

A SYSTEM FOR MANAGING A POWER GRID

Technical field

The invention relates to a system for managing a power grid.

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Background

Power distribution networks supplying power to end users comprise a network of electric meters that need to communicate with a control system to monitor consumption and other local parameters and to provide appropriate services to the end user.

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For managing grid performance it may be necessary for multiple electrical devices, to communicate with each other. Exchanged parameters may include voltage, frequency, power, disturbance events and statistics, these parameters can be used by control systems to maintain grid stability. Often communications must be low latency, high throughput, or high reliability. This can be challenging in communications networks where a message must traverse multiple routers or hops, or where radio frequency spectrum and therefore throughput is limited, especially in a mesh network. Often there is a plethora of devices in a system and any single device can act as an electrical proxy for other nearby devices.

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Hence, improved systems and methods of communication in power distribution networks are desirable.

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Summary

The choice of which devices need to communicate with each other to achieve a particular goal are many and may be optimised. If a system factors in electrical connectivity, geographical distance and communication link quality, an optimal solution can be computed. A system that can provide this functionality is described herein.

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Aspects of the invention provide a method and system of controlling a network of devices (typically electric meters) to manage grid performance and provide reliable services to end consumers.

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According to a first aspect there is provided a system comprising

a plurality of devices connected to one or more circuits in a power distribution grid;

5 a head end system, HES, configured to communicate with the plurality of devices;

a controller configured to receive data from the plurality of devices and to communicate with the HES via one or more HES application programming interfaces, APIs,

10 wherein the controller is configured to request and receive, via the one or more HES APIs, device information relating to the plurality of devices, and

wherein the controller is configured to manage one or more services relating to the one or more circuits in the power distribution grid based on the device information.

15 The HES to controller interface may comprise typical AMI data, circuit information, communications routing information, geospatial information (GIS e.g. map coordinates) and a direct pass-through communications path to an application on a device. The pass-through communications path provides a tunnel through the AMI communications infrastructure. The application may relate to a service managed by the controller and may for example relate to the voltage in general, harmonics, frequency, average
20 power, phase identification, topology detection, supply impedance, DER, batteries, theft detection, energy trading etc.

Each device of the plurality of devices may be an electric meter configured to measure a power consumption of an end consumer. The controller can be configured to manage
25 power flow and/or voltage by automatically controlling voltage regulator and capacitor bank switching operations. The controller may be configured to manage the voltage in terms of magnitude, phase, harmonics, inter-harmonics, and/or frequency. The controller may also be configured to manage a distributed energy resource, DER, and/or to manage battery charge and discharge at an end user associated with a
30 device of the plurality of devices. For example, based on device information transmitted to the controller and received via an API, the controller may cause a battery to stop charging.

35 A device can belong to multiple circuits simultaneously and a circuit may comprise the entire grid or may only include a conductor immediately connecting two geographically

close devices (e.g. on the same switchboard). A long run of a single cable may be divided into multiple circuits due to the inherent impedance.

The device information may comprise, for each device, one or more of

- 5 location information, relating to the physical location of the device and/or a distance between device and other devices of the plurality of devices,
- circuit information for identifying one or more circuits to which the device is connected,
- load information, relating to the power consumption of the end consumer
- 10 associated with the device,
- phase information, relating to the electric phase of the device,
- quality of supply, QOS, information,
- supply impedance,
- temperature,
- 15 communication congestion, communication latency, communication throughput, communication route,
- acceleration,
- vibration,
- sound, and
- 20 light exposure.

The controller can be configured to select a master device of the plurality of devices based on the device information, wherein the master device is configured to facilitate communication between the plurality of devices. The master device can thereby reduce

25 the communications burden on the path to the HES and/or reduce HES computational requirements. The controller can be configured to transmit an activation message to the selected master device to activate an appropriate application on the master device to act as a master device.

30 The controller can be configured to request from the HES a list of devices comprising a set of properties, and wherein the HES is configured to, in response to receiving the request, provide a list of the plurality of devices filtered based on the set of properties. The controller can be configured to update the set of properties based on a response from the HES. For example, if the first set of properties return a nil result (i.e. none of

35 the devices of the plurality of devices has the first set of properties) the controller can provide a second (less restrictive) set of properties. The set of properties may for

example specify minimum thresholds for QOS parameters and/or for a physical distance.

5 The plurality of devices and the HES are typically comprised by an advanced metering infrastructure (AMI), wherein the HES and one or more of the devices are configured to communicate using the AMI independently of the controller and the HES APIs. That is the APIs can be used in parallel with the AMI technology to directly communicate and/or control applications installed on the devices. The HES is thereby configured to provide pass-through communications between the controller and applications installed
10 on the plurality of devices.

AMI systems are based around a simple master/slave architecture, wherein the HES is the master and the meters are slaves. In the AMI, meters are concerned with being able to communicate with the HES typically to deliver billing (energy consumption)
15 data, and not with peer-to-peer data sharing. In mesh networks meters can talk with other nodes in the mesh but as a means of exchanging information with the HES (not with each other). Peer-to-peer communications in the application layer (of the OSI) is not part of existing AMI systems. The peer-to-peer technology provides an opportunity to perform edge processing, where multiple meters communicate with each other with
20 little or no input from the HES. This can reduce communication traffic at the collectors, which are usually operating at max capacity. It can also reduce CPU load on the HES, lowers communication costs and provide additional redundancy. The APIs provided by the HES can allow visibility of crucial information to the applications within the devices, thereby allowing them to coordinate their behaviour with their peers.

25 Application layer peer-to-peer communications is used to provide edge processing. However, due to the potentially vast network of nodes, the choice of which peers to communicate with, and determining their relative significance is a complex decision. The controller can be configured to utilise multiple APIs in order to make these decisions, and may forward some of the extracted data to the edge device, which the
30 edge device may use to make further decisions for edge processing. Accordingly, application layer peer-to-peer communications for coordinating behaviour between nodes (without direct involvement from the HES) combined with multiple interfaces (APIs) at the HES may be particularly advantageous for managing the power grid. The
35 APIs can provide information from the meters and/or from other sources such as

databases at the HES to provide e.g. circuit information, communications routing information, and geospatial information.

5 For bandwidth, latency and congestion reasons, a subset of devices may be preferred points for performing edge processing (e.g. using peer-to-peer communication), and a different subset may be suitable for generating data for the HES. The information extracted via the APIs would aid that decision making process. For other reasons (e.g. geographic location, circuit positioning, prior erroneous activity, account payment) another subset of devices may again be preferred points where edge processing
10 occurs and/or where data destined for the HES is generated. The information extracted via the APIs can be used to make that decision.

The controller can be configured to group devices of the plurality of devices based on the device information. For example, the controller may identify and group a plurality of
15 problem meters based on the device information (e.g. based on QOS information or voltage information). The problem meters may be defined as having a QOS below a quality threshold. For example, a problem device may be a device with a voltage outside 10% of a nominal voltage for that device.

20 The controller can be configured to transmit an activation message to the group of devices to activate an application installed in the devices in that group. For example, in response to identifying a problem meter, the controller can be configured to transmit an activation message to the HES via a HES API to cause the HES to activate an application in each device in a same group as the problem meter. The application may
25 for example be configured to provide real time voltage data, in order to provide closer monitoring and enable better control of problem meters.

For a single controller the API's can provide an interface to multiple classes of information. The classes of information may comprise AMI data, circuit information,
30 communications routing information, geospatial information (GIS e.g. map coordinates) or a direct pass-through communications path to an application on a device.

According to a second aspect there is provided a device configured for use as one of the devices of the plurality of devices in the system of the first aspect. The device may
35 comprise one or more of an internet gateway for communicating with an internet network or private network, a HES gateway for communicating with the HES via an

AMI network, a traditional AMI process module for sending AMI data to the HES over the AMI network, a plurality of applications (apps) for providing one more services to the end consumer and/or to the utility provider, and an application management module for managing the plurality of applications installed on the device. The device
5 can be configured to share application data with other devices of the plurality via an application layer. The device comprises an API to allow applications installed on the device to communicate with other applications on the same device, with applications in other devices, and with the controller and/or the HES.

10 The one or more of the applications installed on the device can be configured to communicate with the HES via the HES gateway. Alternatively or in addition, the applications can be configured to communicate directly with the controller via the internet gateway. This alternate path of not using the AMI network can be advantageous because of the potentially high bandwidth.

15 The device can comprises an API configured to enable the one or more applications to read sensor data within the device e.g. for a meter this may comprise main voltage, load current, power and temperature. The device can further comprise an API to allow the applications to reconfigure or control the device e.g. for a meter change the
20 disconnect relay state or reconfigure LP intervals. The device can be configured to enable and disable application functionality on command from the HES and/or as required by a prior set expiration date.

25 The device is typically configured to run AMI metering functionality independent of the one or more applications.

According to a third aspect there is provided a head-end system (HES) configured for use as the HES of the system of the first aspect. The HES can comprise an API to allow the controller to obtain a list of devices. Device information can include an ID and
30 a status indicating if the device is active. The HES can further comprise an API to allow the controller to obtain a list of all electrical circuits a specific device is connected to and/or a list of all electrical circuits and the devices in those circuits. A single device may be connected to multiple circuits. A particular circuit can have a type being one of local, street, feeder, distribution, transmission, etc. A particular circuit can have a phase
35 of AN,BN,CN, AB, BC, or CA. The HES can be configured to provide one of more of

circuit ID, circuit type, phase and associated device list information to the controller when requested.

5 The HES can further comprise an API to allow the controller to obtain the physical distance between two devices and/or obtain a list of devices within a specified range of a specified device or co-ordinate. The HES can comprise an API to allow the controller to obtain one or more of past load profile (LP) data, quality of supply (QOS) event data, QOS event statistics, sag/swell information, peak current, max demand, distributed energy resource (DER) configuration. The LP data can comprise a set of interval
10 readings of consumed energy and may include other measurements like hour average voltage, temperature, exported energy (e.g. solar DER), and max demand for example. The HES can comprise an API to allow the controller to inform the HES that an application is to be enabled in a particular device or in a group of devices. The HES can be configured to track which apps have been enabled, how long they have been
15 enabled, and/or check that license fees have been paid. The HES may be configured to block applications from being enabled, for example, if monetary funds are insufficient and to disable applications for which licenses have expired.

20 The HES can comprise an API to allow the controller to obtain a list of IP addresses and ports of all devices running an application, and provide an API to allow the controller to transparently communicate using IP with an application in a device over a secure communication network managed by the HES.

25 The HES can comprise an API to allow the controller to request the ID of a suitable device in the mesh network to use as a master device. The HES can be configured to respond with an indication of latency/congestion to allow the controller to alter its behaviour if a suitable device meeting the requirements specified by the controller cannot be found amongst the plurality of devices. The HES can be configured to provide a mechanism to block or depersonalize information presented to the controller
30 via a HES API.

The HES can be configured to provide a mechanism for peer-to-peer communication in the mesh network. The plurality of devices may be neighbours, in the same PAN or in different PANs. The HES can be further configured to run AMI metering functionality
35 independent of the controller and the application functionality.

According to a fourth aspect there is provided a controller configured for use in the system of the first aspect. The controller is independent from any traditional AMI functionality, and can be configured to manage a particular grid management feature, e.g. instantaneous power flow or overvoltage for multiple circuits in the grid. The controller may form a part of a control loop, wherein the output it generates causes a modification of behaviour of the grid as part of an automated system. For example, the controller output may cause voltage tap changes or coordinated load and DER management in a target zone of the grid. The controller is configured to communicate with the HES via the HES APIs.

The controller may further be configured to communicate with applications within the plurality of devices via the HES APIs and/or via alternate communication networks (not managed by the HES). The controller can also be configured to communicate with other systems unrelated to the HES and its AMI network e.g. alert notification systems via SMS/email, or a public website providing customers with information about a particular grid management feature.

According to a fifth aspect there is provided a method of controlling a power distribution network, the method comprising:

at a controller, requesting device information from a head-end system, HES, wherein the device information relates to a plurality of devices connected to one or more circuits in a power distribution grid;

at the HES, transmitting device information to the controller via one or more HES application programming interfaces, APIs;

at the controller, managing power flow and/or voltage in the one or more circuits in the power distribution grid based on the device information.

The step of managing may comprises automatically controlling voltage regulator and capacitor bank switching operations. The step of managing may comprise automatically controlling a distributed energy resource, DER, or the battery charge or discharge at an end user associated with a device of the plurality of devices.

The method may comprise, in the controller, selecting a master device of the plurality of devices based on the device information, wherein the master device facilitates communication between the plurality of devices. The method may further comprise, in

the controller, transmitting an activation message to the selected master device to activate an appropriate application on the master device to act as a master device.

5 The method may comprise, in the controller, for each master device not already in an active group, send a request to the HES to cause it to enable and pay for an application. Whilst the method is applicable to many different applications installed on the devices relating to different services managed by the controller, as an example, the application may be an intelligent voltage monitoring application, which is configured to automatically report to the controller if the voltage exceeds a threshold value. The
10 method may further comprise, in the HES, for each enabled device, send a message to the device to enable the application and optionally to provide a license expiration date, and for each device running the application, send a message informing the application of the IP address of the controller.

15 The step of requesting device information comprises requesting from the HES a list of devices comprising a set of properties, and wherein the HES, in response to receiving the request, provides a list of the plurality of devices filtered based on the set of properties. The controller can use the HES APIs to obtain a list of all known meters in the field in an area of interest. The controller can iterate through each meter on the list
20 to create multiple circuit lists using a HES API.

The method may further comprise, in the controller, updating the set of properties based on a response from the HES and sending a new request with the updated set of properties.

25 The method may comprise, in the controller, for each group of devices, test if any problem meters exist and, if so, then declare it an active group and send a request to the HES to cause it to enable an application for each meter in the active group. A problem meter may be a meter with a voltage or QOS value outside an acceptable
30 range. For example, a problem meter may have a voltage 10% greater than a nominal voltage for that meter. This application can be an intelligent voltage monitoring application, wherein meters with voltage outside of a tolerance automatically send near real time data to the controller, which then feeds into the system that automatically changes voltage taps on transformers. This can allow utility customers to run
35 additional/enhanced functionality in areas where they struggle to manage supply. By limiting the activation of an application to a smaller group of devices, costs can be

reduced as well as communication activity. The application activation causes the meters in the group to coordinate and generate near real time voltage data. The worst meters (highest and lowest) can stream their data, and the group can automatically choose who shall stream.

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The method may further comprise, facilitating communication between the plurality of devices and the HES over an advanced metering infrastructure, AMI. AMI may be used as normal to communicate meter readings from the plurality of devices to the HES.

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The method may further comprise, in the controller, grouping devices of the plurality of devices based on the device information. For example, the controller may group problem meters, or may group devices based on the distance to each other and/or to a problem meter.

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The method may further comprise, in the controller, identifying a problem meter based on the device information and, in response to identifying the problem meter, transmitting an activation message to the HES via a HES API to cause the HES to activate an application in each device in a same group as the problem meter.

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The method may be implemented using the system of the first aspect.

Specific embodiments of the invention will now be described with reference to the accompanying drawings.

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Brief description of drawings

Figure 1 shows a schematic diagram of a power distribution network;

Figure 2 shows a schematic diagram of a power grid;

Figure 3 shows a schematic diagram of a communication network of a power grid;

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Figure 4 shows a schematic diagram of a system comprising a plurality of devices, a head-end system (HES) and a controller; and

Figure 5 shows a flow diagram illustrating the steps of a method of controlling a power distribution network.

Detailed description

FIG. 1 shows a portion of an exemplary power distribution network. A substation 110 is connected to a distribution network 175, such as a power grid, and is in turn connected to transformers 120, 130, 160, 162, 164. Devices, being meters 140, 142, 144, 146, 148, 150, are connected to transformers 120 and 130.

The meters can communicate with a head-end system (HES) 100. In one example, multiple meters are connected via a wireless mesh network. A device in the network, such as a collector or personal area network (PAN) coordinator, may facilitate the communication of data from the wireless mesh network to the HES 100 via one or more networks 170. Other types of communication between the meters and the HES 100 are also possible including, but not limited to, cellular communications and power line communications.

A meter may communicate consumption information to the HES 100, as well as other information measured or detected by the meter. In some examples, the meter communicates voltage information to the HES. The voltage information may be associated with a time interval, such as a 15 minute interval. The meter may provide voltage information for multiple time intervals over multiple days. The HES may maintain voltage information provided by the meters in a database 102 or other data storage facility.

The HES may also maintain other types of information about the meters and other devices in the distribution network. For example, GIS information describing the location of a meter or a transformer may be maintained. In some networks, the HES also receives data related to the operation of a device other than a meter, such as a substation, a transformer, or other device.

The head-end 100 system may maintain connectivity information for the meters 140, 142, 144, 146, 148, 150 and the transformers 120, 130 in a database 102. The information may be initially provided upon installation or deployment of the meters and transformers or may be obtained from a legacy system.

A power distribution network typically comprises an advanced metering infrastructure (AMI) system. AMI systems are used for measuring, collecting and analysing utility

consumption data, for example the consumption of electrical energy, gas, heat, water, etc. The measurements are conducted with the help of metering devices located at the premises of utility consumers, such as households, businesses, industries or alike. The metering devices communicate with each other in order to electronically exchange measurement data and other information in that they are configured and arranged as a communication mesh network, wherein each metering device acts as a node within the mesh network.

Certain numbers of metering devices, for example metering devices installed in a block of flats which establish a mesh network with each other, constitute a metering cluster. Within the cluster, the metering devices commonly are connected to each other via Radio Frequency signals (RF) and/or Power Line Communication (PLC). In addition to the metering devices, a Data Concentrator (DC) is installed which acts as a gateway establishing an uplink and/or downlink within the AMI system and that the DC gathers measurement data from the metering devices within the cluster and forwards the data in an aggregated state via an uplink towards a Head End System (HES) of the AMI.

The HES receives and collects metering data from a plurality of DCs. The DCs communicate with the HES typically via Ethernet or Cellular IP-based technologies or as an alternative via RF and/or PLC, in particular G3 PLC. Within the HES, the metering data can be verified and prepared for analysis. The HES commonly forwards the so consolidated metering data to a clearing system for billing of the consumption. Moreover, the metering data and values from analyses thereof can be used for controlling energy consumption. For example, the AMI system can be used for switching to or between multiple networks to optimize communication between an energy device, e.g., meter, in proximity to at least one of the multiple networks and a head end server to facilitate communication of energy-related data therebetween. The system includes a communications module associated with the energy device for controlling the switching between networks and/or the directing of energy-related data communications over different networks in accordance with data type.

AMI networks are designed to maximise communications utilization, requiring optimal strategies for data exchange. Furthermore, AMI systems focus on the delivery of consumption information, supply quality and some status info from meters to the HES. HES-to-device communications over AMI are typically limited to software updates, configuration changes, requests for missing data, and health status checks. An AMI

system does not allow optimised direct communication and/or control of applications in the device by the HES or by a controller, and does not allow for direct communications between applications on a device with a HES or a controller as described herein.

- 5 FIG. 2 shows a schematic diagram of a power grid 200 comprising a substation 210 with circuit breakers (CB) 211 connected to respective feeders 212 and 213. The feeders 212 and 213 provide power to a plurality end consumers 214 (each associated with a device, such as an electric meter) via distribution transformers (DT) 220.
- 10 Dashed lines illustrate different groupings of the devices, wherein a first grouping 231 comprises all devices connected to the same feeder 213, a second grouping 232 comprises all devices connected to a the same distribution transformer, a third grouping 233 connected to the first feeder 212 and comprising devices located close to the substation, a fourth grouping 234 connected to the first feeder 212 and located
- 15 midway along the feeder 212, and a fifth grouping 235 connected to the first feeder 212 and located at the end of the feeder 212.

- Device information requested by a controller from the HES may comprise one or more of the groupings 231 to 235. For example, the controller may request a list of devices
- 20 located within a threshold distance of the substation 211, in response to which the HES may transmit a list of devices in the third grouping 233. In another example, the controller may request a list of devices connected to the second feeder 213, in response to which the HES may transmit a list of devices in the first grouping 231.

- 25 Figure 3 shows a schematic diagram of a power grid 300 with an advanced metering infrastructure (AMI), allowing two way communication between devices (e.g. electric meters) associated with the end consumers 314 and a head-end system (HES) 310. The devices communicate with the HES 310 via collectors 340, 341. Light dashed lines are mesh radio communications (e.g. between neighbouring devices), heavy dashed
- 30 lines indicate cellular communications (e.g. between the collector 340 and a cellular tower 350), and solid line indicate wired communications (e.g. between the HES 310 and an internet network 360).

- Embodiments described herein provide an alternative communication system, which
- 35 can operate in parallel with any existing AMI systems and processes and which may thereby improve the communication reliability. In particular, the described herein is a

- system comprising a controller for managing grid management events (e.g. instantaneous power flow or over voltage in circuits on the grid), which is configured to communicate with the HES 310 via one or more HES application programming interfaces (APIs). The controller receives device information from the HES and can be configured to communicate with and/or control applications (apps) installed on the devices via the HES APIs (or via another, direct, communication means). The HES is configured to provide AMI metering functionality independent of the controller and any app functionality.
- Figure 4 shows a schematic diagram of a system 400 according to an embodiment. The system 400 comprises a plurality of devices 401 connected to one or more circuits, a head end system (HES) 410 configured to communicate with the plurality of devices 401, and a controller 420 configured to control the plurality of devices 401.
- The HES 410 can comprise an API to allow the controller 420 to obtain list of all devices in the system 400. Device information can include an ID and a status indicating if device is active. The HES 410 can further comprise an API to allow the controller 420 to obtain a list of all electrical circuits a specific device is connected to and/or a list of all electrical circuits and the devices in those circuits. A single device may be connected to multiple circuits. A particular circuit can have a type being one of local, street, feeder, distribution, transmission, etc. A particular circuit can have a phase of AN,BN,CN, AB, BC, or CA. The HES 410 can be configured to provide one of more of circuit ID, circuit type, phase and associated device list information the controller 420 when requested.
- The HES 410 can further comprise an API to allow the controller 420 to obtain the physical distance between two devices and/or obtain a list of devices within a specified range of a specified device or co-ordinate. The HES 410 can comprise an API to allow the controller 420 to obtain one or more of past load profile (LP) data, quality of supply (QOS) event data, QOS event statistics, sag/swell information, peak current, max demand, distributed energy resource (DER) configuration. The LP data comprises a set of interval readings of consumed energy e.g. within a 1/2 hour period and may include other measurements like hour average voltage, temperature, exported energy (solar DER), max demand for example. The QOS refers to the quality of the voltage, magnitude, noise, phase angle, harmonics, and THD etc. The HES 410 can comprise an API to allow the controller 420 to inform the HES 410 that an application is to be enabled in a particular device. The HES 410 can track which apps have been enabled,

how long they have been enabled, and check that license fees have been paid. The HES 410 may be configured to block applications from being enabled if monetary funds are insufficient and disable applications for which licenses have expired.

- 5 The HES 410 can comprise an API to allow the controller 420 to obtain a list of IP addresses and ports of all devices running an application, and provide an API to allow the controller 420 to transparently communicate using IP to an application in a device over the secure communication network (the AMI network) managed by the HES.
- 10 The HES 410 can comprise an API to allow the controller 420 to request the ID of a (most) suitable device in the mesh network to use as a “router” between devices defined in a supplied list. A response from the HES 410 can include an indication of latency/congestion to allow the controller 420 to alter its behaviour if a suitable device meeting the requirements specified by the controller 420 cannot be found amongst the
- 15 plurality of devices 401, i.e. the controller 420 can request IDs of a (slightly) different set of devices. The HES 410 can be configured to provide a mechanism to block or depersonalize information presented to the controller 420 via the HES API, if for example the information is declared personal or a security concern.
- 20 The HES 410 can be configured to provide a mechanism for peer-to-peer communication in the mesh network. The plurality of devices 401 may be neighbours, in the same PAN or in different PANs. In conventional mesh networks, meters talk with other nodes in the mesh but only as a means of exchanging information with the HES (and not in order to exchange data with each other). The system described can provide
- 25 peer-to-peer communications between devices in the application layer of the OSI (Open Systems Interconnection) model. This allows edge processing wherein multiple devices communicate with each other with little or no input from the HES 410. The HES 410 is further configured to run AMI metering functionality independent of the controller 420 and the app functionality.
- 30 The plurality of devices 401 comprises a first device 401a comprising an internet gateway for communicating with an internet network or private network, a HES gateway for communicating with the HES 410 via an AMI network, a traditional AMI process module for sending AMI data to the HES 410 over the AMI network, a plurality
- 35 of applications (apps) for providing one more services to the end consumer and/or to

the utility provider, and an application management module for managing the plurality of applications installed on the device 401a.

5 The one or more of the applications installed on the device 401a can be configured to communicate with the HES 410 via the HES gateway and over the AMI network. Alternatively or in addition the applications can be configured to communicate directly with the controller 420 via the internet gateway and over the internet/private network. This alternate path of not using the AMI network can be advantageous because of the
10 potentially high bandwidth. However, the path may have lower reliability as it may be dependent on the end users internet connection, which could be disabled unexpectedly. The device 401a comprises an API to allow applications installed on the device 401a to communicate with other application on the same device, application in other devices, the controller 420 and/or the HES.

15 The device comprises an API configured to enable the one or more applications to read sensor data within the device e.g. for a meter this may comprise main voltage, load current, power and temperature. The device further comprises an API to allow the applications to reconfigure or control the device e.g. for a meter change the disconnect relay state or reconfigure LP intervals. The device can be configured to enable or
20 disable app functionality on command from the HES 410 and/or as required by a prior set expiration date.

The device 401a is configured to run AMI metering functionality independent of the controller 420 and of the new app functionality.

25 The controller 420 is independent from any traditional AMI functionality, and can be configured to manage a particular grid management feature, e.g. instantaneous power flow or overvoltage for multiple circuits in the grid. The controller 420 is configured to communicate with the HES 410 via the HES APIs.

30 The controller 420 may further be configured to communicate with applications within the plurality of devices 401 via the HES APIs and/or via alternate communication networks (not managed by the HES 410). The controller 420 can also be configured to communicate with other systems unrelated to the HES 410 and its AMI network e.g.
35 alert notification systems via SMS/email, or a public website providing customers with information about a particular grid management feature.

Systems described herein can be used to automatically control a grid voltage regulator and capacitor bank switching operations. For example, the system may operate as set out in the following steps:

- 5 S1. The controller uses the HES APIs to obtain a list of all known meters in the field in an area of interest.
- S2. The controller iterates through each meter on the list to create multiple circuit lists using a HES API.
- 10 S3. In the controller, for each circuit list, identify meters that are within a threshold distance (e.g. 3km) of each other, to create multiple group lists, wherein a HES API is used to provide distance information.
- S4. In the controller, for each meter in a group list, query the HES via an API for past voltage information (e.g. in the form of past 360 days of voltage LP or any voltage
- 15 QOS events). Determine a min and max voltage for each group list and flag any problem meters. A problem meter may be a meter with a voltage outside 10% of a nominal voltage for that meter.
- S5. In the controller, for each group list, test if any problem meters exist and if so then declare it an active group and send a request to the HES to cause it to enable and
- 20 pay for the application for each meter in the active group. This application can be an intelligent voltage monitoring application, wherein meters with voltage outside of tolerance automatically send near real time data to the controller, which then feeds into the system that automatically changes voltage taps on transformers.
- S6. In the controller, for each active group provide a list of devices to the HES and
- 25 have it inform the controller of a (suitable and/or optimal) device to act as a master device (e.g. based on shortest RF distance/hops/least congestion etc.), the device may not be in an active group. Other devices in the same group are slaves.
- S7. In the controller, for each master device if not already in an active group send a request to the HES to cause it to enable and pay for the application.
- 30 S8. In the HES, for each enabled device, send a message to the device to enable the application and optionally to provide a license expiration date.
- S9. In the HES, for each device running the application, send a message informing the application of the IP address of the controller.
- 35 S10. In the controller, wait for registration notifications from the application running on the device, the registration notification informs the controller that the application is operational.

S11. In the controller, in response to any registration notifications received from the master devices, send configuration information relating to sensitivity of voltage logic and flag the device as registered. The information may inform the master device of a configuration to use in order to make decision about which meters should stream data.

5 For example, the information may indicate that average voltage over a period of three minutes is to be used to calculate max/min and the four worst case meters are to stream their data. This type of configuration can be manually specified by the user in a GUI and then automatically disseminated when needed.

10 S12. In the controller, in response to receiving a registration notification from a slave device, send configuration information to the slave device relating to the identity of the master device and flag the slave device as registered.

15 S13. In a plurality of (slave) devices, have the application send consumption information e.g. min/max voltage information, to the application of the master device associated with that group of devices at set intervals. This can circumvent throughput bottle necks within the controller and/or the communication network exit points compared to alternative designs where all devices send voltage information to the controller instead of using localized processing within a master device.

20 S14. In one or more master devices, have an application automatically select and inform a slave device in the associated group that it is a reference meter. The system can be configured so that other meters compare themselves to the reference meter. For example, when a meters compares its own reading to the readings from a reference meter and determines that there is a large (e.g. >10%) difference it can be configured to send a message to a master device or to the controller.

25 S15. In multiple reference devices, have app send additional voltage information (short interval load profile) to the HES and/or to the controller.

S16. In the HES or in the controller, use high resolution voltage data provided by the reference meters to automatically control voltage regulator and capacitor bank switching operations.

30 S17. In the controller, request or wait for information from master devices relating to statistics on min/max voltage for all slave devices associated with each master.

S18. Repeat above process to account for system changes such as changes to the grid, changes to customer load patterns and insertion/removal of meters.

35 Figure 5 shows a flow diagram illustrating some steps of a method of controlling a power grid, which may comprise method steps S1 to S18 described above. The method comprises, at a controller, request device information from a HES (S100), and,

at the HES, transmitting device information to the controller via one or more HES APIs (S101), and, at the controller, managing instantaneous power flow and/or overvoltage in the one or more circuits in the power distribution grid based on the device information (S102).

5

While specific embodiment have been described above, the skilled person will appreciate that further embodiments falling within the scope of the claims are possible. The features of any one embodiment may be suitably combined with those of one or more other embodiments.

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CLAIMS:

1. A system comprising:
 - a plurality of devices connected to one or more circuits in a power distribution
 - 5 grid;
 - a head end system, HES, configured to communicate with the plurality of devices;
 - a controller configured to receive data from the plurality of devices and to communicate with the HES via one or more HES application programming interfaces,
 - 10 APIs,
 - wherein the controller is configured to request and receive, via the one or more HES APIs, device information relating to the plurality of devices, and
 - wherein the controller is configured to manage one or more services relating to the one or more circuits in the power distribution grid based on the device information.
 - 15
2. A system according to claim 1, wherein each device of the plurality of devices is an electric meter configured to measure a power consumption of an end consumer.
3. A system according to claim 1 or 2, wherein the controller is configured to
- 20 manage power flow and/or voltage by automatically controlling voltage regulator and capacitor bank switching operations and/or wherein the controller is configured to manage a distributed energy resource, DER, and/or to manage battery charge and discharge at an end user associated with a device of the plurality of devices.
4. A system according to any one of the preceding claims, wherein the device
- 25 information comprises, for each device, one or more of
 - location information, relating to the physical location of the device and/or a distance between device and other devices of the plurality of devices,
 - circuit information for identifying one or more circuits to which the device is
 - 30 connected,
 - load information, relating to the power consumption of the end consumer associated with the device,
 - phase information, relating to the electric phase of the device,
 - quality of supply, QOS, information,
 - 35 supply impedance,

- temperature,
communication congestion, communication latency, communication throughput,
communication route,
acceleration,
5 vibration,
supply voltage,
load current,
power,
sound, and
10 light exposure.
5. A system according to any one of the preceding claims, wherein the controller is configured to select a master device of the plurality of devices based on the device information, wherein the master device is configured to facilitate communication
15 between the plurality of devices.
6. A system according to claim 5, wherein the controller is configured to transmit an activation message to the selected master device to activate an appropriate application on the master device to act as a master device.
20
7. A system according to any one of the preceding claims, wherein the controller is configured to request from the HES a list of devices comprising a set of properties, and wherein the HES is configured to, in response to receiving the request, provide a list of the plurality of devices filtered based on the set of properties.
25
8. A system according to any one of the preceding claims, wherein the controller is configured to update the set of properties based on a response from the HES.
9. A system according to any one of the preceding claims, wherein the plurality of
30 devices and the HES are comprised by an advanced metering infrastructure ,AMI, and wherein the HES and one or more of the devices are configured to communicate using the AMI and independently of the controller and the HES APIs.
10. A system according to any one of the preceding claims, wherein the controller is
35 configured to group devices of the plurality of devices based on the device information.

11. A system according to any one of the preceding claims, wherein the controller is configured to identify a problem meter based on the device information and, in response to identifying the problem meter, transmit an activation message to the HES via a HES API to cause the HES to activate an application in each device in a same group as the problem meter.

12. A system according to any one of the preceding claims, wherein the HES is configured to provide a mechanism for peer-to-peer communication between devices of the plurality of devices.

13. A system according to any one of the preceding claims, wherein the plurality of devices is configured for peer-to-peer communication in an application layer of an Open Systems Interconnection model.

14. A method of controlling a power distribution network, the method comprising:
at a controller, requesting device information from a head-end system, HES, wherein the device information relates to a plurality of devices connected to one or more circuits in a power distribution grid;
at the HES, transmitting device information to the controller via one or more HES application programming interfaces, APIs;
at the controller, managing power flow and/or voltage in the one or more circuits in the power distribution grid based on the device information.

15. A method according to claim 14, wherein the step of managing comprises automatically controlling voltage regulator and capacitor bank switching operations, and/or wherein the step of managing comprises automatically controlling a distributed energy resource, DER, or battery charge or discharge at an end user associated with a device of the plurality of devices.

16. A method according to claim 14 or 15 further comprising, in the controller, selecting a master device of the plurality of devices based on the device information, wherein the master device facilitates communication between the plurality of devices.

17. A method according to any one of claims 14 to 16 further comprising, in the controller, transmitting an activation message to the selected master device to activate an appropriate application on the master device to act as a master device.
- 5 18. A method according to any one of claims 14 to 17, wherein the step of requesting device information comprises requesting from the HES a list of devices comprising a set of properties, and wherein the HES, in response to receiving the request, provides a list of the plurality of devices filtered based on the set of properties.
- 10 19. A method according to claim 18, in the controller, updating the set of properties based on a response from the HES and sending a new request with the updated set of properties.
20. A method according to any one of claims 14 to 19 further comprising, facilitating
15 communication between the plurality of devices and the HES over an advanced metering infrastructure, AMI.
21. A method according to any one of claims 14 to 20 further comprising, in the
20 controller, grouping devices of the plurality of devices based on the device information.
22. A method according to claim 21 further comprising, in the controller, identifying
a problem meter based on the device information and, in response to identifying the
problem meter, transmitting an activation message to the HES via a HES API to cause
the HES to activate an application in each device in a same group as the problem
25 meter.