limit the claims attached hereto. Those skilled in the art will readily recognize various modifications and changes that may be made without following the example embodiments and applications illustrated and described herein, and without departing from the full scope of the following claims.

Claims

1-20. (canceled)
21. A method of controlling a fleet of distributed energy resources, the method comprising: receiving an energy control request including an energy target and a scheduled time to achieve the energy target; determining an allocation of an energy adjustment across a group of distributed energy resources from a fleet of distributed energy resources to achieve the energy target by the scheduled time using a virtual model of the fleet of distributed energy resources, the virtual model comprising virtual representations of battery storage systems for each distributed energy resource of the fleet of distributed energy resources; and instructing the group of distributed energy resources of the fleet to make energy adjustments according to allocations to cause the fleet of distributed energy resources to achieve the energy target by the scheduled time.
22. The method of claim 21, wherein, for each distributed energy resource of the fleet, the virtual representations comprise any one of: (i) a capacity, (ii) a current storage level, (iii) a rate of charge, (iv) a rate of discharge, (v) an assigned energy adjustment, (vi) an adjustment cost, or (vii) any combination of (i)-(vi).
23. The method of claim 21, further comprising monitoring the group of distributed energy resources making the energy adjustments in real-time.
24. The method of claim 23, further comprising: determining the energy adjustments are insufficient to achieve the energy target by the scheduled time based on the monitoring; determining one or more additional energy adjustments for a second group of distributed energy

resources of the fleet; and instructing the second group of distributed energy resources of the fleet to make the one or more additional energy adjustments to cause the fleet of distributed energy resources to achieve the energy target by the scheduled time.

25. The method of claim 21, wherein determining the allocation of the energy adjustment across the group of distributed energy resources is based at least in part on selecting distributed energy resources that can achieve the energy target by the scheduled time for a lowest cost.

26. The method of claim 21, wherein determining the allocation of the energy adjustment across the group of distributed energy resources is based at least in part on adjustment costs associated with the distributed energy resources of the fleet.

27. The method of claim 21, wherein instructing the group of distributed energy resources comprises instructing the group of distributed energy resources to begin the energy adjustments at one or more starting times.

28. A system for controlling a fleet of distributed energy resources, the system comprising: at least one computing device; and at least one computer-readable storage device storing data instructions that, when executed by the at least one computing device, cause the at least one computing device to: receive an energy control request including an energy target and a scheduled time to achieve the energy target; determine an allocation of an energy adjustment across a group of distributed energy resources from a fleet of distributed energy resources to achieve the energy target by the scheduled time using a virtual model of the fleet of distributed energy resources, the virtual model comprising virtual representations of battery storage systems for each distributed energy resource of the fleet of distributed energy resources; and instruct the group of distributed energy resources of the fleet to make energy adjustments according to allocations to cause the fleet of distributed energy resources to achieve the energy target by the scheduled time.

29. The system of claim 28, wherein, for each distributed energy resource of the fleet, the virtual representations comprise any one of: (i) a capacity, (ii) a current storage level, (iii) a rate of charge, (iv) a rate of discharge, (v) an assigned energy adjustment, (vi) an adjustment cost, or (vii) any combination of (i)-(vi).

30. The system of claim 28, wherein the at least one computer-readable storage device stores additional data instructions that, when executed by the at least one computing device, cause the at least one computing device to monitor the group of distributed energy resources making the energy adjustments in real-time.

31. The system of claim 30, wherein the additional data, when executed by the at least one computing device, further cause the at least one computing device to: determine the energy adjustments are insufficient to achieve the energy target by the scheduled time based on the monitoring; determine one or more additional energy adjustments for a second group of distributed energy resources of the fleet; and instruct the second group of distributed energy resources of the fleet to make the one or more additional energy adjustments to cause the fleet of distributed energy resources to achieve the energy target by the scheduled time.

32. The system of claim 28, wherein to determine the allocation of the energy adjustment across the group of distributed energy resources is based at least in part on selecting distributed energy resources that can achieve the energy target by the scheduled time for a lowest cost.

33. The system of claim 28, wherein to determine the allocation of the energy adjustment across the group of distributed energy resources is based at least in part on adjustment costs associated with the distributed energy resources of the fleet.

34. The system of claim 28, wherein to instruct the group of distributed energy resources comprises instructing the group of distributed energy resources to begin the energy adjustments at one or more starting times.

35. A method of controlling a virtual power plant, the method comprising: predicting an electrical need; determining an energy target to be met by a virtual power plant to respond to the need; determining a scheduled time to achieve the energy target; and instructing the virtual power plant to meet the energy target by the scheduled time, causing the virtual power plant to: receive an energy control request including the energy target and the scheduled time to achieve the energy target; determine an allocation of an energy adjustment across a group of distributed energy resources from a fleet of distributed energy resources to achieve the energy target by the scheduled time using a virtual model of the fleet of distributed energy resources, the virtual model comprising virtual representations of battery storage systems for each distributed energy resource of the fleet of distributed energy resources; and instruct the group of distributed energy resources of the fleet to make energy adjustments according to allocations to cause the fleet of distributed energy resources to achieve the energy target by the scheduled time.

36. The method of claim 35, wherein predicting the electrical need comprises: monitoring a distribution grid; predicting a future supply and a future demand of the distribution grid based at least in part on the monitoring; and predicting the electrical need based at least in part on the future supply and the future demand.

37. The method of claim 35, wherein predicting the electrical need is based at least in part on any one of: (i) a predicted future demand a distribution grid, (ii) a predicted future supply of the distribution grid, (iii) a reliability event, (iv) a price of electricity, or (v) any combination of (i)-(iv).

38. The method of claim 35, wherein the virtual power plant if further caused to: monitor the group of distributed energy resources making the energy adjustments; determine the energy adjustments are insufficient to achieve the energy target by the scheduled time based on the monitoring; determine one or more additional energy adjustments for a second group of distributed energy resources of the fleet; and instruct the second group of distributed energy resources of the fleet to make the one or more additional energy adjustments to cause the fleet of distributed energy resources to achieve the energy target by the scheduled time.

39. The method of claim 35, wherein to determine the allocation of the energy adjustment across the group of distributed energy resources is based at least in part on adjustment costs associated with the distributed energy resources of the fleet.

40. The method of claim 35, wherein to instruct the group of distributed energy resources comprises to instruct the group of distributed energy resources to begin the energy adjustments at one or more starting times.