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REAL-TIME VALIDATION OF DISTRIBUTED ENERGY RESOURCE DEVICE COMMITMENTS

Abstract

A computing device receives a commitment generated by a distributed resource device, the commitment indicating an operation performed by the distributed resource device and a time interval when the distributed resource device modified usage of a resource at a location; receives an event corresponding to a pattern of usage of the resource at the location during the time interval; identifies an event model that is associated with a pattern of usage of the resource that matches the pattern of usage of the resource at the location during the time interval, the event model being included in a library of event models that associate different patterns of usage of the resource with corresponding types of operations; and validates the commitment in response to determining that at least a type of operation associated with the event model corresponds to the operation performed by the distributed resource device indicated in the commitment.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation of United States patent application titled, "Real-Time Validation of Distributed Energy Resource Device Commitments", filed Dec. 9, 2022, and having Ser. No. 18/078,866, which is a continuation of United States patent application titled, "Real-Time Validation of Distributed Energy Resource Device Commitments," filed on Mar. 13, 2019, and having Ser. No. 16/352,761, issued as U.S. Pat. No. 11,532,055, and claims the priority benefit of United States provisional patent application titled, "Real-Time Validation of Distributed Energy Resource Device Commitments," filed on Jan. 31, 2019 and having Ser. No. 62/799,673. The subject matter of these related applications is hereby incorporated herein by reference.

BACKGROUND
Field of the Various Embodiments
[0002] Embodiments of the present invention relate generally to utility networks and utility distribution infrastructures and, more specifically, to real-time validation of distributed energy resource device commitments.
Description of the Related Art
[0003] In conventional utility networks and utility distribution infrastructures, one or more utility providers generate resources that are distributed to one or more downstream resource consumers. For example, a nuclear power plant could generate electricity that is then distributed to various electricity consumers within a city. A given downstream resource consumer usually has a utility meter that monitors various characteristics associated with the distribution and/or consumption of resources. For example, a residence could have an electricity meter that monitors the rate at which the residence consumes electricity, the total amount of electricity distributed to the residence over a particular period of time, and so forth.
[0004] In more modern utility networks and utility distribution infrastructures, the downstream resource consumers sometimes have distributed energy resource (DER) devices that are configured to help distribute, generate, and/or store resources. One example of a DER device is a smart thermostat that, under specific circumstances, limits the amount of electricity being consumed by a consumer. Another example of a DER device is a solar power system that generates solar-based electricity for consumption by one or more consumers and/or for distribution onto a utility distribution infrastructure. Yet another example of a DER device is a home battery system that stores electricity that can be subsequently consumed during periods of peak electricity demand. As a general matter, DER devices are deployed to reduce costs and to improve the efficiency with which resources can be distributed to consumers.
[0005] In certain situations, a consumer can configure a given DER device to participate in one or more energy markets in order to earn financial incentives. For example, a consumer could configure a smart thermostat to participate in a demand-response program offered by a utility

provider in exchange for a rebate or other form of compensation. As part of such a program, the consumer could configure the smart thermostat to turn off climate control at the residence of the consumer whenever the utility provider instructs the smart thermostat to do so, and the consumer would be compensated for participating in the program. Among other things, these types of arrangements enable utility providers to limit how much electricity is consumed during periods of peak electricity demand.

[0006] When a DER device participates in an energy market, the DER device is usually configured to operate in accordance with the terms of a contract. For example, a smart thermostat could be configured to operate in accordance with a contract that specifies the particular circumstances under which a utility provider can cause the smart thermostat to turn off or turn off climate control. The owners of such contracts can be utility providers, but, more typically, the contract owners are third-party vendors that manage the participation of DER devices in various energy markets on behalf of the utility providers.

[0007] Contracts that manage the participation of DER devices in energy markets can specify a wide variety of different operations that participating DER devices need to perform. One requirement found in some contracts is that a participating DER device should generate "commitments" that indicate the specific actions the DER device implemented to fulfill various terms of the relevant contract. For example, a smart thermostat could generate a commitment indicating that the smart thermostat turned off climate control at the residence of a given consumer when instructed to do so by the relevant utility provider. Upon receiving a commitment, the contract owner analyzes the commitment to confirm that the terms of the contract have been met and thereby validate the commitment. The contract owner then compensates the consumer for participation in the energy market. The process of validating commitments and compensating consumers is referred to as the "settlement" process.

[0008] One drawback of the above approach is that the settlement process can take three months or more to complete. Consequently, consumers have to wait for extended periods of time to receive compensation when participating in energy market programs. These lengthy wait times can dissuade consumers from participating in energy market programs. If fewer consumers participate in energy market programs, then utility providers may have greater difficulty providing resources to consumers efficiently and at reduced cost.

[0009] As the foregoing illustrates, what is needed in the art are more effective ways to validate DER device commitments.

SUMMARY

[0010] Some embodiments include a computer-implemented method for validating distributed resource device commitments, including determining that a first commitment received from a first distributed resource device indicates that the first distributed resource device modified how much of a resource was consumed at a first location during a first time interval, generating first metrology data that indicates how much of the resource was consumed at the first location during the first time interval, and validating the first commitment based on the first metrology data associated with the first location.

[0011] One technological advantage of the disclosed approach relative to the prior art is that commitments reported by distributed resource devices are validated automatically by the utility meter, which enables the settlement process to be performed much faster relative to conventional approaches.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] So that the manner in which the above recited features of the various embodiments can be

understood in detail, a more particular description of the inventive concepts, briefly summarized above, may be had by reference to various embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of the inventive concepts and are therefore not to be considered limiting of scope in any way, and that there are other equally effective embodiments.

[0013] FIG. **1** illustrates a network system configured to implement one or more aspects of the present embodiments;

[0014] FIG. **2** illustrates an exemplary behind-the-meter configuration, according to various embodiments;

[0015] FIG. **3** is a more detailed illustration of the node of FIG. **2**, according to various embodiments;

[0016] FIG. **4** is a more detailed illustration of the validation application of FIG. **3**, according to various embodiments;

[0017] FIG. **5** is a graph of metrology data that is processed by the node of FIG. **2** when validating a commitment, according to various embodiments; and

[0018] FIG. **6** is a flow diagram of method steps for validating DER device commitments, according to various embodiments.

DETAILED DESCRIPTION

[0019] In the following description, numerous specific details are set forth to provide a more thorough understanding of the various embodiments. However, it will be apparent to one of skilled in the art that the inventive concepts may be practiced without one or more of these specific details.

[0020] As noted above, DER devices can be configured to participate in energy markets in order to earn financial incentives for a consumer. To participate in a given energy market, the consumer or a third party configures the given DER device to operate in accordance with a contract that at least partially defines the operation of the DER device. When the DER device performs various operations in accordance with the contract, the DER device also generates a "commitment" indicating the specific actions the DER device performs to fulfil the terms of the contract. A contract holder, such as a utility provider or a third-party intermediary, then validates the commitment and compensates the consumer via a process that is referred to as "settlement."

[0021] One drawback associated with a conventional settlement process is that validating commitments generally takes a long time, sometimes in excess of three months. For example, suppose a given DER device participates in an energy market and reports commitments to a contract holder to initiate the settlement process. To validate a given commitment, an analyst associated with the contract holder would first have to analyze the commitment to identify the particular operations performed by the DER device. The analyst would then have to analyze a contract associated with the energy market to determine whether those operations meet the terms of the contract. The analyst would also have to access utility meter data associated with the location where the DER device resides in order to verify that the DER device did, indeed, perform the reported operations. Specifically, the analyst would have to analyze the meter data during a time interval where the reported operations are supposed to have occurred, and then determine whether the meter data supports the occurrence of these operations. Depending on the availability of data, these analyses are carried out at varying levels of aggregation and accuracy.

[0022] The steps described above are manually performed by the analyst and can therefore take a long time. Further, contract holders are oftentimes backlogged with commitments and therefore cannot begin the settlement process immediately. These various delays ultimately cause the consumer to have to wait to be compensated for participating in the energy market. Consumers usually do not appreciate having to wait for compensation. As such, when the settlement process takes a long time, consumers may find participating in energy markets less desirable. Energy markets help improve the efficiency with which resources can be distributed. When fewer consumers participate in energy markets, utility providers can have difficulty providing consumers

with resources efficiently and/or at low cost.

[0023] To address these issues, embodiments of the invention include a smart utility meter that validates commitments generated by DER devices coupled behind the smart utility meter. The DER devices reside in a location where the utility meter monitors the distribution of resources. The DER devices can modify the distribution, generation, and/or storage of resources at the location in accordance with, at least to some degree, a contract associated with an energy market. When a given DER device operates in accordance with a given contract, the DER device reports a commitment to the smart utility meter indicating the specific operations the DER device performs to fulfill the terms of the contract.

[0024] The utility meter analyzes the commitment to determine a time interval when the reported operations were to occur. The utility meter then analyzes meter data associated with the distribution of resources at the location to identify any events associated with the time interval. Upon identifying an event, the utility meter can map the event to the DER device based on a library of events corresponding to different DER devices. The utility meter can also map the event to the reported operation. If the utility meter successfully maps the event to both the DER device and the reported operations, then the occurrence of the operations is confirmed and the DER device generates a validated commitment. The validated commitment can be transmitted to relevant parties in order to expedite the settlement process.

[0025] One technological advantage of the disclosed approach relative to the prior art is that commitments reported by DER devices are validated automatically by the utility meter, which enables the settlement process to be performed much faster relative to conventional approaches. Accordingly, consumers can be compensated for participating in energy markets much faster than the three-month or longer periods typically associated with conventional settlement processes. This technological advantage represents at least one technological advancement relative to prior art approaches.

System Overview

[0026] FIG. **1** illustrates a network system configured to implement one or more aspects of the present embodiments. As shown, network system **100** includes a field area network (FAN) **110**, a wide area network (WAN) backhaul **120**, and a control center **130**. FAN **110** is coupled to control center **130** via WAN backhaul **120**. Control center **130** is configured to coordinate the operation of FAN **110**.

[0027] FAN **110** includes personal area network (PANs) A, B, and C. PANs A and B are organized according to a mesh network topology, while PAN C is organized according to a star network topology. Each of PANs A, B, and C includes at least one border router node **112** and one or more mains powered device (MPD) nodes **114**. PANs B and C further include one or more battery powered device (BPD) nodes **116**.

[0028] MPD nodes **114** draw power from an external power source, such as mains electricity or a power grid. MPD nodes **114** typically operate on a continuous basis without powering down for extended periods of time. BPD nodes **116** draw power from an internal power source, such as a battery. BPD nodes **116** typically operate intermittently and power down for extended periods of time in order to conserve battery power. MPD nodes **114** and BPD nodes **116** are configured to gather sensor data, process the sensor data, and communicate data processing results and other information to control center **130**. Border router nodes **112** operate as access points to provide MPD nodes **114** and BPD nodes **116** with access to control center **130**.

[0029] Any of border router nodes **112**, MPD nodes **114**, and BPD nodes **116** are configured to communicate directly with one or more adjacent nodes via bi-directional communication links. The communication links may be wired or wireless links, although in practice, adjacent nodes of a given PAN exchange data with one another by transmitting data packets via wireless radio frequency (RF) communications. The various node types are configured to perform a technique known in the art as "channel hopping" in order to periodically receive data packets on varying

channels. As known in the art, a "channel" may correspond to a particular range of frequencies. In one embodiment, a node may compute a current receive channel by evaluating a Jenkins hash function based on a total number of channels, the media access control (MAC) address of the node, and other information associated with the node.

[0030] Each node within a given PAN may implement a discovery protocol to identify one or more adjacent nodes or "neighbors." A node that has identified an adjacent, neighboring node may establish a bi-directional communication link with the neighboring node. Each neighboring node may update a respective neighbor table to include information concerning the other node, including the MAC address of the other node as well as a received signal strength indication (RSSI) of the communication link established with that node.

[0031] Nodes may compute the channel hopping sequences of adjacent nodes to facilitate the successful transmission of data packets to those nodes. In embodiments where nodes implement the Jenkins hash function, a node computes a current receive channel of an adjacent node using the total number of channels, the MAC address of the adjacent node, and a time slot number assigned to a current time slot of the adjacent node.

[0032] Any of the nodes discussed above may operate as a source node, an intermediate node, or a destination node for the transmission of data packets. A given source node may generate a data packet and then transmit the data packet to a destination node via any number of intermediate nodes (in mesh network topologies). The data packet may indicate a destination for the packet and/or a particular sequence of intermediate nodes to traverse in order to reach the destination node. In one embodiment, each intermediate node may include a forwarding database indicating various network routes and cost metrics associated with each route.

[0033] Nodes may transmit data packets across a given PAN and across WAN backhaul **120** to control center **130**. Similarly, control center **130** may transmit data packets across WAN backhaul **120** and across any given PAN to a particular node included therein. As a general matter, numerous routes may exist which traverse any of PANs A, B, and C and include any number of intermediate nodes, thereby allowing any given node or other component within network system **100** to communicate with any other node or component included therein.

[0034] Control center **120** includes one or more server machines (not shown) configured to operate as sources for, or destinations of, data packets that traverse within network system **100**. The server machines may query nodes within network system **100** to obtain various data, including raw or processed sensor data, power consumption data, node/network throughput data, status information, and so forth. The server machines may also transmit commands and/or program instructions to any node within network system **100** to cause those nodes to perform various operations. In one embodiment, each server machine is a computing device configured to execute, via a processor, a software application stored in a memory to perform various network management operations.

[0035] Nodes may likewise include computing device hardware configured to perform processing operations and execute program code. Each node may further include various analog-to-digital and digital-to-analog converters, digital signal processors (DSPs), harmonic oscillators, transceivers, and any other components generally associated with RF-based communication hardware.

[0036] Any of the nodes discussed above can be configured as a smart utility meter and be coupled to a utility line in order to monitor the distribution of resources at a particular location via the utility line. For example, an MPD node **114** could be configured as a smart electric meter and be coupled to a power line in order to monitor the distribution of electricity at a residence via the power line. A given node that is configured as a smart utility meter generates real-time metrology data quantifying the distribution of resources at the location where the given node resides. The given node then periodically reports this metrology data to control center **130** via FAN **110**.

[0037] A given node that is configured as a smart utility meter can be coupled to, and configured to interoperate with, one or more DER devices in a "behind-the-meter" configuration. As referred to herein, a behind-the-meter or BTM configuration generally includes a node that is coupled to a

utility line and one or more DER devices that are coupled to the utility line downstream of the node. The node monitors the distribution of resources via the utility line. The DER devices modify the distribution of resources via the utility line in a detectable manner. An exemplary behind-the-meter configuration is described in greater detail below in conjunction with FIG. **2**.

Exemplary Behind-the-Meter Configuration

[0038] FIG. **2** illustrates an exemplary behind-the-meter (BTM) configuration, according to various embodiments. As shown, BTM configuration **200** includes DER devices **210**(**0**) through **210**(N), a node **220**, and utility line **230**. DER devices **210** are coupled to node **220**. DER devices **210** and node **220** are coupled to a utility line **230**. In one embodiment, DER devices **210** may be coupled indirectly to utility line **230** via node **220**. In another embodiment, DER devices **210** may be connected directly to utility line **230**.

[0039] Utility line **230** is configured to distribute resources to a given location where BTM configuration **200** is deployed. For example, utility line **230** could be a power line that distributes electricity to a residence. Node **220** is configured as a smart utility meter that monitors the distribution of resources via utility line **230** to generate metrology data **222**. For example, node **220** could be a smart electric meter configured to generate metrology data that reflects the distribution of electricity via utility line **230**. Node **220** may be any of the node types discussed above in conjunction with FIG. **1**. Metrology data **222** quantifies the distribution and/or consumption of resources at the location where node **220** is deployed. Metrology data **222** may have any technically feasible resolution, although in practice metrology data **222** has sufficient resolution to identify relevant DER-oriented events (e.g., one-second resolution).

[0040] Each DER device **210** is configured to perform various operations to modify the distribution of resources via utility line **230**. For example, DER device **210**(**0**) could be a smart thermostat that limits the consumption of electricity via utility line **230** by modifying climate control settings. Alternatively, DER device **210**(**0**) could be a solar power system configured to generate electricity and distribute at least a portion of that electricity onto utility line **230**. DER device **210**(**0**) could also be a home battery system configured to draw electricity from utility line **230** for storage.

[0041] A given DER device **210** can modify the distribution of resources based on the terms of a contract associated with an energy market. In so doing, the given DER device **210** may generate one or more commitments **212** that indicate the specific operation(s) the DER device **210** performs over one or more time intervals to fulfill the terms of the corresponding contract. As is shown, DER devices **210**(**0**) through **210**(N) generate commitments **212**(**0**) through **212**(N) and then transmit these commitments to node **220**.

[0042] Node **220** is configured to perform a real-time validation of commitments **212** based on metrology data **222**. Node **220** validates commitments **212** to confirm that DER devices **210** operate in accordance with any associated energy market contracts. As is shown, node **220** generates validated commitments **224** based on commitments **212**(**0**) through **212**(N) and metrology data **222**. Node **220** performs various operations to validate a given commitment **224**, as described in greater detail below in conjunction with FIGS. **3-6**.

[0043] Node **220** transmits validated commitments **224** to control center **130** to facilitate various settlement processes associated with the energy market(s) in which DER devices **210** participate. Because node **220** has already confirmed that commitments **212** accurately reflect the various operations DER devices **210** perform to participate in the energy market(s), those settlement processes can be performed expeditiously and with minimal oversight. Accordingly, the real-time validation performed by node **220** can accelerate how quickly consumers are compensated for participation in energy markets. Node **220** is described in greater detail below in conjunction with FIG. **3**.

Node Hardware Components

[0044] FIG. **3** is a more detailed illustration of the node of FIG. **2**, according to various embodiments. As shown, node **220** includes a computing device **300** coupled to a transceiver **340**

and an oscillator **350**. Computing device **300** coordinates the operations of node **220**. Transceiver **340** is configured to transmit and receive data packets across network system **100** using a range of channels and power levels. Oscillator **350** provides one or more oscillation signals according to which the transmission and reception of data packets can be scheduled. Node **220** may be used to implement any of border router nodes **112**, MPD nodes **114**, and BPD nodes **116** of FIG. **1**.

[0045] Computing device **300** includes a processor **310**, input/output (I/O) **320**, and memory **330**, coupled together. Processor **310** may include any hardware configured to process data and execute software applications. Processor **310** may include a real-time clock (RTC) (not shown) according to which processor **310** maintains an estimate of the current time. I/O devices **320** include devices configured to receive input, devices configured to provide output, and devices configured to both receive input and provide output. Memory **330** may be implemented by any technically feasible storage medium.

[0046] Memory **330** includes a validation application **332**. Validation application **332** includes program code that, when executed by processor **310**, analyzes one or more commitments **212** based on metrology data **222** to generate validated commitments **224**. To validate a given commitment **212** associated with a given DER device **210**, node **220** analyzes the commitment **212** to determine a specific operation the DER device **210** performs during a particular time interval. Node **220** then analyzes metrology data **222** to identify an "event" associated with that particular time interval. The event could be, for example, a change in resource distribution that exceeds a threshold during the time interval, among other possible events. Node **220** attempts to map the identified event back to the DER device **210** based on a library of events associated with different DER devices. In one embodiment, the library of events may include various signature patterns of activity that can be uniquely associated with specific DER devices. Node **220** also attempts to map the identified event to the specific operation set forth in the commitment **212**. If node **220** successfully maps the identified event to the DER device **210** and to the specific operation set forth in commitment **212**, then node **220** generates a validated commitment **224** confirming that the DER device **210** is responsible for performing the specific operation. Validation application **332** transmits the validated commitment **224** to control center **230** to facilitate a settlement process associated with an energy market in which the DER device **210** participates. Validation application **332** is described in greater detail below in conjunction with FIG. **4**.

Node Software Modules

[0047] FIG. **4** is a more detailed illustration of the validation application of FIG. **3**, according to various embodiments. As shown, validation application **332** includes a distribution monitor **400**, an event analyzer **410**, and a commitment validator **420**. These various software modules interoperate to generate a validated commitment **224** based on metrology data **222** and a commitment **212**, as described in greater detail herein.

[0048] Distribution monitor **400** is coupled to utility line **230** and configured to measure the real-time distribution of resources via utility line **230** to generate metrology data **222**. Metrology data **222** includes one or more different channels of data collected over any technically feasible time period and with any resolution. As previously mentioned, in practice, metrology data **222** has one-second resolution.

[0049] Event analyzer **410** analyzes metrology data **222** to generate a distribution event **402**. Distribution event **402** indicates some type of fluctuation in the distribution of resources. For example, distribution event **402** could indicate that the distribution of resources fell beneath a threshold level during a particular time interval. Event analyzer **410** can be configured to detect any technically feasible type of distribution event based on metrology data **222**. Distribution events are discussed in greater detail below in conjunction with FIG. **5**.

[0050] Event analyzer **410** queries event models **412** based on distribution event **402** to identify a particular event model **412** that corresponds to distribution event **402**. A given event model **412** generally describes a time-varying pattern of resource distribution fluctuations that can be

attributed to the operation of a DER device **210**. In one embodiment, each event model **412** may indicate an electrical signature associated with a specific type of DER device **210** when performing a specific operation, such as powering on, powering off, or changing state. For example, one event model **412** could specify a decrease in electricity consumption that has specific characteristics indicative of a smart thermostat deactivating an air conditioning unit. Event models **412** can include Machine Learning models, parametric models, or any other technically feasible type of model that reflects time-varying behavior. Event models **412** are discussed in greater detail below in conjunction with FIG. **5**.

[0051] Once event analyzer **410** successfully maps distribution event **402** to an event model **412**, event analyzer **410** generates device identifier (ID) **414** to identify the particular type of DER device **210** responsible for causing distribution event **402**. Event analyzer **410** then transmits distribution event **410** and device ID **414** to commitment validator **420**. In one embodiment, once event analyzer **410** maps the distribution event **402** to the event model **412**, event analyzer **410** may then update the event model **412** to reflect one or more characteristics of distribution event **402**. In doing so, event analyzer **410** may implement Machine Learning to modify one or more parameters associated with the event model **402**. This approach allows event models **412** to remain up-to-date with changing operational characteristics of DER devices **210**.

[0052] Commitment validator **420** analyzes commitment **212** to determine the particular DER device **210** responsible for generating commitment **212**. Commitment validator **420** also determines the specific operations the DER device **210** performs to satisfy the terms of an energy market contract during the time interval when those specific operations are to have occurred. Commitment validator **420** then processes distribution event **402** to confirm that those specific operations did, indeed, occur during the specified time interval.

[0053] For example, suppose commitment **212** indicates that DER device **210(0)** begins storing power in a home battery system at a first point in time. Commitment validator **420** could confirm the occurrence of this particular operation upon determining that event **402** indicates a characteristic increase in electrical loading at the first point in time. Commitment validator **420** also processes device ID **414** to verify the identity of the DER device **210** responsible for generating commitment **212**. In particular, commitment validator **420** determines that commitment **212** and device ID **414** are both associated with the same type of DER device **210** or the same instance of a DER device **210**.

[0054] When commitment validator **420** successfully confirms that distribution event **402** and device ID **414** collectively indicate that the DER device **210** performs the operations set forth in commitment **212** during the specified time interval, commitment validator **420** then generates validated commitment **224**. Via the above techniques, validated commitments **224** can be generated automatically and in real time. Validated commitments **224** can then be used to expedite a settlement process associated with an energy market.

[0055] FIG. **5** is a graph of exemplary metrology data that is processed by the node of FIG. **2** when validating a commitment, according to various embodiments. As shown, a graph **500** includes metrology data **502** plotted against a time axis **510** and a wattage axis **520**. Metrology data **502** indicates a time-varying wattage associated with a location where node **220** is deployed. That wattage decreases at time T.sub.0, increases at T.sub.1, and then decreases again at time T.sub.2.

[0056] In the example described herein, validation application **332** within node **220** could analyze metrology data **502** and parameterize the various fluctuations shown in order to identify these fluctuations with specific DER devices **210**. For example, validation application **332** could identify the slight decrease in wattage at time T.sub.0 with DER device **210(0)** powering off based on an event model **412** that characterizes the operation of DER device **210(0)**. In this manner, validation application **332** can determine signature patterns within metrology data **502** that uniquely identify specific DER devices **210** and/or specific operations performed by DER devices **210**. The techniques described herein can also be implemented relative to any technically feasible metric

other than wattage, including other electrical parameters and other parameters associated with resource distribution.

[0057] Referring generally to FIGS. **1**-**5**, any of the techniques discussed herein can be performed by one or more separate elements of network system **1**. In one embodiment, validation application **332** may be a distributed software application that executes partially on node **220** and partially in one or more other computing environments. For example, a first portion of validation application **332** could execute on node **220** to generate metrology data **222** and distribution events **402**. A second portion of validation application **332** could execute remotely in a cloud-based environment to generate validated commitments **224** based on distribution events **402** and commitments **212**. The second portion of validation application **332** could also execute locally on a device that resides proximate to node **220**, such as a local server or a home smart device. In either case, when the first portion of validation application **332** detects an event, the second portion of validation application **332** may retroactively analyze metrology data **222** in greater detail to validate one or more commitments **212**.

[0058] In another embodiment, node **220** may execute a distributed ledger client in order to share validated commitments **224** with other nodes that also execute the distributed ledger client. For example, node **220** could execute a blockchain client to participate in a blockchain network. In so doing, node **220** could transmit validated commitments **224** to other nodes in a hierarchy of nodes that participate in the blockchain network.

[0059] Persons skilled in the art will recognize that the techniques described herein can be implemented to validate any technically feasible type of operation that is performed by any technically feasible type of device coupled to any technically feasible type of resource distribution infrastructure. For example, the disclosed techniques could be implemented to validate modifications made to the distribution of water by a device that is coupled (directly or indirectly) to a water main.

Automatically Validating DER Device Commitments

[0060] FIG. **6** is a flow diagram of method steps for validating a DER device commitment in real time, according to various embodiments. Although the method steps are described in conjunction with the systems of FIGS. **1**-**5**, persons skilled in the art will understand that any system configured to perform the method steps in any order falls within the scope of the present invention.

[0061] As shown, a method **600** begins at step **602**, where node **220** of FIG. **1** obtains a commitment from a DER device. Node **220** is coupled to a utility line at a given location and configured to monitor the distribution of resources to the location via the utility line, in like fashion as shown in FIG. **2**. The DER device is coupled to node **220** in a BTM configuration and can modify the distribution of resources at the location. For example, the DER device could be configured to draw resources from the utility line or distribute resources onto the utility line. The resources could be, for example, electricity, gas, water, or any other technically feasible type of resource.

[0062] At step **604**, node **220** generates metrology data that reflects the distribution of resources via utility line **230**. For example, the metrology data could indicate a kilowatt-hour measurement of electricity distributed to a residence. The metrology data may include one or more channels of real-time data having any technically feasible resolution, including one-second resolution (or less).

[0063] At step **606**, node **220** determines a modification to the distribution of resources that occurs during a first time interval based on the commitment. The DER device generates the commitment upon performing various operations that modify the distribution of resources at the location. The DER device generally performs these operations in accordance with a contract associated with an energy market. For example, the DER device could be a solar power system that distributes at least a minimum amount of power onto the power grid.

[0064] At step **608**, node **220** identifies a distribution event that occurs during the time interval based on the metrology data. As referred to herein, a distribution event refers to a measurable

fluctuation in the distribution of resources at the location, such as, for example, a spike in resource consumption or production, among others. Node **220** can be configured to detect any technically feasible type of distribution event associated with any type of utility.

[0065] At step **610**, node **220** confirms that the DER device modifies the distribution of resources during the time interval based on the event. In particular, node **220** maps the event to the DER device based on a library of event models that characterize different DER devices. In so doing, node **220** validates the authenticity of the DER device and can generate a device ID, such as device ID **414** of FIG. **4**. Node **220** also maps the event to the modification of resource distribution indicated in the commitment, thereby confirming that the DER device did, in fact, modify the distribution of resources as reported in the commitment.

[0066] At step **612**, node **220** generates a validated commitment confirming that the DER device modifies the distribution of resources during the time interval. Node **220** may then transmit the validated commitment to control center **130** in order expedite a settlement process associated with the energy market contract. The disclosed approach advantageously generates validated commitments automatically and with minimal oversight.

[0067] In sum, a distributed energy resource (DER) device is coupled to a utility meter in a "behind-the-meter" configuration. The utility meter analyzes a commitment generated by the DER device to determine a specific operation performed by the DER device at a particular time. The utility meter analyzes metrology data to identify an "event" associated with the particular time and then attempts to map the identified event back to the DER device based on a library of events associated with different DER devices. The utility meter also attempts to map the identified event to the specific operation set forth in the commitment. If the utility meter can successfully map the identified event to both the DER device and to the specific operation set forth in the commitment, then the utility meter generates a validated commitment. The validated commitment can be used to facilitate an energy market settlement process.

[0068] One technological advantage of the disclosed approach relative to the prior art is that commitments reported by DER devices are validated automatically by the utility meter, which enables the settlement process to be performed much faster relative to conventional approaches. Accordingly, consumers can be compensated for participating in energy markets much faster than the three-month or longer periods typically associated with conventional settlement processes. This technological advantage represents at least one technological advancement relative to prior art approaches.

[0069] 1. Some embodiments include a computer-implemented method for validating distributed resource device commitments, the method comprising determining that a first commitment received from a first distributed resource device indicates that the first distributed resource device modified how much of a resource was consumed at a first location during a first time interval, generating first metrology data that indicates how much of the resource was consumed at the first location during the first time interval, and validating the first commitment based on the first metrology data.

[0070] 2. The computer-implemented method of clause 1, wherein validating the first commitment comprises generating a first validated commitment confirming that the first commitment indicates that the first distributed resource device modified how much of the resource was consumed at the first location during the first time interval.

[0071] 3. The computer-implemented method of any of clauses 1-2, further comprising generating a first distributed ledger transaction based on the first validated commitment, and transmitting the first distributed ledger transaction to one or more nodes included in a distributed ledger network.

[0072] 4. The computer-implemented method of any of clauses 1-3, wherein validating the first commitment comprises identifying a first event that occurs at the first location based on the first metrology data, and determining that the first event indicates that the first distributed resource device modified how much of the resource was consumed at the first location during the first time

interval.

[0073] 5. The computer-implemented method of any of clauses 1-4, wherein determining that the first event indicates that the first distributed resource device modified how much of the resource was consumed at the first location during the first time interval comprises mapping the first event to a first event model included in a library of event models, wherein the first event model indicates at least one operational attribute of the first distributed resource device.

[0074] 6. The computer-implemented method of any of clauses 1-5, further comprising modifying the first event model based on the first event, wherein the first event model comprises a Machine Learning model.

[0075] 7. The computer-implemented method of any of clauses 1-6, wherein the first distributed resource device restricts resource consumption at the first location to modify how much of the resource was consumed at the first location.

[0076] 8. The computer-implemented method of any of clauses 1-7, wherein the first distributed resource device offsets resource consumption at the first location via generation of additional resources to modify how much of the resource was consumed at the first location.

[0077] 9. The computer-implemented method of any of clauses 1-8, wherein generating the first metrology data comprises measuring, in real time, one or more electrical characteristics corresponding to an electrical load associated with the first location.

[0078] 10. The computer-implemented method of any of clauses 1-9, wherein identifying the first event comprises determining that at least one of the one or more electrical characteristics exceeds a threshold value.

[0079] 11. Some embodiments include a non-transitory computer-readable medium storing program instructions that, when executed by a processor, causes the processor to validate distributed energy resource (DER) device commitments by performing the steps of determining that a first commitment received from a first distributed resource device indicates that the first distributed resource device modified how much of a resource was consumed at a first location during a first time interval, generating first metrology data that indicates how much of the resource was consumed at the first location during the first time interval, and validating the first commitment based on the first metrology data.

[0080] 12. The non-transitory computer-readable medium of clause 11, wherein the step of validating the first commitment comprises generating a first validated commitment confirming that the first commitment indicates that the first distributed resource device modified how much of the resource was consumed at the first location during the first time interval.

[0081] 13. The non-transitory computer-readable medium of any of clauses 11-12, wherein the step of validating the first commitment comprises identifying a first event that occurs at the first location based on the first metrology data, and determining that the first event indicates that the first distributed resource device modified how much of the resource was consumed at the first location during the first time interval.

[0082] 14. The non-transitory computer-readable medium of any of clauses 11-13, wherein determining that the first event indicates that the first distributed resource device modified how much of the resource was consumed at the first location during the first time interval comprises mapping the first event to a first event model included in a library of event models, wherein the first event model indicates at least one operational attribute of the first distributed resource device.

[0083] 15. The computer-implemented method of any of clauses 11-14, wherein the first distributed resource device restricts resource consumption at the first location or generates additional resources at the location to modify how much of the resource was consumed at the first location.

[0084] 16. The computer-implemented method of any of clauses 11-15, wherein the first distributed resource device comprises a smart electric device, a smart water device, or a smart gas device.

[0085] 17. Some embodiments include a system, comprising a memory that stores a software application, and a processor that, when executing the software application, is configured to perform

the steps of determining that a first commitment received from a first distributed resource device indicates that the first distributed resource device modified how much of a resource was consumed at a first location during a first time interval, and validating the first commitment based on first metrology data that indicates how much of the resource was consumed at the first location during the first time interval.

[0086] 18. The system of clause 17, wherein the processor resides within a smart utility meter that monitors resource consumption at the first location to generate the metrology data.

[0087] 19. The system of any of clauses 17-18, wherein the processor is further configured to perform the additional step of obtaining the first metrology data from a node that is coupled to a resource distribution infrastructure and monitors resource consumption at the first location to generate the metrology data.

[0088] 20. The system of any of clauses 17-19, wherein the processor validates the first commitment by identifying a first event that occurs at the first location based on the first metrology data, determining that the first event indicates that the first distributed resource device modified how much of the resource was consumed at the first location during the first time interval, and generating a validated commitment confirming that the first commitment indicates that the first distributed resource device modified how much of the resource was consumed at the first location during the first time interval.

[0089] Any and all combinations of any of the claim elements recited in any of the claims and/or any elements described in this application, in any fashion, fall within the contemplated scope of the present invention and protection.

[0090] The descriptions of the various embodiments have been presented for purposes of illustration, but are not intended to be exhaustive or limited to the embodiments disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the described embodiments.

[0091] Aspects of the present embodiments may be embodied as a system, method or computer program product. Accordingly, aspects of the present disclosure may take the form of an entirely hardware embodiment, an entirely software embodiment (including firmware, resident software, micro-code, etc.) or an embodiment combining software and hardware aspects that may all generally be referred to herein as a "module" or "system." In addition, any hardware and/or software technique, process, function, component, engine, module, or system described in the present disclosure may be implemented as a circuit or set of circuits. Furthermore, aspects of the present disclosure may take the form of a computer program product embodied in one or more computer readable medium(s) having computer readable program code embodied thereon.

[0092] Any combination of one or more computer readable medium(s) may be utilized. The computer readable medium may be a computer readable signal medium or a computer readable storage medium. A computer readable storage medium may be, for example, but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, or device, or any suitable combination of the foregoing. More specific examples (a non-exhaustive list) of the computer readable storage medium would include the following: an electrical connection having one or more wires, a portable computer diskette, a hard disk, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), an optical fiber, a portable compact disc read-only memory (CD-ROM), an optical storage device, a magnetic storage device, or any suitable combination of the foregoing. In the context of this document, a computer readable storage medium may be any tangible medium that can contain, or store a program for use by or in connection with an instruction execution system, apparatus, or device.

[0093] Aspects of the present disclosure are described above with reference to flowchart illustrations and/or block diagrams of methods, apparatus (systems) and computer program products according to embodiments of the disclosure. It will be understood that each block of the

flowchart illustrations and/or block diagrams, and combinations of blocks in the flowchart illustrations and/or block diagrams, can be implemented by computer program instructions. These computer program instructions may be provided to a processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine. The instructions, when executed via the processor of the computer or other programmable data processing apparatus, enable the implementation of the functions/acts specified in the flowchart and/or block diagram block or blocks. Such processors may be, without limitation, general purpose processors, special-purpose processors, application-specific processors, or field-programmable gate arrays.

[0094] The flowchart and block diagrams in the figures illustrate the architecture, functionality, and operation of possible implementations of systems, methods and computer program products according to various embodiments of the present disclosure. In this regard, each block in the flowchart or block diagrams may represent a module, segment, or portion of code, which comprises one or more executable instructions for implementing the specified logical function(s). It should also be noted that, in some alternative implementations, the functions noted in the block may occur out of the order noted in the figures. For example, two blocks shown in succession may, in fact, be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved. It will also be noted that each block of the block diagrams and/or flowchart illustration, and combinations of blocks in the block diagrams and/or flowchart illustration, can be implemented by special purpose hardware-based systems that perform the specified functions or acts, or combinations of special purpose hardware and computer instructions.

[0095] While the preceding is directed to embodiments of the present disclosure, other and further embodiments of the disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

Claims

1. A method comprising: receiving, by a computing device, a commitment generated by a distributed resource device, wherein the commitment indicates an operation performed by the distributed resource device to satisfy the commitment and a time interval when the distributed resource device performed the operation at a location, the distributed resource device being associated with a utility meter; receiving, by the computing device, an event that is generated by the utility meter based on a pattern detected in metrology data indicating usage of a resource at the location during the time interval; identifying, by the computing device, a first event model that is associated with a pattern of usage of the resource that matches the pattern detected in the metrology data indicating the usage of the resource at the location during the time interval, wherein the first event model is included in a library of event models that associate different patterns of usage of the resource with corresponding operations of distributed resource devices; validating, by the computing device, the commitment in response to determining that at least a type of operation associated with the first event model corresponds to the operation performed by the distributed resource device indicated by the commitment to generate a validated commitment; and in response to validating the commitment, performing, by the computing device, one or more computing operations to generate an output based on the validated commitment.

2. The method of claim 1, wherein validating the commitment further comprises determining that the distributed resource device modified the usage of the resource at the location during the time interval.

3. The method of claim 1, wherein the commitment indicates a type of the distributed resource device.

4. The method of claim 3, wherein validating of the commitment is further based on the type of the

distributed resource device.

5. The method of claim 1, wherein the operation comprises reducing generation of resources at the location.

6. The method of claim 1, wherein the operation is selected from a group consisting of: reducing consumption of the resource; turning off climate control; powering off a device; powering on a device; changing a charging state of a device; storing of energy in a battery system; and altering distribution of solar power to a power grid.

7. The method of claim 1, wherein the one or more computing operations comprise transmitting the commitment to a control center to facilitate settlement of the commitment.

8. The method of claim 1, further comprising updating, by the computing device, the first event model based on the event.

9. The method of claim 1, wherein the first event model is a machine learning model or a parametric model.

10. A server, comprising: one or more processors; and a memory storing executable instructions that, when executed by the one or more processors, cause the one or more processors to perform steps comprising: receiving a commitment generated by a resource management device, wherein the commitment indicates a time period when the resource management device performed an operation to alter resource consumption at a location, the resource management device being associated with a utility meter; receiving an event that is generated by the utility meter based on a pattern detected in metrology data indicating resource consumption at the location during the time period; mapping the pattern detected in the metrology data indicating the resource consumption to a first event model included in a library of event models, wherein respective event models in the library associate respective operations of resource management devices with respective patterns of resource consumption; validating the commitment by determining that at least a type of operation associated with the first event model matches the operation performed by the resource management device; and in response to validating the commitment, performing one or more computing operations to generate an output based on the validated commitment.

11. The server of claim 10, wherein the commitment identifies a type of the resource management device.

12. The server of claim 11, wherein validating the commitment is further based on the type of the resource management device.

13. The server of claim 12, wherein the operation comprises reducing resource consumption during the time period or offsetting resource consumption by generating additional resources.

14. The server of claim 10, wherein the commitment is received from the utility meter.

15. The server of claim 10, wherein the steps further comprise updating the first event model based on the event.

16. A non-transitory computer-readable medium storing instructions that, when executed by one or more processors of a computing device, cause the one or more processors to perform steps comprising: receiving a commitment, wherein the commitment identifies an action performed by a distributed resource device that generated the commitment and a time interval when the distributed resource device managed consumption of a resource at a location by performing the action, the distributed resource device being associated with a utility meter; receiving an event that is generated by the utility meter based on a time-varying pattern detected in metrology data that indicates the consumption of the resource at the location during the time interval; identifying, based on the time-varying pattern, a first event model having a matching time-varying pattern for the consumption of the resource, wherein the first event model is included in a library of event models that associate different patterns in the consumption of the resource with corresponding types of actions performed by distributed resource devices; validating the commitment in response to determining that at least a type of action associated with the first event model corresponds to the action performed by the distributed resource device; and in response to validating the commitment,

performing one or more computing operations to generate an output based on the validated commitment.

17. The non-transitory computer-readable medium of claim 16, wherein: the commitment identifies a type of the distributed resource device; and validating the commitment further comprises confirming that the type of the distributed resource device is a type of distributed resource device corresponding to the first event model.

18. The non-transitory computer-readable medium of claim 17, wherein validating the commitment further comprises confirming, based on the time-varying pattern corresponding to the event, that the action was performed by the distributed resource device during the time interval.

19. The non-transitory computer-readable medium of claim 16, wherein the steps further comprise updating one or more parameters of the first event model based on the event.

20. The non-transitory computer-readable medium of claim 16, wherein the one or more computing operations further comprise: generating a first distributed ledger transaction based on the commitment; and transmitting the first distributed ledger transaction to one or more nodes included in a distributed ledger network.