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(54) Title: NETWORK CENTRIC POWER FLOW CONTROL

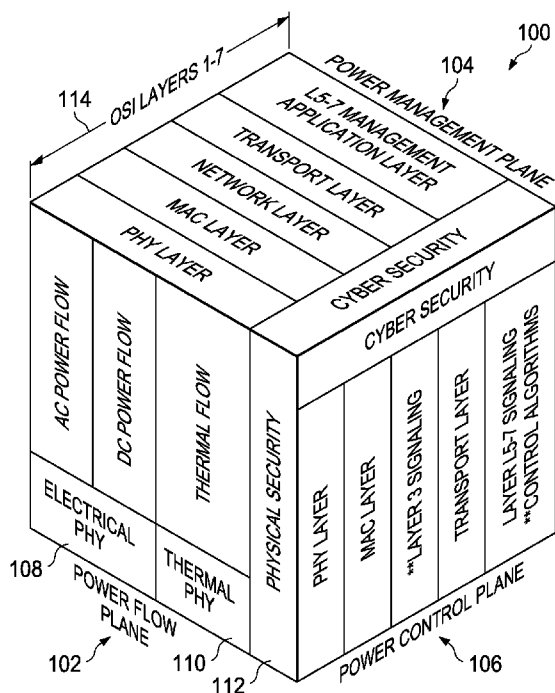


FIG. 1

(57) Abstract: A method and apparatus are present for sending power to a number of loads. A plurality of nodes and a number of lines connected to the plurality of nodes are selected to send electrical power from a number of sources to a number of loads based on a capacity to send the electrical power through the plurality of nodes and the number of lines. The plurality of nodes is configured into a circuit to carry the electrical power from the number of sources to the number of loads using the plurality nodes. The plurality of nodes are controlled to send the electrical power through the circuit to the number of loads using a number of agent processes associated with the plurality of nodes.





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**NETWORK CENTRIC POWER FLOW CONTROL****BACKGROUND INFORMATION****1. Field:**

[0001] The present disclosure relates generally to electrical power and, in particular, to electrical power flow. Still more particularly, the present disclosure relates to a method and apparatus for creating a circuit for transmitting and distributing electrical power.

**2. Background:**

[0002] An electrical power source supplies electrical power to loads. The electrical power source may generate electrical energy from mechanical, chemical, thermal, and/or other types of energy. The electrical power source transmits this electrical energy as electrical power to the loads. A source may also store electrical energy that has been generated previously. Electrical power may be delivered from a number of sources to a number of loads using an electrical power grid. An electrical power grid is comprised of a number of sources, loads, nodes, and power lines. A node is located at a connection of two or more power lines.

[0003] Power lines have impedance. Impedance is a measurement of the opposition to a current flow in a power line. The physical properties of a power line affect the amount of impedance in the power line. In an electrical power grid, this impedance in power lines leads to a loss of power in the electrical power grid. In other words, a portion of the electrical power carried in the power lines is consumed by the power lines.

[0004] In an electrical power grid, different power lines may have different levels of impedance.



Additionally, the impedance of a power line may vary over the course of time. For example, the impedance of a power line decreases in cooler temperatures, such as during winter. The impedance of a power line increases when the power line is in warmer temperatures, such as during summer.

**[0005]** The demand for electrical power varies throughout the course of time. These variations in demand may lead to different amounts of power loss in the electrical power grid, while delivering the same amount of power to a load. Further, the cost of producing electrical power may vary for different electrical power sources and during the course of time.

**[0006]** One commonly used approach for reducing power loss in an electrical power grid is to increase the voltage across a power line. Increasing the voltage across power lines decreases the percentage of electrical power consumed by the power lines and increases the percentage of electrical power distributed to the loads. However, increasing the voltage across power lines may require additional safety precautions. In certain areas, increasing the voltage across power lines may be undesirable.

**[0007]** Currently, organizational boundaries may define the portions of an electrical power grid managed by different electric providers. These electric providers may not have the resources and/or ability to manage the flow of electrical power in the electrical power grid in portions of the electrical power grids across these organizational boundaries. In other words, one electric provider may only have the resources and/or ability to manage the portion of electrical power grids within an organizational boundary.



[0008] Therefore, it would be desirable to have a method and apparatus that may overcome one or more of the issues described above, as well as other possible issues.



**SUMMARY**

[0009] In one advantageous embodiment, an apparatus comprises a number of lines in an electrical power grid, a plurality of nodes in the electrical power grid, a communications network configured to carry information, and a number of agent processes associated with the plurality of nodes. The number of lines is configured to carry electrical power. The plurality of nodes is configured to control the electrical power carried on the number of lines. The number of agent processes is configured to communicate with each other using the communications network, configure the plurality of nodes in the electrical power grid into a circuit, and control a delivery of the electrical power through the circuit to a number of loads associated with the circuit. The circuit is a first circuit and wherein the first circuit shares a line within the number of lines with a second circuit such that a first portion of electrical power in the line is for the first circuit and a second portion of electrical power in the line is for the second circuit. The agent processes associated with nodes in the electrical power grid are configured to select the plurality of nodes from the nodes in the electrical power grid to deliver the electrical power to the number of loads in response to a request for the electrical power from the number of loads. The agent process in the agent processes is configured to send a request for capacity to deliver the electrical power through the nodes in the electrical power grid, receive a number of responses to the request for capacity, and select the plurality of nodes from the nodes in the electrical power grid based on the number of responses. The agent process is a first agent process, and wherein a second agent process



associated with a node in the nodes in the electrical power grid receives the request for capacity sent by the first agent process, identifies a capacity of the node associated with the second agent process, and returns the number of responses to the first agent process. The second agent process in the agent processes associated with the node in the nodes in the electrical power grid sends the request for capacity to a third agent process in the agent processes in response to receiving the request for capacity. The number of agent processes is configured to change a flow of the electrical power in the plurality of nodes in the electrical power grid in response to changes in capacity while delivering the electrical power to the number of loads. The communications network comprises communications links selected from at least one of lines in the electrical power grid, wireless communications links, wired communications links, and fiber optic cables. The number of lines and the plurality of nodes form a power flow circuit in the circuit, wherein the number of agent processes form a power control circuit in the circuit. The apparatus may further comprise a first end point for the circuit; and a second end point for the circuit. The first end point is selected from one of a source in a number of sources and a node in the plurality of nodes, and the second end point is selected from one of a load in the number of loads and a node in the plurality of nodes. The circuit is a virtual power circuit. A control process communicates with the number of agent processes using the communications network to cause the number of agent processes to configure the plurality of nodes in the electrical power grid into the circuit. An agent process in the agent processes includes at least one of a control device interface process, a demand and response system interface process, an optimization process, a



stabilization process, a power flow signaling process, an advertisement process, and a cyber security process. At least one of the number of agent processes is an intelligent power gateway agent process.

**[00010]** In another advantageous embodiment, a method is present for sending power to a number of loads. A plurality of nodes and a number of lines connected to the plurality of nodes are selected to send electrical power from a number of sources to the number of loads based on a capacity to send the electrical power through the plurality of nodes and the number of lines. The plurality of nodes is configured into a circuit to carry the electrical power from the number of sources to the number of loads using the plurality of nodes. The plurality of nodes is controlled to send the electrical power through the circuit to the number of loads using a number of agent processes associated with the plurality of nodes. The plurality of nodes may be configured into a circuit to carry the electrical power from the number of sources to the number of loads using the plurality of nodes and the plurality of nodes may be controlled to send the electrical power through the circuit to the number of loads using a number of agent processes associated with the plurality of nodes. A plurality of nodes and the number of lines connected to the plurality of nodes may be selected to send the electrical power from the number of sources to the number of loads based on the capacity to send the electrical power through the plurality of nodes. The number of lines is responsive to receiving a request for electrical power, identifying the plurality of nodes from nodes in an electrical power grid. A plurality of nodes and the number of lines connected to the plurality of nodes may be selected to send the electrical power from the number of sources to the number of loads based on the capacity to send the



electrical power through the plurality of nodes and the number of lines. A first agent process in the number of agent processes, sends a request for capacity to deliver the electrical power through the plurality of nodes; a number of responses to the request for capacity is receive; and the plurality of nodes from nodes in an electrical power grid is selected based on the number of responses. A second agent process in the number of agent processes, receives the request for capacity; a capacity of a node in the plurality of nodes associated with the second agent process is identified; and a number of responses to the first agent process is returned. In response to receiving the request for capacity, the second agent process sends, the request for capacity to a third agent process in the number of agent processes. Nodes in the plurality of nodes with other nodes in an electrical power grid may be changed in response to detecting changes in the capacity while delivering the electrical power to the number of loads, changing nodes in the plurality of nodes with other nodes in an electrical power grid.

**[00011]** In yet another advantageous embodiment, an apparatus comprises a number of lines in an electrical power grid, a plurality of nodes in the electrical power grid, a communications network configured to carry information, a number of agent processes associated with the plurality of nodes, and a control system. The number of lines is configured to carry electrical power. The plurality of nodes is configured to control the electrical power carried in the number of lines. The number of agent processes is configured to communicate with each other using the communications network, configure the plurality of nodes in the electrical power grid into a circuit, and control a delivery of the electrical power through the circuit to a number of loads



associated with the circuit. The control system is configured to monitor a number of parameters in a number of circuits in the electrical power grid, determine whether to make a change to the number of circuits based on the number of parameters and a policy, and change the number of circuits using the policy in response to a determination to make the change to the number of circuits. The number of agent processes is within a plurality of agent processes, wherein the control system comprises at least a portion of the plurality of agent processes. In changing the number of circuits using the policy, the control system is configured to change a configuration of at least a portion of the plurality of nodes. In changing the number of circuits using the policy, the control system is configured to change a composition of the plurality of nodes in at least one of the number of circuits. In changing the number of circuits using the policy, the control system is configured to add a new circuit to the number of circuits. A number of sensors may be associated with the number of circuits in the electrical power grid, wherein the control system is configured to monitor the number of parameters in the number of circuits in the electrical power grid by receiving the information from the number of sensors. The control system is configured to determine whether to make the change to the number of circuits based on the information received from the number of sensors associated with the number of circuits in the electrical power grid. The number of parameters comprises at least one of a capacity in a line, a temperature in the line, a presence of a voltage having a value greater than a desired level, and a reduction in capacity in the line.

**[00012]** In still yet another advantageous embodiment, a method is present for identifying capacity for power flow



in an electrical power grid. Information about the capacity for power flow is received from a number of sensors in the electrical power grid. The information is stored in a database associated with an agent process in a plurality of agent processes for the electrical power grid. The information is sent to a number of other agent processes within the plurality of agent process. The information is stored in a number of databases associated with the number of other agent processes. A plurality of nodes within nodes in the electrical power grid is selected for delivering the electrical power to a number of loads in the electrical power grid based on the information about the capacity for power flow. The information includes at least one of a capacity, a bus voltage, volts amps reactive, a power flow, a phase of power, and an amount of power consumed. The database and the number of databases are distributed databases located on data processing systems associated with nodes in the electrical power grid.

**[00013]** In another advantageous embodiment, an apparatus comprises a number of sensors in an electrical power grid, an agent process, and a plurality of agent processes. The number of sensors is configured to generate information about a capacity for power flow in the electrical power grid. The agent process is configured to receive the information about the capacity for power flow in the electrical power grid from the number of sensors and store the information about the capacity for power flow in a database associated with the agent process. The plurality of agent processes is configured to receive the information from the agent process and store the information about the capacity for power flow in the electrical power grid in a plurality of databases associated with the plurality of agent processes. Each agent process within the plurality of



agent processes is associated with a database within the plurality of databases. The information for the capacity for power flow is stored in the database and the plurality of databases. At least a portion of the plurality of agent processes select a plurality of nodes within nodes in the electrical power grid for delivering electrical power to a number of loads in the electrical power grid based on the information about the capacity for power flow. The information includes at least one of a capacity, a bus voltage, volts amps reactive, a power flow, a phase of power, and an amount of power consumed. The plurality of databases are distributed databases located on data processing systems associated with nodes in the electrical power grid.

**[00014]** The features, functions, and advantages can be achieved independently in various embodiments of the present disclosure or may be combined in yet other embodiments in which further details can be seen with reference to the following description and drawings.



**BRIEF DESCRIPTION OF THE DRAWINGS**

[00015] The novel features believed characteristic of the advantageous embodiments are set forth in the appended claims. The advantageous embodiments, however, as well as a preferred mode of use, further objectives, and advantages thereof, will best be understood by reference to the following detailed description of an advantageous embodiment of the present disclosure when read in conjunction with the accompanying drawings, wherein:

[00016] **Figure 1** is an illustration of a power model in accordance with an advantageous embodiment;

[00017] **Figure 2** is an illustration of a block diagram of an electrical power environment in accordance with an advantageous embodiment;

[00018] **Figure 3** is an illustration of a block diagram of a plurality of nodes in accordance with an advantageous embodiment;

[00019] **Figure 4** is an illustration of a block diagram of a data processing system in accordance with an advantageous embodiment;

[00020] **Figure 5** is an illustration of an electrical power environment in accordance with an advantageous embodiment;

[00021] **Figure 6** is an illustration of an electrical power environment in accordance with an advantageous embodiment;

[00022] **Figure 7** is an illustration of a control node in accordance with an advantageous embodiment;

[00023] **Figure 8** is an illustration of an agent process in accordance with an advantageous embodiment;

[00024] **Figure 9** is an illustration of an agent process in accordance with an advantageous embodiment;



[00025] **Figure 10** is an illustration of a message flow at a node in accordance with an advantageous embodiment;

[00026] **Figures 11A and 11B** are illustrations of a message flow in an electrical power grid in accordance with an advantageous embodiment;

[00027] **Figure 12** is an illustration of a message flow in an electrical power grid in accordance with an advantageous embodiment;

[00028] **Figure 13** is an illustration of a message flow for terminating a virtual power circuit in accordance with an advantageous embodiment;

[00029] **Figure 14** is an illustration of a flowchart of a process for sending power to a number of loads in accordance with an advantageous embodiment;

[00030] **Figure 15** is an illustration of a flowchart of a process for controlling a number of circuits in an electrical power grid in accordance with an advantageous embodiment;

[00031] **Figure 16** is an illustration of a flowchart of a process for stabilizing power in an electrical power grid in accordance with an advantageous embodiment; and

[00032] **Figure 17** is an illustration of a process for selecting a plurality of nodes for a circuit in accordance with an advantageous embodiment.



**DETAILED DESCRIPTION**

[00033] With reference now to **Figure 1**, an illustration of a power model is depicted in accordance with an advantageous embodiment. In this illustrative example, power model **100** is a three-dimensional power model. Power model **100** may be used to model electrical power in an electrical power grid. More specifically, power model **100** allows power flow, power management, and power control for an electrical power grid to be treated independently of each other.

[00034] As depicted, power model **100** includes power flow plane **102**, power management plane **104**, and power control plane **106**. In this illustrative example, power flow plane **102** includes physical aspects of the flow of electrical power through an electrical power grid. These physical aspects include electrical flow **108**, thermal flow **110**, and physical security **112**.

[00035] In this illustrative example, power management plane **104** and power control plane **106** include layers **114**, which are part of the Open System Interconnection (OSI) model. The Open System Interconnection model is a model of a communications and computer network architecture divided into seven layers.

[00036] Power management plane **104** includes functions performed by a centralized computer system to manage the flow of electrical power in an electrical power grid. For example, a centralized computer system may communicate with the portion of an electrical power grid within a boundary to manage the flow of electrical power within the boundary.

[00037] A boundary provides a separation for portions of an electrical power grid. The boundary may be, for example, a geographical boundary, an organizational



boundary, an administrative boundary, or some other suitable type of boundary. For example, an organizational boundary may separate two portions of an electrical grid managed by two different electric providers.

[00038] Power control plane **106** includes functions performed by components associated with an electrical power grid across multiple organizational boundaries. These components include, for example, processes running on data processing systems associated with the electrical power grid. These processes may communicate autonomously to control the flow of electrical power through the electrical power grid. As used herein, the term "autonomously" means without human control and/or intervention.

[00039] The depiction of power model **100** in **Figure 1** is intended as an illustration and not as an architectural limitation for the different advantageous embodiments.

[00040] The different advantageous embodiments recognize and take into account a number of different considerations. For example, the different advantageous embodiments recognize and take into account that electrical power loss occurs in power lines of an electrical power grid. The different advantageous embodiments also recognize and take into account that using some portions of an electrical power grid to transfer electrical power may result in less electrical power loss than using other portions.

[00041] Further, the different advantageous embodiments recognize that it may be desirable to consume electrical power from selected sources in certain situations. These situations include, for example, a cost associated with a particular source, environmental preferences, and/or other types of situations.



**[00042]** The different advantageous embodiments recognize that currently, the flow of electrical power in an electrical power grid may not be controlled across organizational boundaries. Further, the different advantageous embodiments recognize and take into account that currently, portions of an electrical power grid are managed by operations centers. Each operations center may include a centralized computer system that manages the portions of the electrical power within an organizational boundary.

**[00043]** The different advantageous embodiments recognize and take into account that a network configured to allow components in an electrical power grid across organizational boundaries to communicate autonomously with each other is desirable. This type of communication allows the components in the electrical power grid to have control over the flow of electrical power without requiring input from the operations centers.

**[00044]** Thus, the different advantageous embodiments provide a method and apparatus for network centric power flow control. In one advantageous embodiment, an apparatus comprises a number of lines in an electrical power grid, a plurality of nodes in the electrical power grid, a communications network configured to carry information, and a number of agent processes associated with the plurality of nodes. The number of lines is configured to carry electrical power. The plurality of nodes is configured to control the electrical power carried on the number of lines. The number of agent processes is configured to communicate with each other using the communications network, configure the plurality of nodes in the electrical power grid into a circuit, and control a delivery of the electrical power through the circuit to a number of loads associated with the circuit.



[00045] With reference now to **Figure 2**, an illustration of a block diagram of an electrical power environment is depicted in accordance with an advantageous embodiment. In this illustrative example, electrical power environment **200** includes electrical power grid **202** and communications network **204**. Electrical power grid **202** is configured for use with power flow plane **102** in **Figure 1**. Communications network **204** is configured for use with power management plane **104** and/or power control plane **106** in **Figure 1**.

[00046] As depicted in this example, electrical power grid **202** includes number of sources **206**, number of loads **208**, lines **210**, and nodes **212**. Electrical power grid **202** is configured to deliver electrical power **214** from number of sources **206** to number of loads **208**. Lines **210** may be used to deliver electrical power **214** from number of sources **206** to number of loads **208**. In this illustrative example, lines **210** take the form of transmission lines. More specifically, lines **210** take the form of electrical power lines.

[00047] Two or more lines in lines **210** are connected at a node in nodes **212**. Nodes **212** transfer electrical power **214** carried in one line in lines **210** to one or more other lines in lines **210**. Nodes **212** include at least one of a line sensor, a cooperative flexible alternating current transmission system device, an electronic filter, a phase shifter, a transformer, an adapter, a processor unit, and/or other suitable devices.

[00048] As used herein, the phrase "at least one of", when used with a list of items, means that different combinations of one or more of the listed items may be used and only one of each item in the list may be needed. For example, "at least one of item A, item B, and item C" may include, for example, without limitation, item A or item A and item B. This example also may include item A,



item B, and item C, or item B and item C. In other examples, "at least one of" may be, for example, without limitation, two of item A, one of item B, and 10 of item C; four of item B and seven of item C; and other suitable combinations.

[00049] In these depicted examples, lines **210** and nodes **212** are interconnected in electrical power grid **202**. In other words, the flow of electrical power **214** through at least one of lines **210** and/or at least one of nodes **212** may affect the flow of electrical power **214** through other lines **210** and/or nodes **212**. Further, the devices within a node in nodes **212** may affect the flow of electrical power **214** through other nodes **212**.

[00050] In these illustrative examples, communications network **204** is associated with electrical power grid **202**. A first component may be considered to be associated with a second component by being secured to the second component, bonded to the second component, fastened to the second component, and/or connected to the second component in some other suitable manner. For example, a first component may be connected to a second component through wires, wirelessly, or in some other manner. The first component also may be connected to the second component by a third component. The first component also may be considered to be associated with the second component by being part of and/or an extension of the second component.

[00051] Communications network **204** includes data processing systems **216** and communications links **223**. Data processing systems **216** are associated with nodes **212**. As one example, data processing systems **216** may be connected by wires to nodes **212**. In these illustrative examples, each data processing system in data processing systems **216** is associated with a node in nodes **212**. In



other illustrative examples, only a portion of nodes **212** may be associated with data processing systems **216**.

[00052] Agent processes **218** run on data processing systems **216**. Agent processes **218** are software processes in the form of program code. Agent processes **218** are associated with at least a portion of nodes **212**. This portion may be some or all of nodes **212**.

[00053] In these illustrative examples, each of agent processes **218** runs on a different one of data processing systems **216** in these illustrative examples. In this manner, each agent process in agent processes **218** is associated with a node in nodes **212**.

[00054] In these depicted examples, when a node in nodes **212** is associated with an agent process in agent processes **218**, the node is referred to as control node **213**. In some illustrative examples, a node in nodes **212** may be associated with more than one agent process in agent processes **218**. For example, a data processing system in data processing systems **216** associated with a node in nodes **212** may run more than one of agent processes **218**.

[00055] Communications network **204** allows the exchange of information between agent processes **218** running on data processing systems **216**. Further, communications network **204** allows the exchange of information between a number of processes running on data processing system **219** and agent processes **218**. In these examples, data processing system **219** may be part of operations center **235**. Operations center **235** may be located outside of electrical power grid **202**. An operator at operations center **235** may monitor and/or control the flow of electrical power **214** through electrical power grid **202** using communications network **204**.

[00056] This exchange of information in communications network **204** occurs using communications links **223** in



communications network **204**. For example, agent processes **218** communicate with each other using communications links **223** in communications network **204**.

[00057] Communications links **223** may include at least one of lines **210**, wireless communications links **225**, wired communications links **227**, fiber optic cables **229**, and other suitable communications links. Further, communications network **204** may include other types of devices, such as, for example, without limitation, switches, routers, and other suitable types of communications devices. In these depicted examples, communications network **204** may be implemented using an Internet Protocol (IP) network.

[00058] Agent processes **218** running on data processing systems **216** are part of control system **221** in electrical power environment **200**. In other illustrative examples, control system **221** may include other processes running on other data processing systems. These other data processing systems may be located within and/or outside of electrical power grid **202**. For example, control system **221** may include data processing system **219** in operations center **235**.

[00059] In these illustrative examples, control system **221** is configured to control the flow of electrical power **214** through electrical power grid **202** using agent processes **218**. More specifically, each agent process in agent processes **218** controls the flow of electrical power through the node in nodes **212** associated with the agent process.

[00060] In these illustrative examples, agent processes **218** in control system **221** communicate with each other using communications network **204** to form circuit **220**. Circuit **220** is virtual power circuit **222** in these examples. Virtual power circuit **222** includes power flow circuit **242** and power control circuit **244**. Power flow



circuit **242** is formed within electrical power grid **202**. Further, power flow circuit **242** operates within power flow plane **102** in **Figure 1**. Power control circuit **244** is formed within communications network **204**. Power control circuit **244** operates within power control plane **106** in **Figure 1**.

[00061] Power flow circuit **242** is formed in electrical power grid **202** by first end point **230**, second end point **232**, plurality of nodes **224** in nodes **212**, and number of lines **233** in lines **210**. First end point **230** may be selected from one of a source in number of sources **206** and a node in plurality of nodes **224**. Second end point **232** may be selected from one of a load in number of loads **208** and a node in plurality of nodes **224**.

[00062] First end point **230**, second end point **232**, and plurality of nodes **224** are connected by number of lines **233** in lines **210**. Virtual power circuit **222** carries portion **231** of electrical power **214** in electrical power grid **202** in number of lines **233** in these examples. Portion **231** may be some or all of electrical power **214**, depending on the configuration of virtual power circuit **222**.

[00063] Power flow circuit **242** in virtual power circuit **222** may share components with a number of other power flow circuits in electrical power grid **202**. As one illustrative example, power flow circuit **242** may share at least a portion of number of lines **233** with another power flow circuit.

[00064] For example, a portion of the electrical power flowing in number of lines **233** may or may not have a same starting point as another portion of the electrical power flowing in number of lines **233**. Further, a portion of the electrical power flowing in number of lines **233** may or may not be delivered to a same ending point as another portion of the electrical power flowing in number of



lines **233**. These different portions of electrical power flowing in number of lines **233** may be indistinguishable from each other. Further, these different portions of electrical power flowing in number of lines **233** may be indistinguishable in power flow plane **102** in **Figure 1**.

[00065] In these depicted examples, plurality of nodes **224** is selected by agent processes **218** as a group. For example, one, some, or all of agent processes **218** selects plurality of nodes **224**. In other words, plurality of nodes **224** for virtual power circuit **222** is selected by at least a portion of agent processes **218** in control system **221**. At least a portion of agent processes **218** communicates with each other to identify number of agent processes **226** in agent processes **218** associated with plurality of nodes **224**.

[00066] Number of agent processes **226** runs on number of data processing systems **228** associated with plurality of nodes **224**. Number of agent processes **226** running on number of data processing systems **228** forms power control circuit **244** in virtual power circuit **222**.

[00067] In these examples, the locations of number of data processing systems **228** in power control circuit **244** may follow the locations of plurality of nodes **224** in power flow circuit **242** in electrical power grid **202**. In other words, power control circuit **244** may mirror power flow circuit **242** in these examples.

[00068] Number of agent processes **226** configures plurality of nodes **224** to be part of power flow circuit **242** in virtual power circuit **222**. This configuring of plurality of nodes **224** may be based on a number of policies for number of agent processes **226**. In some examples, an agent process in number of agent processes **226** may use more than one policy.

[00069] Further, the configuring of plurality of nodes **224** includes using communications network **204** to select



number of lines **233** and reserve a capacity in number of lines **233** for the delivery of portion **231** of electrical power **214** through plurality of nodes **224**. Number of agent processes **226** in power control circuit **244** monitors and controls the delivery and flow of portion **231** of electrical power **214** through number of lines **233** and plurality of nodes **224** in power flow circuit **242**.

[00070] A line in a power flow circuit may carry different flows of electrical power **214** for different power flow circuits formed within electrical power grid **202**. Different power control circuits within communications network **204** allow these different flows of electrical power **214** carried in the line to be distinguished from each other in power control plane **106** in **Figure 1**. In other words, each power control circuit monitors and controls the flow of electrical power **214** for a particular power flow circuit.

[00071] The illustration of electrical power environment **200** in **Figure 2** is not meant to imply physical or architectural limitations to the manner in which different advantageous embodiments may be implemented. Other components in addition to and/or in place of the ones illustrated may be used. Some components may be unnecessary in some advantageous embodiments. Also, the blocks are presented to illustrate some functional components. One or more of these blocks may be combined and/or divided into different blocks when implemented in different advantageous embodiments.

[00072] For example, control process **238** in control system **221** may run on data processing system **219** located outside of electrical power grid **202**. Control process **238** may communicate with agent processes **218** through wireless communications links **225**. Control process **238** may select number of agent processes **226** in agent



processes **218** for power control circuit **244**. Further, control process **238** may send commands to number of agent processes **226** to configure plurality of nodes **224** to be part of power flow circuit **242**.

[00073] In yet other advantageous embodiments, agent processes **218** may be run on processor units **240** in nodes **212**. For example, processor units **240** may be part of devices in nodes **212**.

[00074] With reference now to **Figure 3**, an illustration of a block diagram of a plurality of nodes is depicted in accordance with an advantageous embodiment. In this illustrative example, plurality of nodes **300** is an example of one implementation for plurality of nodes **224** in **Figure 2**. Plurality of nodes **300** is part of a circuit in an electrical power grid, such as circuit **220** in electrical power grid **202** in **Figure 2**.

[00075] As depicted, plurality of nodes **300** includes node **302**. Node **302** is located at the connection of power line **301** and power line **303**. Node **302** includes line sensor **306**, line sensor **307**, control device **308**, control device **309**, and processor unit **310**. Line sensor **306** and control device **308** are located on power line **301**. Line sensor **307** and control device **309** are located on power line **303**.

[00076] In this illustrative example, processor unit **310** may be implemented in a number of different devices, such as a data processing system, a node, a sensor, or some other suitable device. For example, the data processing system may be a data processing system in data processing systems **216** in **Figure 2**. Examples of processor unit **310** include a digital signal processor, a controller, a central processing unit, a multi-core processor, or some other similar type of hardware component. Processor unit **310** is configured for



communications with line sensor **306**, line sensor **307**, control device **308**, and control device **309**.

[00077] In this depicted example, agent process **318** runs on processor unit **310**. Agent process **318** monitors, tracks, and controls the flow of electrical power **316** through node **302**. Agent process **318** includes a number of processes. These processes include at least one of control device interface process **321**, demand and response system interface process **323**, optimization process **325**, stabilization process **327**, power flow signaling process **329**, advertisement process **331**, cyber security process **333**, and other processes.

[00078] Different agent processes associated with plurality of nodes **300** may be configured to perform different operations, depending on the processes within the different agent processes. For example, some agent processes may be configured to perform only a single operation, while other agent processes may be configured to perform four or five different types of operations.

[00079] When agent process **318** includes control device interface process **321**, demand and response system interface process **323**, optimization process **325**, stabilization process **327**, power flow signaling process **329**, advertisement process **331**, and cyber security process **333**, agent process **318** is referred to as intelligent power gateway agent process **320**.

[00080] Intelligent power gateway agent process **320** may have more memory, more computing resources, and faster data transmission rates as compared to other types of agent processes. Intelligent power gateway agent process **320** may be in selected locations in an electrical power grid. These locations are selected to reduce latencies in the exchanging information, optimize data use, coordinate nodes in plurality of nodes **300** for load-



balancing, and reduce the bandwidth used in exchanging of information.

[00081] In this illustrative example, line sensor 306 and line sensor 307 are configured to send information 319 about a number of parameters for power line 301 and power line 303, respectively, to agent process 318.

Information 319 includes, for example, capacity for the power line, voltage, and/or other suitable information. A capacity for the power line may be a thermal capacity. Further, this capacity may vary with respect to time.

[00082] Information 319 may be sent to agent process 318 using a communications network, such as communications network 204 in **Figure 2**. Information 319 is sent to agent process 318 in response to an event. This event may be, for example, without limitation, a request for information 319, the elapsing of a period of time, a beginning of a cycle in a signal, or some other suitable event. A request for information 319 may be made in response to a request for a service received by agent process 318. The service may include, for example, without limitation, translation of data, generation of alerts, providing of an interface for exchanging information, and/or other suitable operations.

[00083] Agent process 318 makes determinations about the flow of electrical power through node 302 using information 319. Agent process 318 sends commands 322 to control device 308 and/or control device 309 based on these determinations. Control device 308 and control device 309 are cooperative flexible alternating current transmission system (FACTS) devices in this illustrative example. Control device 308 and control device 309 are configured to change the flow of electrical power 316 through node 302 in response to receiving commands 322.

[00084] In this illustrative example, agent process 318 stores information 319 in database 324 in processor unit



**310.** Database **324** is a collection of information. Further, database **324** may be comprised of a number of processes and/or interfaces for accessing the collection of information.

[00085] Database **324** may be updated with information **319** when information **319** is received by agent process **318**. In other illustrative examples, database **324** may be updated based on an event. The event may be, for example, without limitation, the elapsing of a period of time, receiving a request for an update to database **324**, or some other suitable event.

[00086] Database **324** is distributed database **341** in these examples. Distributed database **341** contains information for other nodes in plurality of nodes **300** in addition to node **302**. Distributed database **341** may be associated with all or part of plurality of nodes **300** in this illustrative example. For example, agent process **318** may send information **319** stored in distributed database **341** in node **302** to other agent processes in other nodes in plurality of nodes **300**. These other agent processes may store information **319** in databases associated with these other nodes. These databases are substantially the same as distributed database **341** in these illustrative examples.

[00087] Further, in these illustrative examples, distributed database **341** may be distributed across organizational boundaries. In this manner, at least a portion of the agent processes for plurality of nodes **300** may exchange information across organizational boundaries to create and/or update distributed database **341**.

[00088] As one illustrative example, agent process **326** runs on processor unit **328** associated with node **330** in plurality of nodes **300**. Agent process **326** receives information **332** and stores information **332** in database **324** in processor unit **328**. Agent process **326** also sends



information **332** to agent process **318** using a communications network, such as communications network **204** in **Figure 2**. Agent process **318** then stores information **332** in database **324** stored in processor unit **310**. In this manner, plurality of nodes **300** may autonomously update database **324**.

[00089] Information is stored in database **324** based on a number of factors. These factors may include, for example, without limitation, the type of information, the quality of information, a length of time for storage, the availability of storage space in database **324**, and other suitable factors. The storage of information **319** in database **324** also may be based on a latency and/or throughput of the communications network used by the different agent processes.

[00090] In these illustrative examples, the agent processes associated with plurality of nodes **300** exchange information using standard TCP/IP network protocols. However, in some illustrative examples, the agent processes may exchange information using mobile objects. These mobile objects are program code containing information. This information may include information for the node, such as capacity information, routing information, and/or other suitable information. This information may also include, for example, program code for a new process, new rules and/or policies, software upgrades, and/or other suitable types of information.

[00091] The mobile objects may be sent to agent process **318** from an operations center. Agent process **318** reads the mobile object and stores the information within the mobile object. The mobile object clones itself. Agent process **318** sends these clones to other agent processes.

[00092] The illustration of plurality of nodes **300** in **Figure 3** is not meant to imply physical or architectural limitations to the manner in which different advantageous



embodiments may be implemented. Other components in addition to and/or in place of the ones illustrated may be used. Some components may be unnecessary in some advantageous embodiments. Also, the blocks are presented to illustrate some functional components. One or more of these blocks may be combined and/or divided into different blocks when implemented in different advantageous embodiments.

[00093] For example, in some advantageous embodiments, processor unit **310** may be part of data processing system **334**. Data processing system **334** may be connected to node **302** instead of being included in node **302**. In other advantageous embodiments, processor unit **310** may be part of control device **308** and/or control device **309** in node **302**.

[00094] In other advantageous embodiments, power lines, in addition to power line **301** and power line **303**, may be connected to node **302**.

[00095] In yet other illustrative examples, sensors in addition to or in place of line sensor **306** and/or line sensor **307** may be associated with power line **301** and/or power line **303**. These sensors may be configured to detect parameters, such as, for example, without limitation, temperature, current flow, power phase, line tension, a location for the power lines, and/or other suitable parameters for the power lines.

[00096] In some illustrative examples, database **324** may be in a storage device connected to plurality of nodes **300**. For example, database **324** may be in a storage device that may be accessed by agent process **318** and other agent processes associated with other nodes in plurality of nodes **300** using wireless communications links.

[00097] Turning now to **Figure 4**, an illustration of a block diagram of a data processing system is depicted in



accordance with an advantageous embodiment. In this illustrative example, data processing system **400** may be used to implement a data processing system in data processing systems **216** in **Figure 2** and/or processor unit **310** in **Figure 3**. Data processing system **400** includes communications fabric **402**, which provides communications between processor unit **404**, memory **406**, persistent storage **408**, communications unit **410**, input/output (I/O) unit **412**, and display **414**.

[00098] Processor unit **404** serves to execute instructions for software that may be loaded into memory **406**. Processor unit **404** may be a set of one or more processors or may be a multi-processor core, depending on the particular implementation. Further, processor unit **404** may be implemented using one or more heterogeneous processor systems in which a main processor is present with secondary processors on a single chip. As another illustrative example, processor unit **404** may be a symmetric multi-processor system containing multiple processors of the same type.

[00099] Memory **406** and persistent storage **408** are examples of storage devices **416**. A storage device is any piece of hardware that is capable of storing information, such as, for example, without limitation, data, program code in functional form, and/or other suitable information either on a temporary basis and/or a permanent basis. Memory **406**, in these examples, may be, for example, a random access memory or any other suitable volatile or non-volatile storage device. Persistent storage **408** may take various forms, depending on the particular implementation. For example, persistent storage **408** may contain one or more components or devices. For example, persistent storage **408** may be a hard drive, a flash memory, a rewritable optical disk, a rewritable magnetic tape, or some combination of the



above. The media used by persistent storage **408** may be removable. For example, a removable hard drive may be used for persistent storage **408**.

[000100] Communications unit **410**, in these examples, provides for communication with other data processing systems or devices. In these examples, communications unit **410** is a network interface card. Communications unit **410** may provide communications through the use of either or both physical and wireless communications links.

[000101] Input/output unit **412** allows for the input and output of data with other devices connected to data processing system **400**. For example, input/output unit **412** may provide a connection for user input through a keyboard, a mouse, and/or some other suitable input device. Further, input/output unit **412** may send output to a printer. Display **414** provides a mechanism to display information to a user.

[000102] Instructions for the operating system, applications, and/or programs may be located in storage devices **416**, which are in communication with processor unit **404** through communications fabric **402**. In these illustrative examples, the instructions are in a functional form on persistent storage **408**. These instructions may be loaded into memory **406** for execution by processor unit **404**. The processes of the different embodiments may be performed by processor unit **404** using computer implemented instructions, which may be located in a memory, such as memory **406**.

[000103] These instructions are referred to as program code, computer usable program code, or computer readable program code that may be read and executed by a processor in processor unit **404**. The program code in the different embodiments may be embodied on different physical or



computer readable storage media, such as memory **406** or persistent storage **408**.

[000104] Program code **418** is located in a functional form on computer readable media **420** that is selectively removable and may be loaded onto or transferred to data processing system **400** for execution by processor unit **404**. Program code **418** and computer readable media **420** form computer program product **422**. In one example, computer readable media **420** may be computer readable storage media **424** or computer readable signal media **426**. Computer readable storage media **424** may include, for example, an optical or magnetic disk that is inserted or placed into a drive or other device that is part of persistent storage **408** for transfer onto a storage device, such as a hard drive, that is part of persistent storage **408**. Computer readable storage media **424** also may take the form of a persistent storage, such as a hard drive, a thumb drive, or a flash memory, that is connected to data processing system **400**. In some instances, computer readable storage media **424** may not be removable from data processing system **400**.

[000105] Alternatively, program code **418** may be transferred to data processing system **400** using computer readable signal media **426**. Computer readable signal media **426** may be, for example, a propagated data signal containing program code **418**. For example, computer readable signal media **426** may be an electromagnetic signal, an optical signal, and/or any other suitable type of signal. These signals may be transmitted over communications links, such as wireless communications links, an optical fiber cable, a coaxial cable, a wire, and/or any other suitable type of communications link, as well as power lines. In other words, the communications link and/or the connection may be physical or wireless in the illustrative examples.



[000106] In some illustrative embodiments, program code **418** may be downloaded over a network to persistent storage **408** from another device or data processing system through computer readable signal media **426** for use within data processing system **400**. For instance, program code stored in a computer readable storage medium in a server data processing system may be downloaded over a network, such as, for example, communication network **204** in **Figure 2**. This program code may be downloaded from the server to data processing system **400**. The data processing system providing program code **418** may be a server computer, a client computer, or some other device capable of storing and transmitting program code **418**.

[000107] The different components illustrated for data processing system **400** are not meant to provide architectural limitations to the manner in which different embodiments may be implemented. The different advantageous embodiments may be implemented in a data processing system including components in addition to or in place of those illustrated for data processing system **400**.

[000108] Other components shown in **Figure 4** can be varied from the illustrative examples shown. The different embodiments may be implemented using any hardware device or system capable of executing program code. As one example, data processing system **400** may include organic components integrated with inorganic components and/or may be comprised entirely of organic components excluding a human being. For example, a storage device may be comprised of an organic semiconductor.

[000109] As another example, a storage device in data processing system **400** is any hardware apparatus that may store data. Memory **406**, persistent storage **408**, and



computer readable media **420** are examples of storage devices in a tangible form.

[000110] In another example, a bus system may be used to implement communications fabric **402** and may be comprised of one or more buses, such as a system bus or an input/output bus. Of course, the bus system may be implemented using any suitable type of architecture that provides for a transfer of data between different components or devices attached to the bus system. Additionally, a communications unit may include one or more devices used to transmit and receive data, such as a modem or a network adapter. Further, a memory may be, for example, memory **406** or a cache, such as found in an interface and memory controller hub that may be present in communications fabric **402**.

[000111] With reference now to **Figure 5**, an illustration of an electrical power environment is depicted in accordance with an advantageous embodiment. In this illustrative example, electrical power environment **500** is an example of one implementation for electrical power environment **200** in **Figure 2**. Electrical power environment **500** includes electrical power grid **502**. Electrical power grid **502** is an example of one implementation for electrical power grid **202** in **Figure 2**.

[000112] In this illustrative example, electrical power grid **502** has boundary **504**. Boundary **504** separates portion **506** of electrical power grid **502** from portion **508** of electrical power grid **502**. Further, boundary **504** prevents coordinated power management of portion **506** and portion **508**. For example, boundary **504** may be a geographical boundary, an organizational boundary, an administrative boundary, or some other suitable type of boundary.

[000113] As one illustrative example, portion **506** of electrical power grid **502** may be managed by operations



center **507**, while portion **508** of electrical power grid **502** may be managed by operations center **510**. Operations center **507** and operations center **510** may not be able to coordinate power management for electrical power grid **502** in this example.

[000114] As depicted, operations center **507** may include data processing system **509** operated by operator **511**. Operations center **510** may include data processing system **513** operated by operator **515**. In this illustrative example, electrical power grid **502** includes generator **512** and load **514**. Generator **512** is an example of one implementation for a source in number of sources **206** in **Figure 2**. Load **514** is an example of one implementation for a load in number of loads **208**. Load **514** may be a home, a factory, a business, an appliance, or some other suitable type of load. Electrical power grid **502** is configured to deliver power supplied by generator **512** to load **514**.

[000115] Electrical power grid **502** also includes nodes **516**, **518**, **520**, **522**, **524**, and **526** along with power lines **528**, **530**, **532**, **534**, **536**, **538**, **540**, **542**, **544**, and **545**. Nodes **516**, **518**, **520**, **522**, **524**, and **526** include control devices **517**, **519**, **521**, **523**, **525**, and **527**. These control devices are cooperative flexible alternating current transmission system (FACTS) devices in this illustrative example. However, in other illustrative examples, these control devices may be power semiconductor devices or other suitable types of devices.

[000116] Further, node **516** includes line sensor **529** located on power line **530** and line sensor **531** located on power line **532**. Node **518** includes line sensor **533** located on power line **534** and line sensor **535** located on power line **538**. Node **520** includes line sensor **572** located on power line **536** and line sensor **537** located on power line **540**. Node **522** includes line sensor **539**



located on power line 542. Node 524 includes line sensor 541 located on power line 544.

[000117] In this illustrative example, nodes 516, 518, 520, 522, 524, and 526 are connected to data processing systems 546, 548, 550, 552, 554, and 556, respectively. Agent processes 558, 560, 562, 564, 566, and 568 run on data processing systems 546, 548, 550, 552, 554, and 556, respectively. These agent processes control the flow of electrical power through nodes 516, 518, 520, 522, 524, and 526. In particular, the agent processes use a number of policies to control the flow of electrical power through the nodes.

[000118] Agent processes 558, 560, 562, 564, 566, and 568 may communicate autonomously with each other using communications links, such as communications links 223 in **Figure 2**. These communications links are power lines 528, 530, 532, 534, 536, 538, 540, 542, 544, and 545 in this illustrative example. In particular, these communications links take the form of broadband over power lines. Agent processes 558, 560, 562, 564, 566, and 568 communicate with each other to form virtual power circuit 570.

[000119] Virtual power circuit 570 includes power flow circuit 571 and power control circuit 573. Power flow circuit 571 includes generator 512, node 516, node 518, node 524, node 526, load 514, and power lines 528, 530, 532, 538, 542, and 544. Power lines 528, 530, 532, 538, 542, and 544 connect generator 512, node 516, node 518, node 524, node 526, and load 514. Power flow circuit 571 in virtual power circuit 570 is configured to deliver electrical power from generator 512 to load 514.

[000120] Power control circuit 573 in virtual power circuit 570 includes agent processes 558, 560, 564, and 568 associated with nodes 516, 518, 524, and 526, respectively. Power control circuit 573 monitors and



controls the flow of electrical power from generator 512 through nodes 516, 518, 524, and 526, and to load 514.

[000121] In this illustrative example, agent process 558 and agent process 568 are configured to perform a greater number of operations than agent processes 560, 562, 564, and 566. For example, agent process 558 and agent process 568 may be intelligent power gateway agent processes, such as intelligent power gateway agent process 320 in **Figure 3**.

[000122] In this depicted example, agent process 558 and agent process 568 may exchange information with operations center 507 and operations center 510, respectively. This exchange of information allows operator 511 at operations center 507 and operator 515 at operations center 510 to manage portion 506 and portion 508, respectively, of electrical power grid 502 using agent process 558 and agent process 568, respectively.

[000123] Further, virtual power circuit 570 includes components from both portion 506 and portion 508 of electrical power grid 502. Different agent processes within power control circuit 573 in virtual power circuit 570 are selected to exchange information across boundary 504.

[000124] For example, agent process 560 and agent process 564 are selected to exchange information across boundary 504. Agent process 562 and agent process 566 are selected to exchange information across boundary 504. In these illustrative examples, these agent processes exchange information to create and/or update a distributed database, such as distributed database 341 in **Figure 3**.

[000125] With reference now to **Figure 6**, an illustration of an electrical power environment is depicted in accordance with an advantageous embodiment. In this illustrative example, electrical power environment 600 is



an example of one implementation of electrical power environment 200 in **Figure 2**. Electrical power environment 600 includes electrical power grid 602.

[000126] In this illustrative example, electrical power grid 602 includes generator 604, generator 605, generator 606, load 608, load 610, node 612, node 614, node 616, node 618, power line 620, power line 622, power line 624, power line 626, power line 628, power line 630, power line 632, power line 634, and power line 635.

[000127] Nodes 612, 614, 616, and 618 include control devices 613, 615, 617, and 619, respectively. These control devices are cooperative flexible alternating current transmission devices in this example. Further, node 612 includes line sensor 621 located on power line 624 and line sensor 623 located on power line 626. Node 614 includes line sensor 625 located on power line 628. Node 616 includes line sensor 627 located on power line 630. Node 618 includes line sensor 629 located on power line 632 and power line 634.

[000128] As depicted in this example, nodes 612, 614, 616, and 618 are connected to data processing systems 636, 638, 640, and 642. Agent processes 644, 646, 648 and 650 run on data processing systems 636, 638, 640, and 642, respectively. Agent processes 644, 646, 648 and 650 are associated with nodes 612, 614, 616, and 618, respectively. These agent processes control the flow of electrical power through the nodes.

[000129] Further, agent processes 644, 646, 648 and 650 communicate autonomously with each other using communications network 652. Communications network 652 is an example of one implementation for communications network 204 in **Figure 2**. Communications network 652 provides communications through wireless communications links in this illustrative example.



[000130] Generators 604, 605, and 606 may also use communications network 652 to communicate with agent processes 644, 646, 648 and/or 650. Line sensors 621, 623, 625, 627, and 629 use communications network 652 to exchange information with agent processes 644, 646, 648 and 650.

[000131] A number of virtual power circuits may be formed in electrical power grid 602 to provide power supplied by at least one of generators 604, 605, and 606 to at least one of load 608 and load 610. For example, first virtual power circuit 660 may include generator 605, load 608, load 610, node 612, node 614, node 618, power line 622, power line 624, power line 628, power line 632, and power line 634. Agent processes 644, 646, and 650 configure nodes 612, 614, and 618 to be in first virtual power circuit 660.

[000132] Second virtual power circuit 662 may include generator 604, load 608, load 610, node 612, node 616, node 618, power line 620, power line 626, and power line 630. Agent processes 644, 648, and 650 configure nodes 612, 616, and 618 to be in the virtual power circuit 662.

[000133] Third virtual power circuit 664 may include generator 604, load 608, load 610, node 612, node 616, node 618, power line 620, power line 626, and power line 630. Agent processes 644, 648, and 650 configure nodes 612, 616, and 618 to be in third virtual power circuit 664. As depicted, power line 620, power line 626, and power line 630 carry flows of electrical power for both second virtual power circuit 662 and third virtual power circuit 664.

[000134] The flow of electrical power is different in second virtual power circuit 662 and in third virtual power circuit 664. A first portion of the electrical power flowing in power lines 620, 626, and 630 is for second virtual power circuit 662. A second portion of



the electrical power flowing in power lines **620**, **626**, and **630** is for third virtual power circuit **664**. However, these portions of electrical power in power lines **620**, **626**, and **630** for each of these virtual power circuits are indistinguishable in power flow plane **102** in **Figure 1**.

[000135] Agent processes **644**, **648**, and **650** in second virtual power circuit **662** and in third virtual power circuit **664** are able to distinguish between these flows of electrical power through power lines **620**, **626**, and **630**. Further, agent processes **644**, **648**, and **650** track, monitor, and control these multiple flows of electrical power. In this manner, virtual power circuits may be used to load balance the flow of electrical power through electrical power grid **602**.

[000136] The illustrations of electrical power environment **500** in **Figure 5** and electrical power environment **600** in **Figure 6** are not meant to imply physical or architectural limitations to the manner in which different advantageous embodiments may be implemented. For example, in some advantageous embodiments, communications network **652** may provide communications through the power lines in electrical power grid **502**. In other words, information may be exchanged using these power lines rather than wireless communications links.

[000137] With reference now to **Figure 7**, an illustration of a control node is depicted in accordance with an advantageous embodiment. In this illustrative example, control node **700** is an example of one implementation of a node in nodes **212** in **Figure 2**. Further, control node **700** is an example of one implementation for node **302** in **Figure 3**.

[000138] As depicted in this example, power line **701** and power line **703** are connected at control node **700**. Control node **700** includes line sensor **702**, line sensor



704, control device 706, control device 708, switch 710, and processor unit 712 in this illustrative example.

Agent process 713 runs on processor unit 712.

[000139] Line sensor 702 and control device 706 are located on power line 701. Line sensor 704 and control device 708 are located on power line 703. Control device 706 and control device 708 are cooperative flexible alternating current transmission system (FACTS) devices in this illustrative example.

[000140] Line sensor 702 and line sensor 704 are configured to sense a number of parameters for power line 701 and power line 703, respectively. These parameters may include, for example, without limitation, electrical power capacity, temperature, current flow, power phase, line tension, a location of the power lines, and other suitable parameters for the power lines. In these examples, line sensor 702 and line sensor 704 are configured to store information for the number of parameters.

[000141] In this illustrative example, switch 710 allows line sensor 702, line sensor 704, control device 706, control device 708, and agent process 713 running on processor unit 712 to communicate with each other within control node 700. For example, line sensor 702 and line sensor 704 are configured to send the information for the number of parameters for power line 701 and power line 703, respectively, to processor unit 712 through switch 710.

[000142] In this illustrative example, agent process 713 running on processor unit 712 receives the information for the number of parameters sent from line sensor 702 and line sensor 704 through switch 710. Agent process 713 sends commands to control device 706 and/or control device 708 based on the information received.



[000143] In these illustrative examples, agent process **713** may make determinations about whether the flow of electrical power through power line **701** and/or power line **703** is within a desired threshold. Based on these determinations, agent process **713** may send commands to control device **706** and/or control device **708** to control the flow of electrical power through node **700**.

[000144] In this illustrative example, agent process **713** running on processor unit **712** may exchange information with other agent processes associated with other control nodes. Exchanging information includes at least one of sending and receiving information. For example, agent process **713** may send information to agent process **715** running on processor unit **714** and/or agent process **717** running on processor unit **716**. Processor unit **714** and processor unit **716** are each associated with a different control node.

[000145] In this depicted example, the information exchanged between agent process **713**, agent process **715**, and/or agent process **717** may be stored in a distributed database, such as distributed database **341** in **Figure 3**.

[000146] In other illustrative examples, processor unit **712** may not be in control node **700**. For example, processor unit **712** may be implemented in a data processing system connected to control node **700**.

[000147] With reference now to **Figure 8**, an illustration of an agent process is depicted in accordance with an advantageous embodiment. In this illustrative example, agent process **800** is an example of one implementation for an agent process in agent processes **218** in **Figure 2** and/or agent process **318** in **Figure 3**. Further, agent process **800** may be part of a virtual power circuit, such as virtual power circuit **222** in **Figure 2**.

[000148] Agent process **800** includes power control plane interface **802**, power management plane interface **804**, and



power flow plane interface **806**. These interfaces may be, for example, Ethernet interfaces. Power control plane interface **802** allows communications between agent process **800** and other agent processes in an electrical power grid. Power management plane interface **804** allows communications between agent process **800** and an operations center. Power flow plane interface **806** allows communications between agent process **800** and the devices included in a node associated with agent process **800**. The devices in the node may include, for example, a number of cooperative flexible alternating current transmission system devices, a number of line sensors, and other suitable devices.

[000149] Agent process **800** includes power flow signaling process **808**, advertisement process **810**, optimization process **812**, stabilization process **814**, and demand and response interface process **816**. These processes allow agent process **800** to perform operations within power control plane **106** in **Figure 1**.

[000150] In this illustrative example, power flow signaling process **808** sends request for capacity **818** to a control device in the node associated with agent process **800** using power flow plane interface **806**. The control device may be, for example, cooperative flexible alternating current transmission system devices. The control device sends message **820** to power flow signaling process **808** to indicate that the request will be granted.

[000151] Power flow signaling process **808** also sends and/or receives requests for capacity **822** to and/or from other agent processes. Further, power flow signaling process **808** sends and/or receives messages **824** to and/or from other agent processes indicating that requests for capacity **822** will be granted. These agent processes are associated with nodes that may be, for example, along a path between a power source and a load.



[000152] Advertisement process **810** receives information **826** from the line sensor. Advertisement process **810** stores information **826** in a database, such as distributed database **341** in **Figure 3**. Further, advertisement process **810** sends advertisement **828** to other agent processes. Advertisement **828** includes information **826**. The other agent processes may then store information **826** in substantially similar databases. Information **826** may include, for example, without limitation, a capacity of a power line connected to the node associated with agent process **800**, bus voltage, power flow, phase angle, and/or other suitable information.

[000153] In this illustrative example, optimization process **812** receives traffic engineering data **830** from advertisement process **810**. Traffic engineering data **830** includes at least a portion of information **826** in this example, as well as other suitable information. For example, traffic engineering data **830** includes the power flow through and capacity of lines connected to the node associated with agent process **800**, as well as other suitable information.

[000154] Optimization process **812** also receives virtual power circuit path information **832** from the other agent processes associated with other nodes. Virtual power circuit path information **832** includes information, such as, for example, the power flow through and capacity for other nodes and lines not part of the virtual power circuit in which agent process **800** is included.

[000155] Optimization process **812** uses traffic engineering data **830** and virtual power circuit path information **832** to optimize the flow of electrical power through an electrical power grid. For example, optimization process **812** may provision the node associated with agent process **800** to be in a virtual power circuit. This virtual power circuit is used to



load balance power flow within the electrical power grid such that the flow of electrical power through the power lines in the electrical power grid is not greater than a capacity for the power lines.

[000156] Further, this optimization of the flow of electrical power by optimization process **812** reduces power loss within the electrical power grid, reduces a cost of delivering power within the electrical power grid, and reduces congestion in the electrical power grid. Further, this optimization also protects the control devices from operating outside of safety thresholds and increases power flow relative to the capacity of the electrical power grid. In these examples, a cost is a financial cost.

[000157] Optimization process **812** exchanges optimization information **834** with power flow signaling process **808**. Power flow signaling process **808** may use optimization information **834** to configure the node associated with agent process **800** for optimization of the virtual power circuit. Further, optimization process **812** also sends optimization information **836** to the other agent processes in the virtual power circuit. The other agent processes may then use optimization information **836** to configure the other nodes associated with the other agent processes for optimization.

[000158] Optimization information **836** may include, for example, a configuration for a number of virtual power circuits in the electrical power grid that uses the capacity of the power lines in the electrical power grid with a desired efficiency.

[000159] Stabilization process **814** receives stability information **838** from the number of devices in the node associated with agent process **800**. Stability information **838** may include values for a number of parameters for the number of devices. For example, stability information



**838** may include voltage data, volts amps reactive (VAr) data, and other suitable types of data for the node.

[000160] For example, stability information **838** may indicate the presence of undesired fluctuations in the distribution of electrical power through the node. Commands **840** may be sent to a control device in the node to configure the control device to maintain a substantially desired distribution of electrical power through the node.

[000161] Further, stabilization process **814** also sends stability information **839** to advertisement process **810**. Advertisement process **810** may store stability information **838** in the database. Further, advertisement process **810** may send stability information **839** to the other agent processes to be stored in the substantially similar databases.

[000162] Demand and response interface process **816** communicates with an operations center, such as operations center **507** and/or operations center **510** in **Figure 5**. This communication is through power management plane interface **804**. An operator at the operations center may send request **842** for information to demand and response interface process **816**. This information may be from the number of devices in the node and/or from other devices in other nodes. Demand and response interface process **816** sends message **844** to indicate that request **842** will be granted.

[000163] Demand and response interface process **816** sends request for capacity **846** to power flow signaling process **808**. In response to receiving request for capacity **846**, power flow signaling process **808** sends request for capacity **818** to a control device in the node associated with agent process **800** and requests for capacity **822** to other agent processes. In particular, requests for capacity **822** are sent to a number of agent processes



along a path between a power source and a load in the electrical power grid. This number of agent processes may be used to configure the nodes associated with the number of agent processes to be in a virtual power circuit.

[000164] In this depicted example, the node associated with agent process **800** and the nodes associated with the number of agent processes send message **820** and messages **824**, respectively, to power flow signaling process **808**. These messages indicate that request for capacity **818** and requests for capacity **824** will be granted. In other words, these messages indicate that the nodes are available and have the capacity to be part of the virtual power circuit.

[000165] In response to receiving message **820** and messages **824**, power flow signaling process **808** sends message **847** to demand and response interface process **816** indicating that the request for the information will be granted.

[000166] In some illustrative examples, agent process **800** takes the form of an intelligent power gateway agent process, such as intelligent power gateway agent process **320** in **Figure 3**. In these examples, demand and response interface process **816** is used to exchange information with other intelligent power gateway agent processes.

[000167] For example, demand and response interface process **816** may send request for power **850** to another intelligent power gateway agent process through power control plane interface **802**. Demand and response interface process **816** receives message **852** from this intelligent power gateway agent process through power control plane interface **802** acknowledging request for power **850**.

[000168] In this illustrative example, power flow signaling process **808** also sends information **848** to the



operations center using power management plane interface **804**. Information **848** is for the health and status of the virtual power circuit.

[000169] With reference now to **Figure 9**, an illustration of an agent process is depicted in accordance with an advantageous embodiment. In this illustrative example, agent process **900** is an example of one implementation for an agent process in agent processes **218** in **Figure 2** and/or agent process **318** in **Figure 3**. As depicted in this example, agent process **900** includes power control plane interface **902**, power management plane interface **904**, and power flow plane interface **906**. These interfaces may be, for example, Ethernet interfaces.

[000170] Agent process **900** also includes power management process **908**, cyber security process **910**, physical security process **912**, and modeling/simulation interface process **914**. These processes allow agent process **900** to perform operations in power management plane **104** in **Figure 1**. Further, these processes, in this illustrative example, may be only a portion of the processes in agent process **900**.

[000171] Power management process **908** sends commands and status requests **916** to a number of devices in the node associated with agent process **900**. Commands and status requests **916** are for health and status information for the number of devices in the node associated with agent process **900**. The number of devices sends responses **918** to power management process **908**. Responses **918** include the requested health and status information in these examples. Power management process **908** may also receive commands and status requests **920** from an operations center. In response to commands and status requests **920**, power management process **908** sends status information and responses **922** to the operations center.



[000172] Cyber security process 910 sends cyber security information 924 to other agent processes and receives cyber security information 925 from the other agent processes. Cyber security information 924 may include logs, alerts, security events, passwords, rules, thresholds, policies, and/or other suitable types of information. Further, cyber security process 910 receives commands and status requests 926 from the operations center. Cyber security process 910 sends cyber security information 928 to the operations center. Cyber security information 928 may include logs, alerts, security events, and/or other suitable types of information.

[000173] Physical security process 912 sends commands and status requests 930 to a number of devices in the node associated with agent process 900. Physical security process 912 receives physical security information 932 from the number of devices in the node. For example, commands and status requests 930 may be sent to a camera in the node. The camera may send back video in physical security information 932.

[000174] Further, physical security process 912 receives commands and status requests 934 from the operations center. Physical security process 912 sends physical security information 936 to the operations center. Physical security information 936 includes logs, physical security events, alerts, and/or other suitable information.

[000175] Modeling/simulation interface process 914 may perform simulations for the node associated with agent process 900. These simulations may be for a distribution of electrical power in the node.

[000176] Modeling/simulation interface process 914 receives request 938 from the operations center. Request 938 may be for information generated by running the



simulations for the node. Modeling/simulation interface process **914** sends information **940** to the operations center.

[000177] In some illustrative examples, the processes in agent process **900** and the processes in agent process **800** in **Figure 8** may be processes associated with the same node. For example, agent process **800** and agent process **900** may both run on a processor unit in a node.

[000178] The processes in agent process **900** and the processes in agent process **800** in **Figure 8** may exchange information and/or work together to perform operations. For example, cyber security process **910** in agent process **900** may be used with advertisement process **810** in agent process **800**.

[000179] As a more specific example, advertisement **828** may be sent from advertisement process **810** in agent process **800** to other agent processes only after cyber security information **924** is sent by cyber security process **910** in agent process **900** to the other agent processes. In this manner, the other agent processes may verify the node associated with agent process **900** and agent process **800**.

[000180] With reference now to **Figure 10**, an illustration of a message flow for advertising and changing the capacity at a node is depicted in accordance with an advantageous embodiment. The message flow illustrated in **Figure 10** may be implemented at a node, such as node **302** in **Figure 3** and/or node **700** in **Figure 7**.

[000181] In this illustrative example, the message flow is for devices in the node. These devices include first line sensor **1001**, second line sensor **1002**, first agent process **1004**, first control device interface **1006**, second control device interface **1008**, second agent process **1010**, first control device **1012**, and second control device **1014**. First control device **1012** and second control



device **1014** are cooperative flexible alternating current transmission system devices in this example. Further, first control device interface **1006** and second control device interface **1008** are located on first control device **1012** and second control device **1014**, respectively.

[000182] First line sensor **1001** senses a change in the capacity for a first power line (step **1020**). This capacity is a thermal capacity for the first power line. First line sensor **1001** reports the change in the capacity to agent process **1004** (message **1022**). First agent process **1004** updates a database, such as distributed database **341** in **Figure 3**, with the change in the capacity (step **1024**). First agent process **1004** then advertises the change in the capacity to second agent process **1010** (message **1026**).

[000183] Second line sensor **1002** senses a change in the capacity for a second power line (step **1028**). Second line sensor **1002** reports the change in the capacity to first agent process **1004** (message **1030**). First agent process **1004** updates the database with the change in the capacity (step **1032**). First agent process **1004** then advertises the change in the capacity to second agent process **1010** (message **1034**).

[000184] In this illustrative example, first agent process **1004** calculates a configured capacity for a new flow of electrical power through the node associated with agent process **1004** (step **1036**). The configured capacity is different from the capacity for a power line. The capacity for the power line is a measured thermal capacity for the power line. The configured capacity is calculated for a desired flow of electrical power through each power line connected at the node. In other words, the configured capacity may be calculated to override the measured thermal capacity for the power line.



[000185] First agent process **1004** sends commands for first control device **1012** for the configured capacity to first control device interface **1006** (message **1037**). First control device interface **1006** sends these commands to first control device **1012** (message **1038**). First control device **1012** implements the changes for the configured capacity to provide the desired flow of electrical power in the first power line (step **1040**). First control device **1012** sends a response to first control device interface **1006** indicating that the changes have been made (message **1042**). First control device interface **1006** sends the response from first control device **1012** to first agent process **1004** (message **1044**).

[000186] First agent process **1004** sends commands for second control device **1014** for the configured capacity to second control device interface **1008** (message **1046**). Second control device interface **1008** sends these commands to second control device **1014** (message **1048**). Second control device **1014** implements the changes for the configured capacity to provide the desired flow of electrical power in the first power line (step **1050**). Second control device **1014** sends a response to second control device interface **1008** indicating that the changes have been made (message **1052**). Second control device interface **1008** sends the response from second control device **1014** to first agent process **1004** (message **1054**).

[000187] With reference now to **Figures 11A** and **11B**, illustrations of a message flow for forming a virtual power circuit in an electrical power grid is depicted in accordance with an advantageous embodiment. The message flow illustrated in **Figures 11A** and **11B** may be implemented in an electrical power grid, such as electrical power grid **202** in **Figure 2** and/or electrical power grid **502** in **Figure 5**.



[000188] The virtual power circuit includes generator **1100**, load **1118**, and a first, second, third, and fourth node located between generator **1100** and load **1118** in an electrical power grid. This configuration for the virtual power circuit is an example of one implementation for a virtual power circuit, such as virtual power circuit **222** in **Figure 2**. The different components in the virtual power circuit are connected power lines.

[000189] First agent process **1102** and first control device **1104** are associated with a first node connected to generator **1100**. Second agent process **1106** and second control device **1108** are associated with a second node connected to the first node and to a third node. Third agent process **1110** and third control device **1112** are associated with the third node connected to the second node and a fourth node. Fourth agent process **1114** and fourth control device **1116** are associated with the fourth node connected to the third node and load **1118**.

[000190] First agent process **1102** and fourth agent process **1114** are intelligent power gateway agent processes in this illustrative example.

[000191] A message indicating a change in load **1118** is sent to fourth agent process **1114** from load **1118** (message **1120**). In response to the change in load **1118**, fourth agent process **1114** sends a request for electrical power to first agent process **1102** (message **1122**). First agent process **1102** sends a response to fourth agent process **1114** acknowledging the request (message **1123**).

[000192] First agent process **1102** sends a request for capacity to first control device **1104** (message **1124**). A request for capacity is a request to determine whether a node has a desired capacity for electrical power. In this illustrative example, the desired capacity is to allow the requested power to be delivered to load **1118**. First control device **1104** sends a response to first agent



process **1102** indicating that the first node has the desired capacity (message **1126**).

[000193] First agent process **1102** sends a request for capacity to second agent process **1106** (message **1128**). Second agent process **1106** sends the request for capacity to second control device **1108** (message **1130**). Second control device **1108** sends a response to second agent process **1106** indicating that the second node has the desired capacity (message **1132**).

[000194] Second agent process **1106** sends a request for capacity to third agent process **1110** (message **1134**). Third agent process **1110** sends the request for capacity to third control device **1112** (message **1136**). Third control device **1112** sends a response to third agent process **1110** indicating that the third node has the desired capacity (message **1138**).

[000195] Third agent process **1110** sends a request for capacity to fourth agent process **1114** (message **1140**). Fourth agent process **1114** sends the request for capacity to fourth control device **1116** (message **1142**). Fourth control device **1116** sends a response to fourth agent process **1114** indicating that the fourth node has the desired capacity (message **1144**).

[000196] Fourth agent process **1114** sends a response to third agent process **1110** granting the request for capacity (message **1146**). Third agent process **1110** sends a confirmation of the capacity to third control device **1112** (message **1148**). Third control device **1112** provisions the third node for the virtual power circuit (step **1150**). Third control device **1112** sends information for the virtual power circuit to third agent process **1110** (message **1152**). Further, third agent process **1110** advertises the capacity for the third node to the other agent processes (step **1154**).



[000197] Third agent process **1110** sends a response to second agent process **1106** granting the request for capacity (message **1156**). Second agent process **1106** sends a confirmation of the capacity to second control device **1108** (message **1158**). Second control device **1108** provisions the second node for the virtual power circuit (step **1160**). Second control device **1108** sends information for the virtual power circuit to second agent process **1106** (message **1162**). Further, second agent process **1106** advertises the capacity for the second node to the other agent processes (step **1164**).

[000198] Second agent process **1106** sends a response to first agent process **1102** granting the request for capacity (message **1166**). First agent process **1102** sends a confirmation of the capacity to first control device **1104** (step **1168**). First control device **1104** provisions the first node for the virtual power circuit (step **1170**). First control device **1104** sends information for the virtual power circuit to first agent process **1102** (message **1172**). First agent process **1102** advertises the capacity for the first node to the other agent processes (step **1173**).

[000199] After all the nodes in the virtual power circuit are provisioned for the virtual power circuit, first agent process **1102** then sends a command to generator **1100** to begin generating the requested electrical power (message **1174**). Generator **1100** begins generating the requested electrical power (step **1176**).

[000200] In this illustrative example, the request for power is generated in response to a change in load **1118**. However, in other illustrative examples, the request for power may be received from an operations center.

[000201] With reference now to **Figure 12**, an illustration of a message flow denying the formation of a virtual power circuit in an electrical power grid is



depicted in accordance with an advantageous embodiment. The message flow illustrated in **Figure 12** may be implemented in an electrical power grid, such as electrical power grid **202** in **Figure 2** and/or electrical power grid **502** in **Figure 5**.

[000202] An electrical power grid includes load **1200**, generator **1202**, a first node, a second node, a third node, and a fourth node. The first node is associated with first agent process **1204** and includes first control device **1206**. The second node is associated with second agent process **1208** and includes second control device **1210**. The third node is associated with third agent process **1212** and includes third control device **1214**. The fourth node is associated with fourth agent process **1216** and includes fourth control device **1218**.

[000203] In this illustrative example, a message indicating a load change at load **1200** is sent to fourth agent process **1216** (message **1219**). Fourth agent process **1216** sends a request for power to first agent process **1204** (message **1220**). First agent process **1204** sends a response to fourth agent process **1216** acknowledging the request (message **1222**).

[000204] First agent process **1204** sends a request for capacity to first control device **1206** (message **1224**). First control device **1206** sends a response to first agent process **1204** indicating that the first node has the desired capacity (message **1226**).

[000205] First agent process **1204** sends a request for capacity to second agent process **1208** (message **1228**). Second agent process **1208** sends the request for capacity to second control device **1210** (message **1230**). Second control device **1210** sends a response to second agent process **1208** indicating that the second node has the desired capacity for electrical power (message **1232**).



[000206] Second agent process **1208** sends a request for capacity to third agent process **1212** (message **1234**). Third agent process **1212** sends the request for capacity to third control device **1214** (message **1236**). Third control device **1214** sends a response to third agent process **1212** indicating that the third node does not have the desired capacity for electrical power (message **1238**).

[000207] Third agent process **1212** sends a response to second agent process **1208** denying the request for capacity (message **1240**). Second agent process **1208** sends a response to first agent process **1204** denying the request for capacity (message **1242**). First agent process **1204** sends a response to fourth agent process **1216** denying the request for power (message **1244**).

[000208] With reference now to **Figure 13**, an illustration of a message flow for terminating a virtual power circuit in an electrical power grid is depicted in accordance with an advantageous embodiment. The message flow illustrated in **Figure 13** may be implemented in an electrical power grid, such as electrical power grid **202** in **Figure 2** and/or electrical power grid **502** in **Figure 5**. Further, the virtual power circuit terminated may be, for example, virtual power circuit **222** in **Figure 2** and/or virtual power circuit **570** in **Figure 5**.

[000209] The virtual power circuit includes generator **1300**, load **1301**, a first node, a second node, a third node, and a fourth node. The first node is associated with first agent process **1302** and includes first control device **1304**. The second node is associated with second agent process **1306** and includes second control device **1308**. The third node is associated with third agent process **1310** and includes third control device **1312**. The fourth node is associated with fourth agent process **1314** and includes fourth control device **1316**.



[000210] As depicted in this example, a message indicating a load change in load **1301** is sent from load **1301** to fourth agent process **1314** (message **1318**). Fourth agent process **1314** sends a request to stop a flow of electrical power to first agent process **1302** (message **1319**). First agent process **1302** sends a response to fourth agent process **1314** acknowledging the request (message **1320**).

[000211] First agent process **1302** sends a request to generator **1300** to stop supplying electrical power to the virtual power circuit (message **1321**). In other words, the request is to tear down the virtual power circuit. In this illustrative example, tearing down the virtual power circuit involves freeing the capacity at the first node, the second node, the third node, and the fourth node and/or stopping the supply of electrical power by generator **1300**.

[000212] Generator **1300** stops supplying electrical power to the virtual power circuit (step **1322**). Generator **1300** sends a response to first agent process **1302** indicating that the supplying of electrical power has been stopped (message **1324**).

[000213] First agent process **1302** sends a command to first control device **1304** to make available the capacity in a power line carrying the electrical power (message **1326**). First control device **1304** sends a confirmation to first agent process **1302** that the capacity has been made available (message **1328**). First agent process **1302** sends a request to second agent process **1306** to tear down the virtual power circuit (message **1330**).

[000214] Second agent process **1306** sends a command to second control device **1308** to make available the capacity in a power line carrying the electrical power (message **1332**). Second control device **1308** sends a confirmation to second agent process **1306** that the capacity has been



made available (message **1334**). Second agent process **1306** sends a request to third agent process **1310** to tear down the virtual power circuit (message **1336**).

[000215] Third agent process **1310** sends a command to third control device **1312** to make available the capacity in a power line carrying the electrical power (message **1338**). Third control device **1312** sends a confirmation to third agent process **1310** that the capacity has been made available (message **1340**). Third agent process **1310** sends a request to fourth agent process **1314** to tear down the virtual power circuit (message **1342**).

[000216] Fourth agent process **1314** sends a command to fourth control device **1316** to make available the capacity in a power line carrying the electrical power (message **1344**). Fourth control device **1316** sends a confirmation to fourth agent process **1314** that the capacity has been made available (message **1346**).

[000217] The sending of an advertisement by fourth agent process **1314** for the capacity in the power line carrying the electrical power is triggered (step **1348**). This advertisement is sent to a database, such as distributed database **341** in **Figure 3**.

[000218] Fourth agent process **1314** sends a response to third agent process **1310** indicating that the fourth node is no longer part of the virtual power circuit (message **1350**). The sending of an advertisement by third agent process **1310** for the capacity in the power line carrying the electrical power is triggered (step **1352**). Third agent process **1310** sends a response to second agent process **1306** indicating that the third and fourth nodes are no longer part of the virtual power circuit (message **1354**).

[000219] The sending of an advertisement by second agent process **1306** for the capacity in the power line carrying the electrical power is triggered (step **1356**). Second



agent process **1306** sends a response to first agent process **1302** indicating that the second, third, and fourth nodes are no longer part of the virtual power circuit (message **1358**).

[000220] In this manner, the flow of electrical power from generator **1300** to load **1301** through the first, second, third, and fourth nodes is stopped.

[000221] With reference now to **Figure 14**, an illustration of a flowchart of a process for sending power to a number of loads is depicted in accordance with an advantageous embodiment. The process illustrated in **Figure 14** may be implemented in an electrical power environment, such as electrical power environment **200** in **Figure 2** and/or electrical power environment **500** in **Figure 5**.

[000222] The process begins by selecting a plurality of nodes and a number of lines connected to the plurality of nodes to send electrical power from a number of sources to a number of loads based on a capacity to send power through the plurality of nodes and the number of lines (operation **1400**). The number of sources, the number of loads, the plurality of nodes, and the number of lines are components within an electrical power grid, such as electrical power grid **202** in **Figure 2**.

[000223] Thereafter, the process configures the plurality of nodes into a circuit (operation **1402**). In operation **1402**, the circuit is a virtual power circuit. Further, the circuit is used to carry the electrical power from the number of sources to the number of loads. In this illustrative example, the number of loads is associated with the circuit. For example, the number of loads may be part of the circuit, connected to the circuit, and/or associated with the circuit in some other suitable manner.



[000224] The process then controls the plurality of nodes to send the electrical power through the circuit to the number of loads using a number of agent processes associated with the plurality of nodes (operation **1404**), with the process terminating thereafter. In operation **1404**, the number of agent processes may be implemented using agent process **318** in **Figure 3**.

[000225] With reference now to **Figure 15**, an illustration of a flowchart of a process for controlling a number of circuits in an electrical power grid is depicted in accordance with an advantageous embodiment. The process illustrated in **Figure 15** may be implemented in an electrical power environment, such as electrical power environment **200** in **Figure 2**. Further, this process may be implemented in electrical power environment **600** in **Figure 6**.

[000226] The process begins by monitoring a number of parameters in a number of circuits in an electrical power grid (operation **1500**). In operation **1500**, monitoring may include receiving information for the number of parameters from sensors associated with the number of circuits in the electrical power grid. The number of parameters includes, for example, without limitation, a capacity in a line, a temperature in a line, a presence of a voltage having a value greater than a desired level, and a reduction in a capacity in a line.

[000227] Each circuit in the number of circuits includes a number of lines and a plurality of nodes in the electrical power grid. The number of lines is configured to carry electrical power to a number of loads. The plurality of nodes is configured to control the electrical power carried in the number of lines.

[000228] The plurality of nodes is associated with a number of agent processes. The number of agent processes is configured to communicate with each other using a



communications network, such as communications network **204** in **Figure 2**. The number of agent processes configures the plurality of nodes in the electrical power grid into a circuit in the number of circuits. The number of agent processes also controls a delivery of the electrical power through the circuit in the number of circuits to the number of loads.

[000229] Thereafter, the process determines whether to make a change to the number of circuits based on the number of parameters and a policy (operation **1502**). The process then changes the number of circuits using the policy in response to a determination to make the change to the number of circuits (operation **1504**), with the process terminating thereafter.

[000230] In operation **1504**, the number of circuits may be changed in a number of different ways. For example, changing the number of circuits may involve changing a configuration of at least a portion of the plurality of nodes for at least one circuit in the number of circuits. In other examples, changing the number of circuits may involve adding a new circuit to the number of circuits. The number of circuits is changed using a number of agent processes, such as number of agent processes **226** in **Figure 2**, for example.

[000231] With reference now to **Figure 16**, an illustration of a flowchart of a process for stabilizing power in an electrical power grid is depicted in accordance with an advantageous embodiment. The process illustrated in **Figure 16** may be implemented in an electrical power grid in an electrical power environment, such as electrical power grid **202** in electrical power environment **200** in **Figure 2**. Further, this process is used to change the configuration of a plurality of nodes in a virtual power circuit in response to changes in capacity for the plurality of nodes.



[000232] The process begins by selecting a plurality of nodes and a number of lines connected to the plurality of nodes in an electrical power grid to send electrical power from a number of sources to a number of loads based on a capacity to send the electrical power through the plurality of nodes and the number of lines (operation **1600**).

[000233] Thereafter, the process configures the plurality of nodes into a circuit with the number of lines to carry the electrical power in the number of lines from the number of sources to the number of loads using the plurality of nodes (operation **1602**). This circuit is a virtual power circuit in this illustrative example.

[000234] The process then monitors parameters for the number of lines in the circuit (operation **1604**). In operation **1604**, monitoring includes receiving information for the parameters from sensors associated with the circuit in the electrical power grid. The parameters for the number of lines in the power grid may include at least one of a frequency of a current flowing in the number of lines, a phase of power carried in the number of lines, an amount of power consumed by the number of lines, and a voltage drop across the number of loads.

[000235] Thereafter, the process then determines whether the parameters exceed threshold tolerances (operation **1606**). In operation **1606**, the determination may be made by a number of agent processes, such as number of agent processes **226** in **Figure 2**, for example.

[000236] The process then adjusts the configuration of the plurality of nodes in response to determining that the parameters exceed threshold tolerances (operation **1608**), with the process terminating thereafter.

[000237] In operation **1608**, the configuration of the plurality of nodes may be adjusted in a number of



different ways. For example, adjusting the configuration of the plurality of nodes may involve replacing nodes in the plurality of nodes in the circuit with other nodes in the power grid. In another example, adjusting the configuration of the plurality of nodes may involve adjusting the configuration of a control device, such as control device 308 or control device 309 in **Figure 3**.

[000238] With reference now to **Figure 17**, an illustration of a process for selecting a plurality of nodes for a circuit is depicted in accordance with an advantageous embodiment. The process illustrated in **Figure 17** may be implemented in electrical power environment 200 in **Figure 2**, electrical power environment 500 in **Figure 5**, and/or electrical power environment 600 in **Figure 6**.

[000239] The process begins by receiving a request for electrical power at a node in an electrical power grid (operation 1700). In operation 1700, the request is received by an agent process, such as agent process 318 in **Figure 3**, associated with the node. The process then accesses a database for nodes in the electrical power grid (operation 1702). In operation 1702, the database may be, for example, distributed database 341 in **Figure 3**.

[000240] The database contains information, such as, for example, an identifier for each node in the electrical power grid, a location of each node in the electrical power grid, a capacity for electrical power in one or more lines connected at each node in the electrical power grid, security alerts, logs of events occurring at each node in the electrical power grid, and/or other suitable information. The database contains this information for at least one of a current state of each node and a previous state for each node.



[000241] The database is shared by all of the nodes in the electrical power grid. For example, the database may be stored in a processor unit in each node in the nodes in the electrical power grid. An agent process running on the processor unit may access the database. Further, agent processes running on the nodes in the electrical power grid may update the database based on an event. This event may be, for example, the elapsing of a period of time.

[000242] The process then uses the information in the database to select a plurality of nodes in the electrical power grid to form a circuit (operation 1704). In operation 1704, the agent process receiving the request in operation 1700 makes this selection based on the amount of power requested and the capacity of the node to carry the requested electrical power.

[000243] Thereafter, the process configures the plurality of nodes into the circuit to deliver the requested electrical power (operation 1706), with the process terminating thereafter. In operation 1706, the configuration of the plurality of nodes is performed by a number of agent processes associated with the plurality of nodes.

[000244] The flowcharts and block diagrams in the different depicted embodiments illustrate the architecture, functionality, and operation of some possible implementations of apparatus and methods in different advantageous embodiments. In this regard, each block in the flowcharts or block diagrams may represent a module, segment, function, and/or a portion of an operation or step. In some alternative implementations, the function or functions noted in the block may occur out of the order noted in the figures. For example, in some cases, two blocks shown in succession may be executed substantially concurrently, or the blocks may



sometimes be executed in the reverse order, depending upon the functionality involved. Also, other blocks may be added in addition to the illustrated blocks in a flowchart or block diagram.

**[000245]** The different advantageous embodiments can take the form of an entirely hardware embodiment, an entirely software embodiment, or an embodiment containing both hardware and software elements. Some embodiments are implemented in software, which includes, but is not limited to, forms, such as, for example, firmware, resident software, and microcode.

**[000246]** Furthermore, the different embodiments can take the form of a computer program product accessible from a computer usable or computer readable medium providing program code for use by or in connection with a computer or any device or system that executes instructions. For the purposes of this disclosure, a computer usable or computer readable medium can generally be any tangible apparatus that can contain, store, communicate, propagate, or transport the program for use by or in connection with the instruction execution system, apparatus, or device.

**[000247]** The computer usable or computer readable medium can be, for example, without limitation, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, or a propagation medium. Non-limiting examples of a computer readable medium include a semiconductor or solid state memory, magnetic tape, a removable computer diskette, a random access memory (RAM), a read-only memory (ROM), a rigid magnetic disk, and an optical disk. Optical disks may include compact disk - read only memory (CD-ROM), compact disk - read/write (CD-R/W), and DVD.

**[000248]** Further, a computer usable or computer readable medium may contain or store a computer readable or usable



program code such that when the computer readable or usable program code is executed on a computer, the execution of this computer readable or usable program code causes the computer to transmit another computer readable or usable program code over a communications link. This communications link may use a medium that is, for example, without limitation, physical or wireless.

**[000249]** A data processing system suitable for storing and/or executing computer readable or computer usable program code will include one or more processors coupled directly or indirectly to memory elements through a communications fabric, such as a system bus. The memory elements may include local memory employed during actual execution of the program code, bulk storage, and cache memories, which provide temporary storage of at least some computer readable or computer usable program code to reduce the number of times code may be retrieved from bulk storage during execution of the code.

**[000250]** Input/output or I/O devices can be coupled to the system either directly or through intervening I/O controllers. These devices may include, for example, without limitation, keyboards, touch screen displays, and pointing devices. Different communications adapters may also be coupled to the system to enable the data processing system to become coupled to other data processing systems, remote printers, or storage devices through intervening private or public networks. Non-limiting examples are modems and network adapters and are just a few of the currently available types of communications adapters.

**[000251]** The description of the different advantageous embodiments has been presented for purposes of illustration and description and is not intended to be exhaustive or limited to the embodiments in the form disclosed. Many modifications and variations will be



apparent to those of ordinary skill in the art. Further, different advantageous embodiments may provide different advantages as compared to other advantageous embodiments. The embodiment or embodiments selected are chosen and described in order to best explain the principles of the embodiments, the practical application, and to enable others of ordinary skill in the art to understand the disclosure for various embodiments with various modifications as are suited to the particular use contemplated.



**CLAIMS:**

What is claimed is:

1. An apparatus comprising:
  - a number of lines (233) in an electrical power grid (202), wherein the number of lines (210) is configured to carry electrical power;
  - a plurality of nodes (224) in the electrical power grid (202), wherein the plurality of nodes (224) is configured to control the electrical power (214) carried on the number of lines (233);
  - a communications network (204) configured to carry information; and
  - a number of agent processes (226) associated with the plurality of nodes (224), wherein the number of agent processes (226) is configured to communicate with each other using the communications network (204), configure the plurality of nodes (224) in the electrical power grid (202) into a circuit (220), and control a delivery of the electrical power (214) through the circuit to a number of loads (208) associated with the circuit (220).
2. The apparatus of claim 1, wherein the circuit (220) is a first circuit (242, 662) and wherein the first circuit (242, 662) shares a line within the number of lines (233) with a second circuit (664) such that a first portion (231) of electrical power (214) in the line is for the first circuit and a second portion of electrical power (214) in the line is for the second circuit (244, 664).
3. The apparatus of claim 1, wherein agent processes (218) associated with nodes (212) in the electrical power grid (202) are configured to select the plurality of



nodes (224) from the nodes (212) in the electrical power grid (202) to deliver the electrical power (214) to the number of loads (208) in response to a request for the electrical power (214) from the number of loads (208).

4. The apparatus of claim 3, wherein an agent process (318) in the agent processes (218) is configured to send a request for capacity (818, 1128, 1224) to deliver the electrical power (214) through the nodes (212) in the electrical power grid (202), receive a number of responses (1132, 1242), to the request for capacity, and select the plurality of nodes (224) from the nodes (212) in the electrical power grid (202) based on the number of responses (1166).

5. The apparatus of claim 4, wherein the agent process (318) is a first agent process (1102, 1204), and wherein a second agent process (1106, 1206) associated with a node (330) in the nodes (212) in the electrical power grid (202) receives the request for capacity (1128, 1224) sent by the first agent process (1102, 1204), identifies a capacity of the node (330) associated with the second agent process (1106, 1204), and returns the number of responses (1132) to the first agent process (1102, 1204).

6. The apparatus of claim 5, wherein the second agent process (1106, 1204) in the agent processes associated with the node (330) in the nodes (212) in the electrical power grid (202, 502) sends the request for capacity (1134, 1234) to a third agent process (1110, 1212) in the agent processes (218) in response to receiving the request for capacity (1134, 1234).

7. The apparatus of claim 1, wherein the number of agent processes (226) is configured to change a flow of



the electrical power in the plurality of nodes (224) in the electrical power grid (202) in response to changes in capacity while delivering the electrical power (214) to the number of loads (208).

8. The apparatus of claim 1, wherein the communications network (204) comprises communications links (223) selected from at least one of lines (210) in the electrical power grid (202), wireless communications links (225), wired communications links (227), and fiber optic cables (229).

9 The apparatus of claim 1, wherein the number of lines (233) and the plurality of nodes (224) form a power flow circuit (242) in the circuit (220), and wherein the number of agent processes (226) form a power control circuit (244) in the circuit (220).

10. The apparatus of claim 1 further comprising:  
a first end point (230) for the circuit (220); and  
a second end point (232) for the circuit (220).

11. The apparatus of claim 10, wherein the first end point (230) is selected from one of a source in a number of sources (206) and a node in the plurality of nodes (224), and the second end point (232) is selected from one of a load in the number of loads (208) and a node in the plurality of nodes (224).

12. The apparatus of claim 1, wherein the circuit is a virtual power circuit (222).

13. The apparatus of claim 3, wherein a control process (238) communicates with the number of agent processes (226) using the communications network (204) to cause the



number of agent processes (226) to configure the plurality of nodes (224) in the electrical power grid (202) into the circuit (220).

14. The apparatus of claim 3, wherein an agent process (318) in the agent processes (218) includes at least one of a control device interface process (321), a demand and response system interface process (323), an optimization process (325), a stabilization process (327), a power flow signaling process (329), an advertisement process (331), and a cyber security process (333).

15. The apparatus of claim 3, wherein at least one of the number of agent processes (226) is an intelligent power gateway agent process (320).



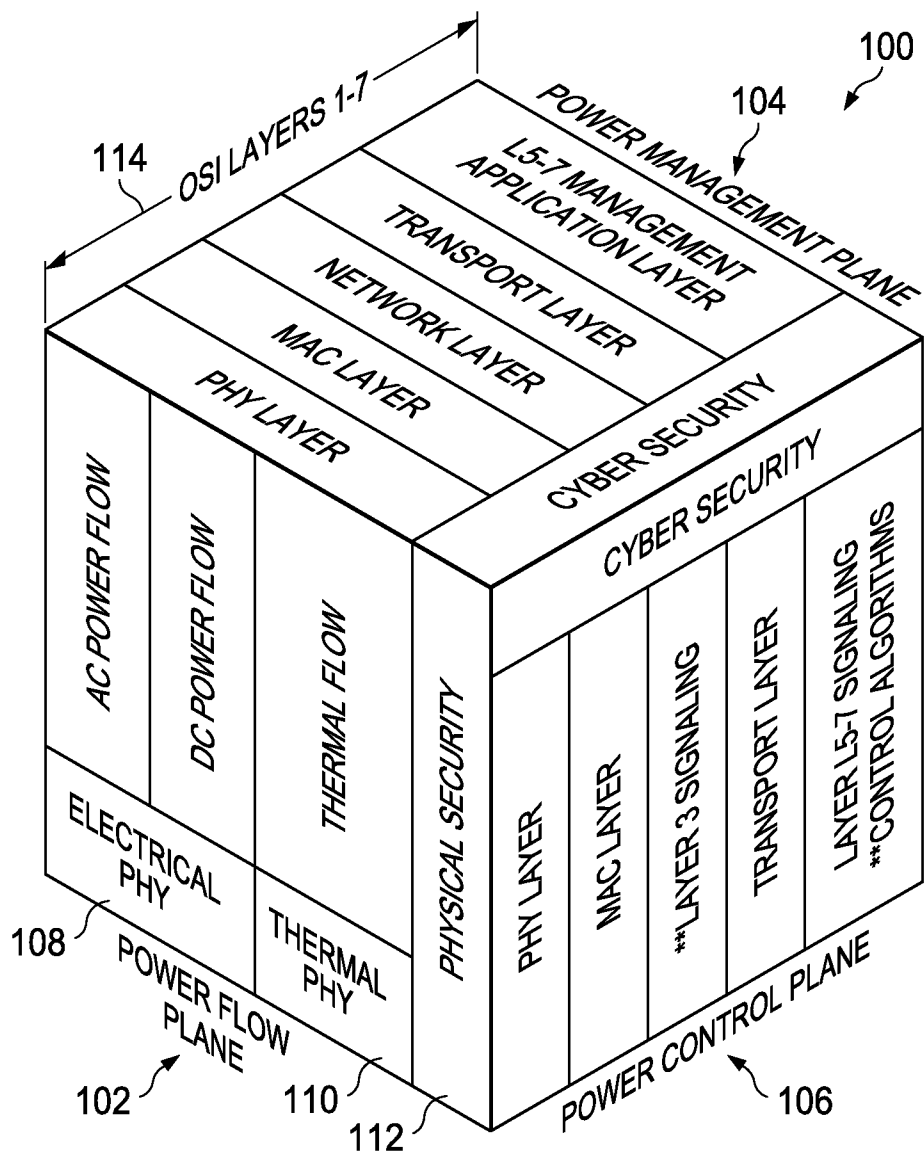


FIG. 1



FIG. 2

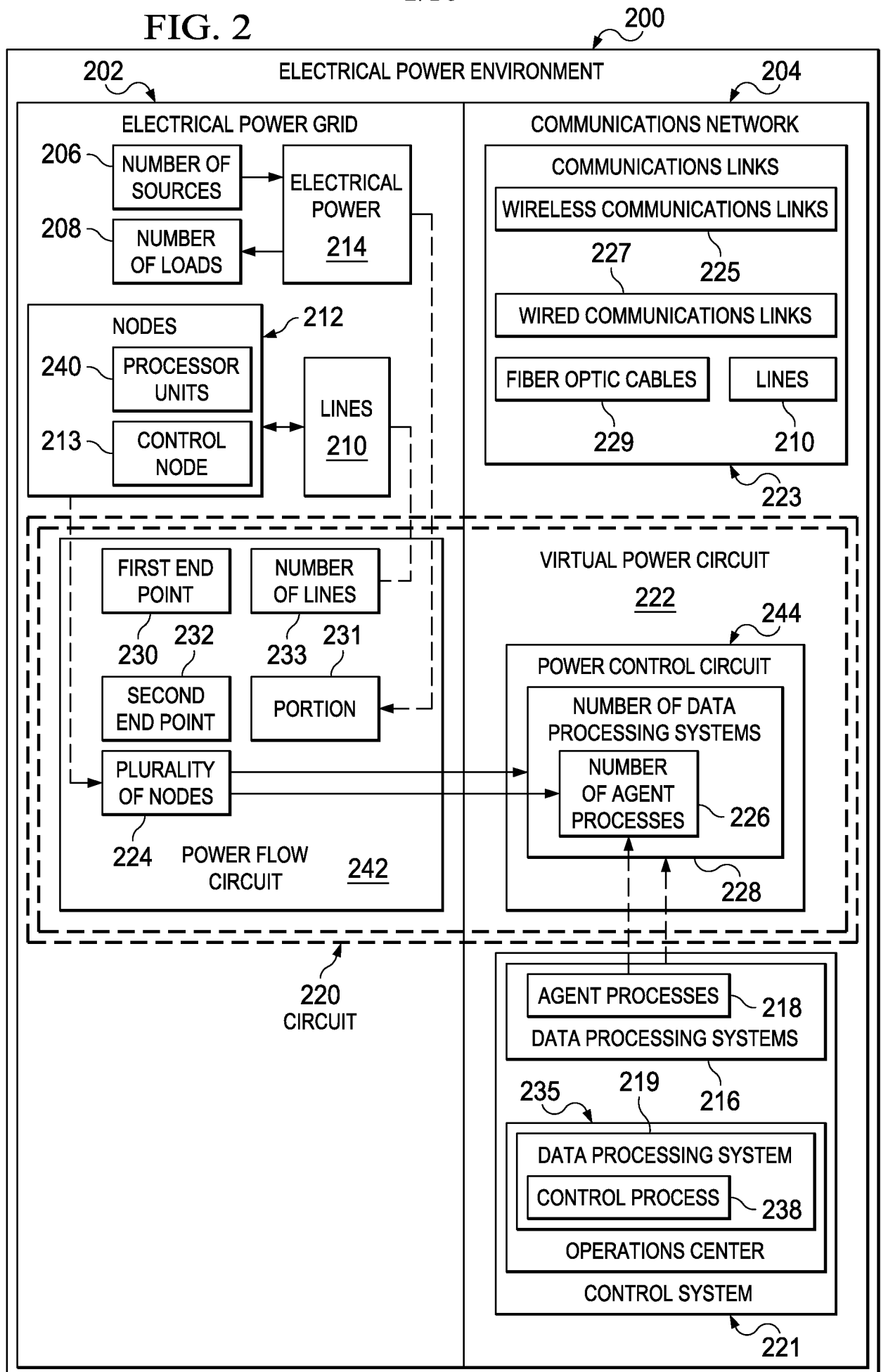
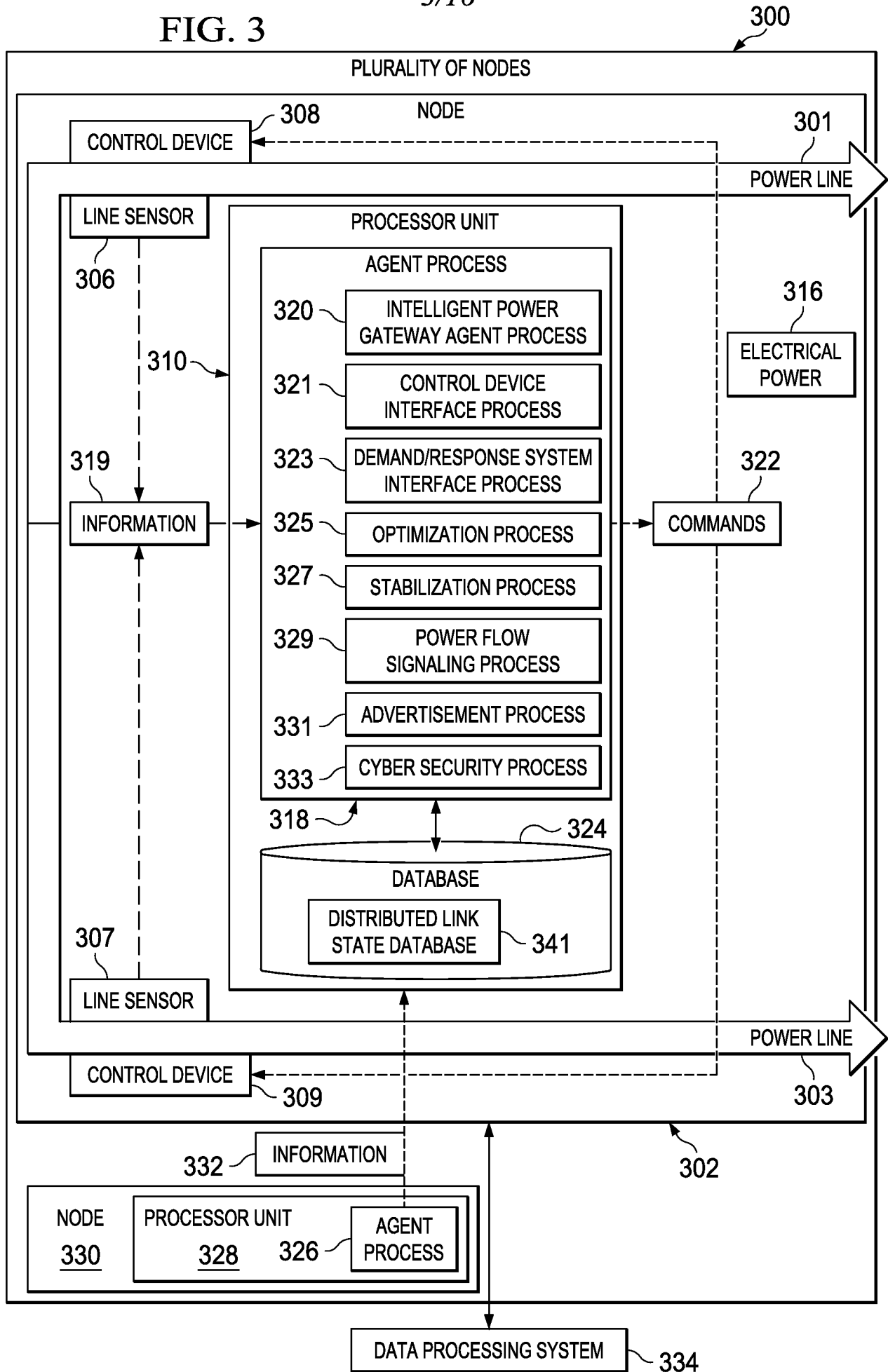


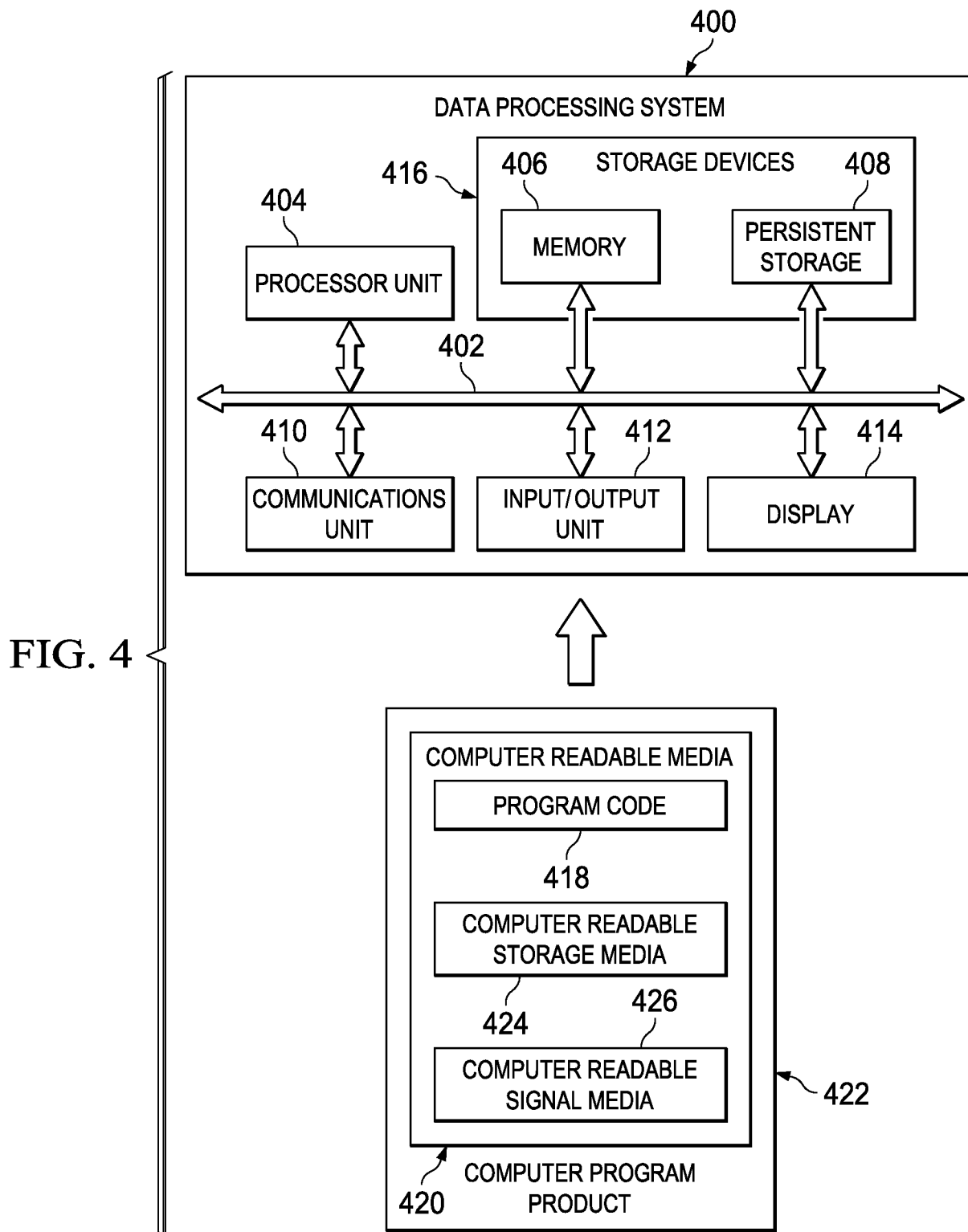


FIG. 3

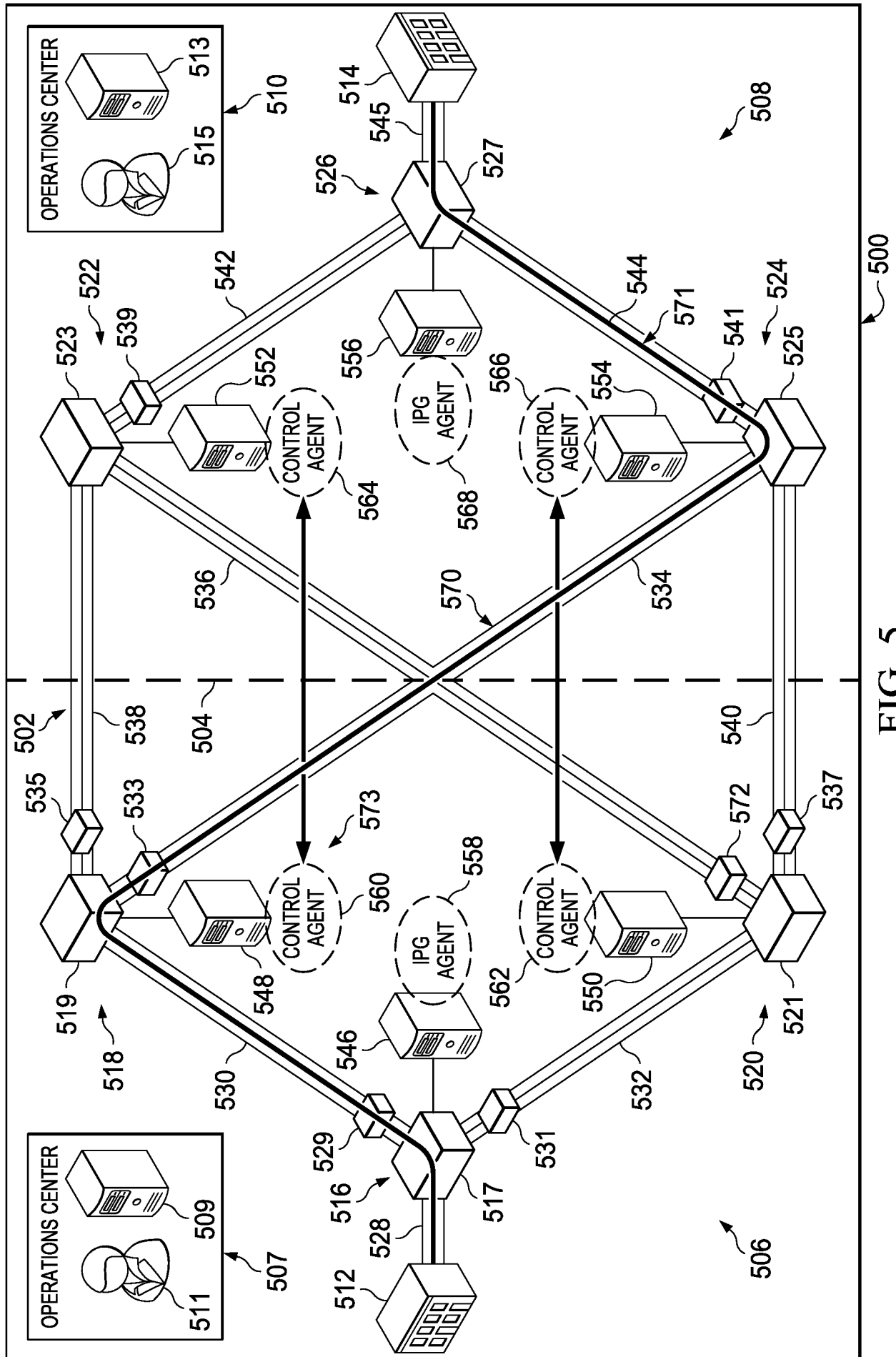




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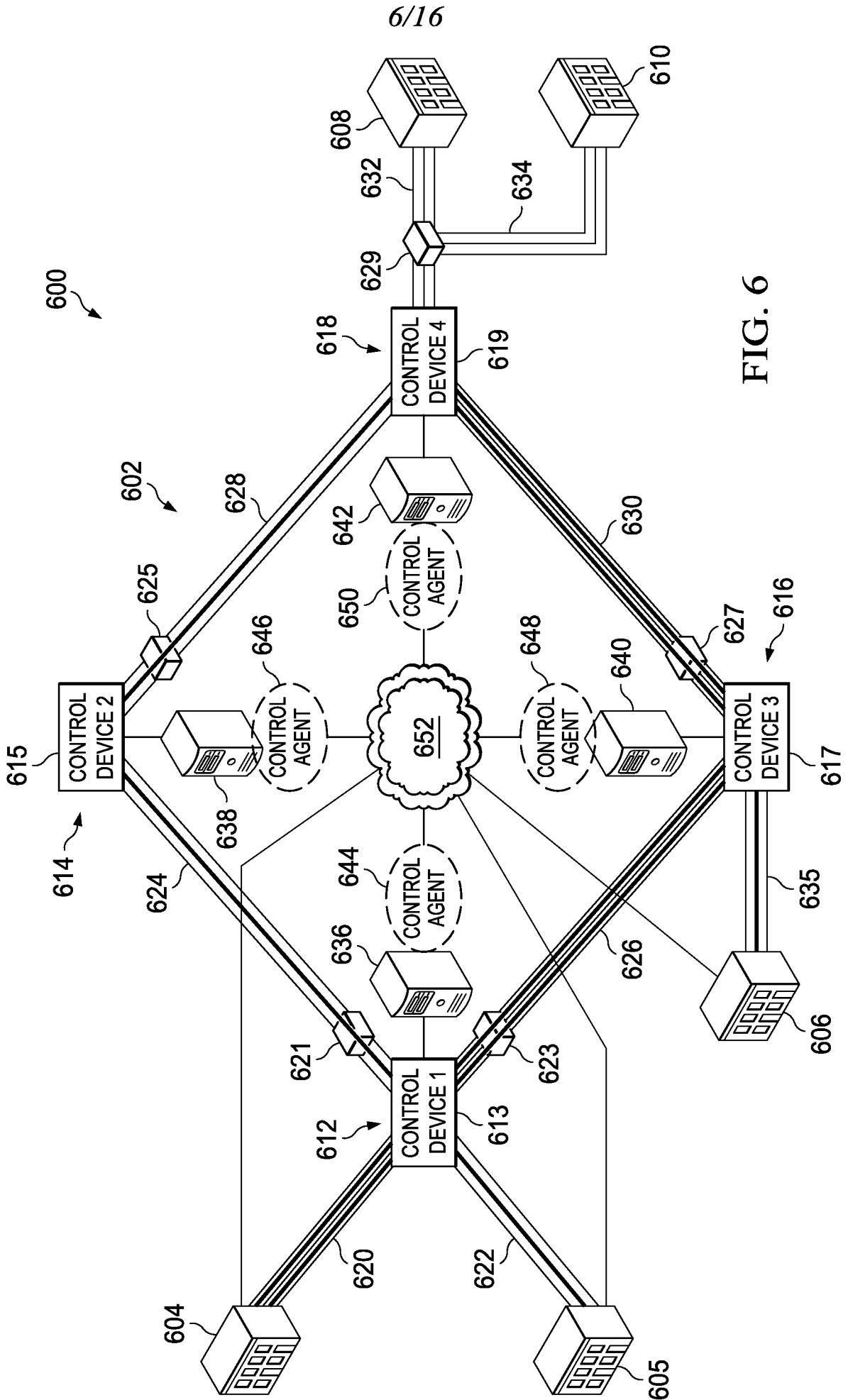
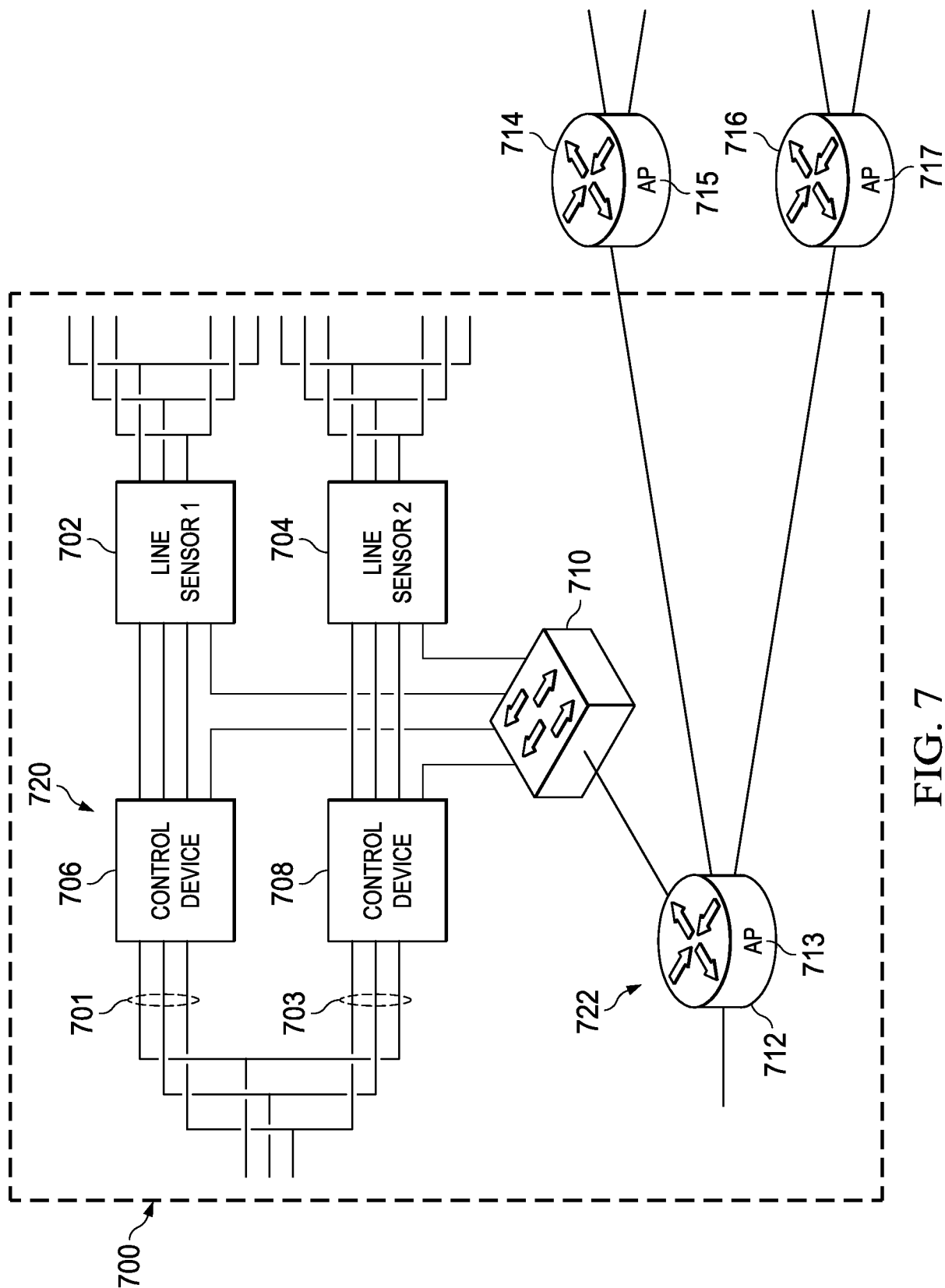


FIG. 6



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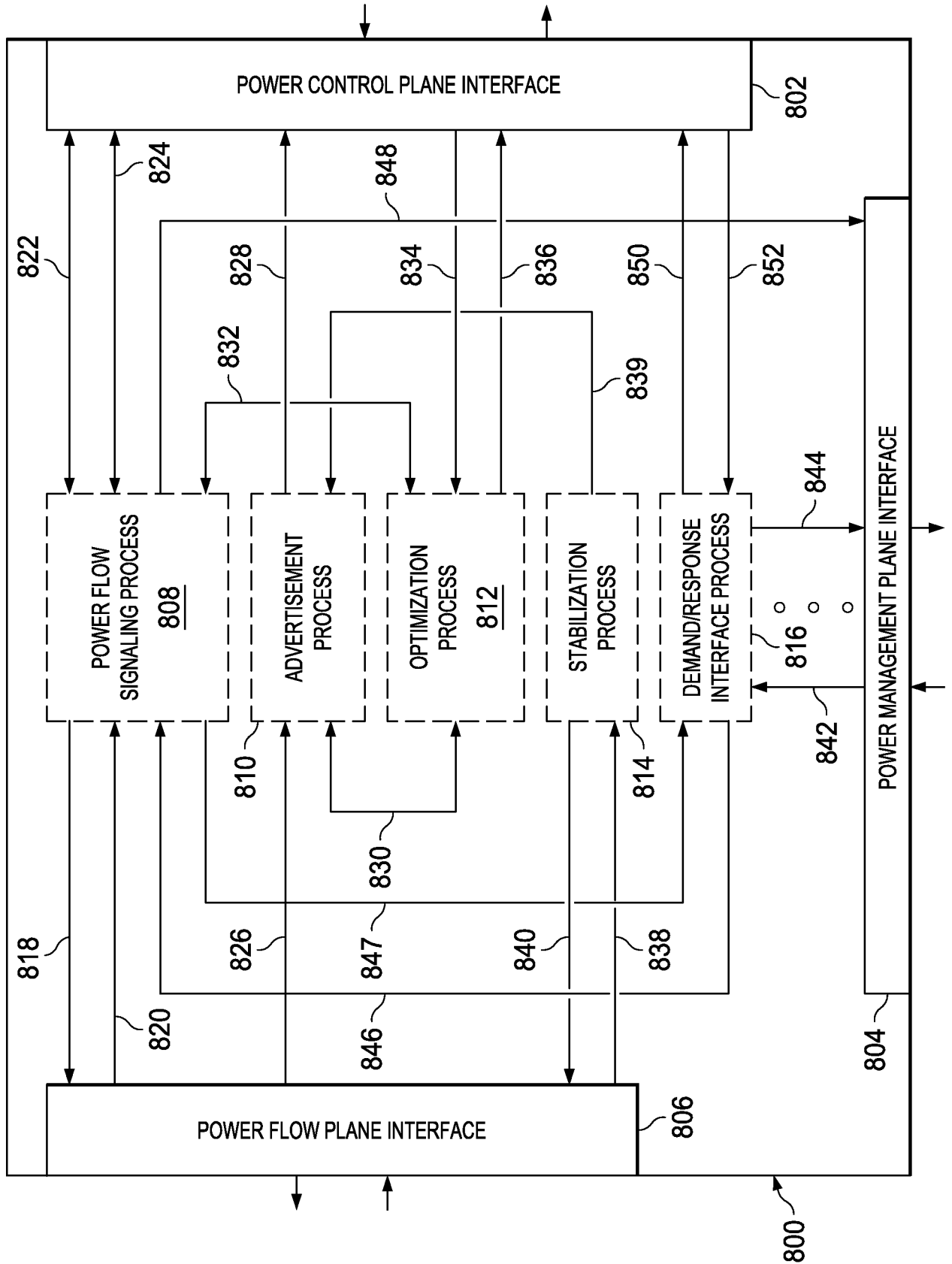


FIG. 8



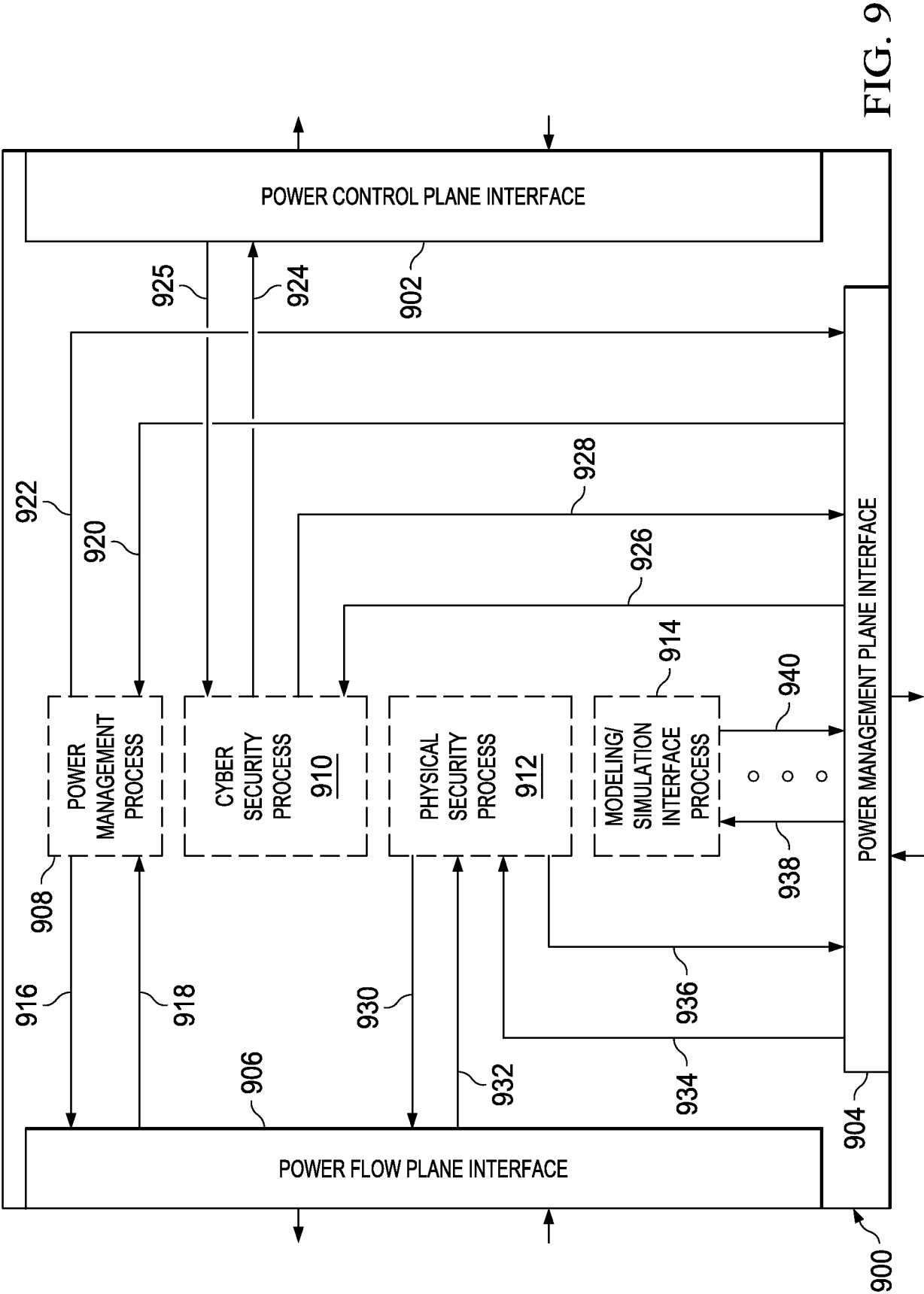
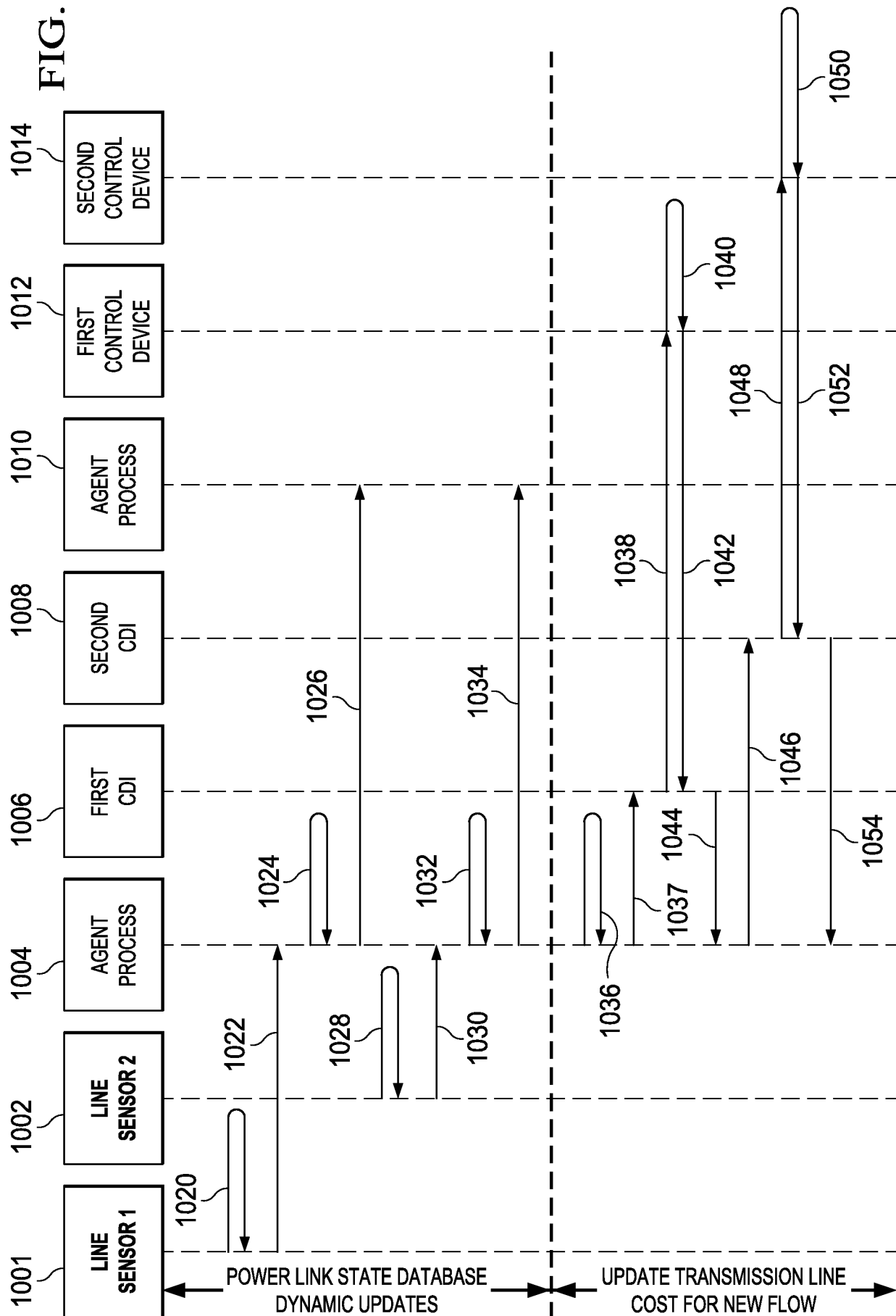




FIG. 10





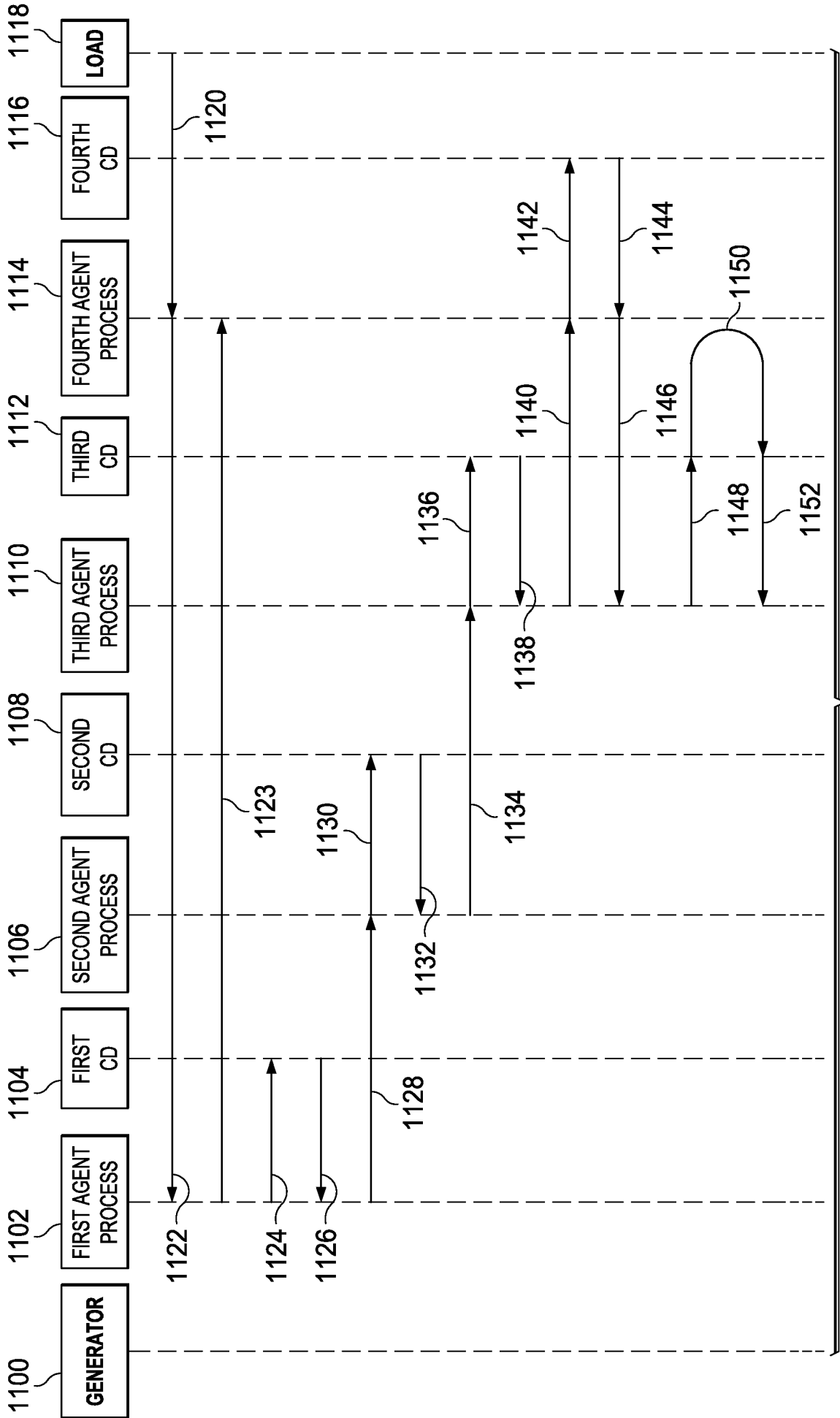


FIG. 11A

TO FIG. 11B



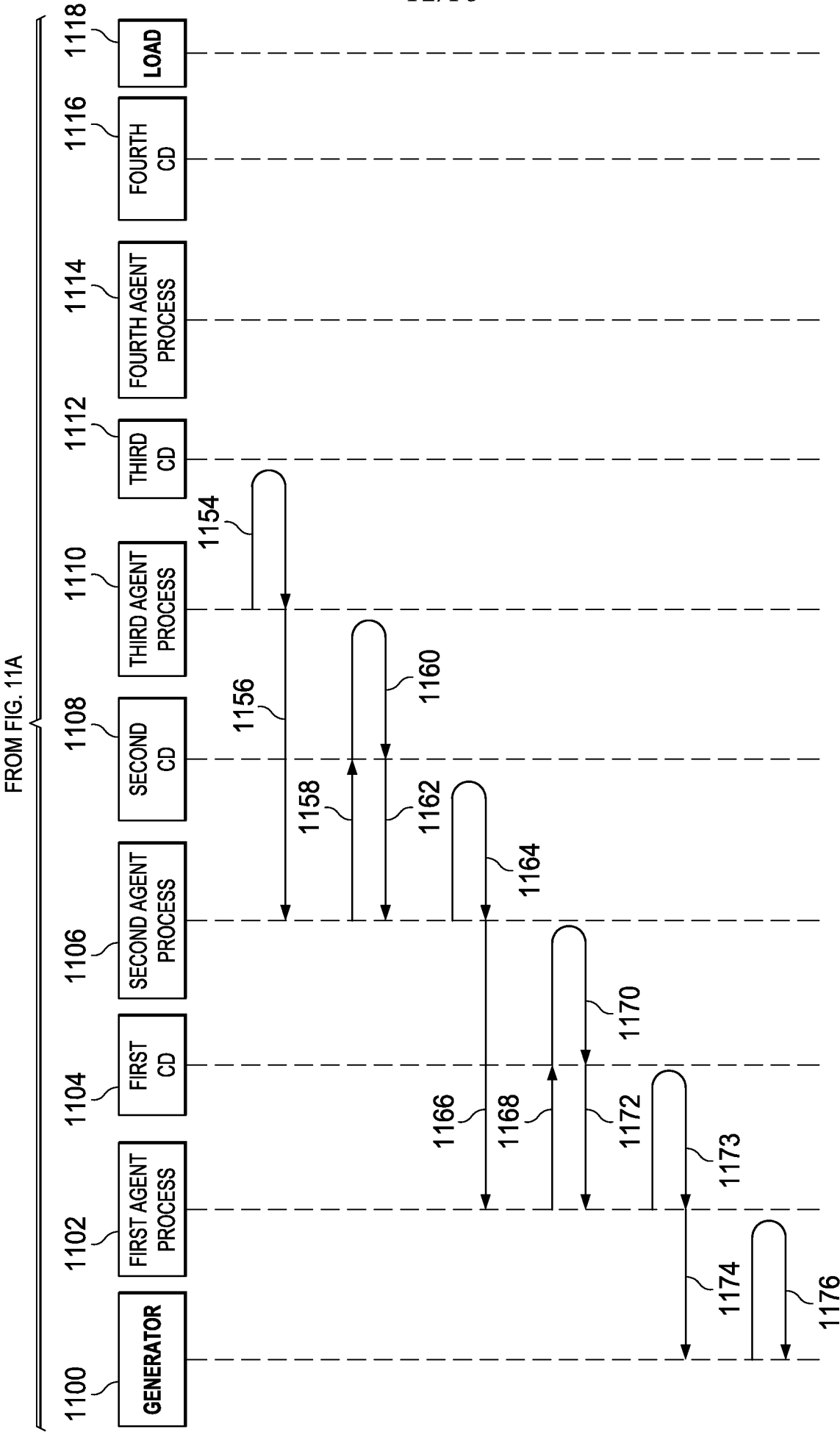


FIG. 11B



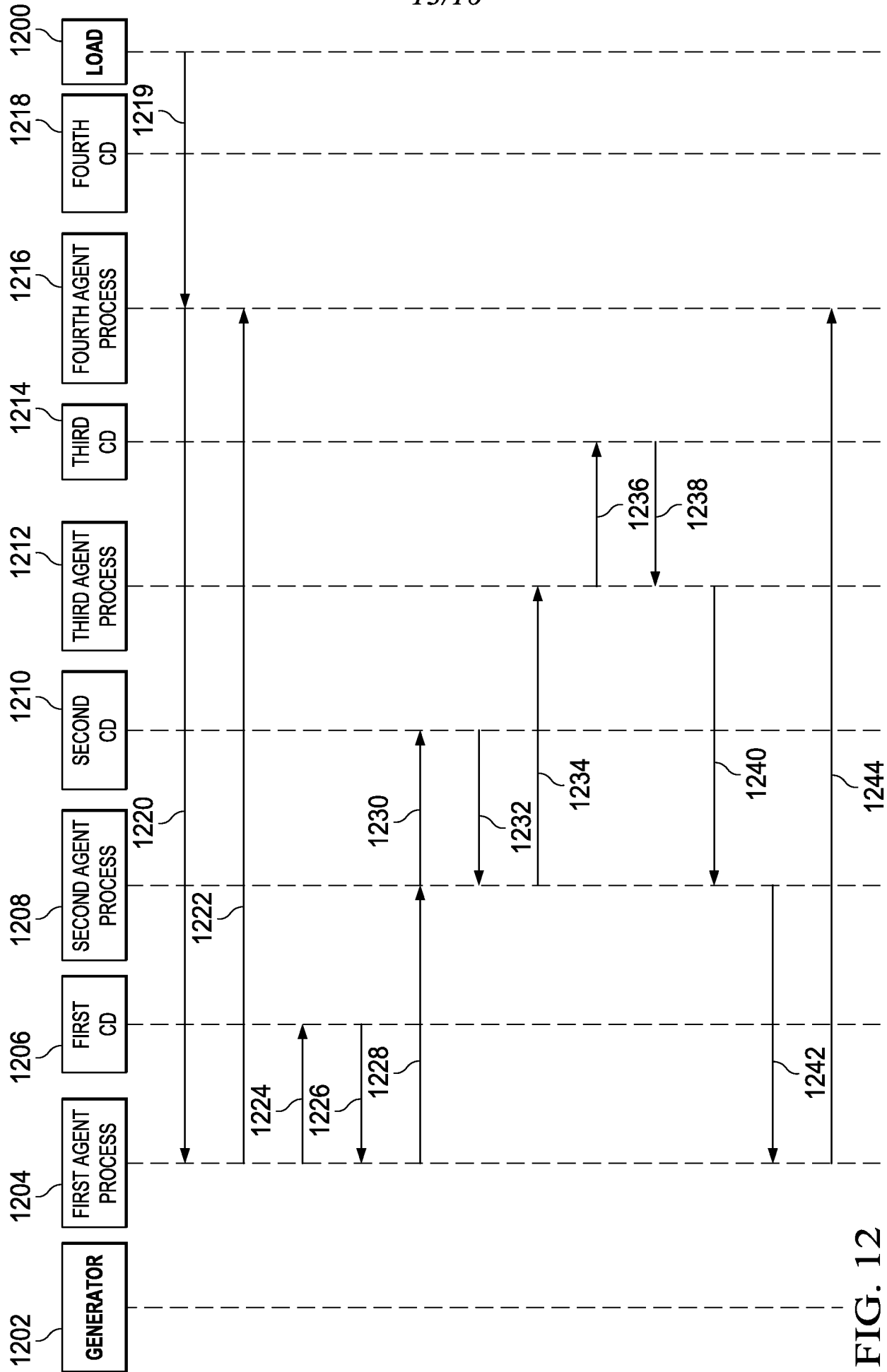


FIG. 12



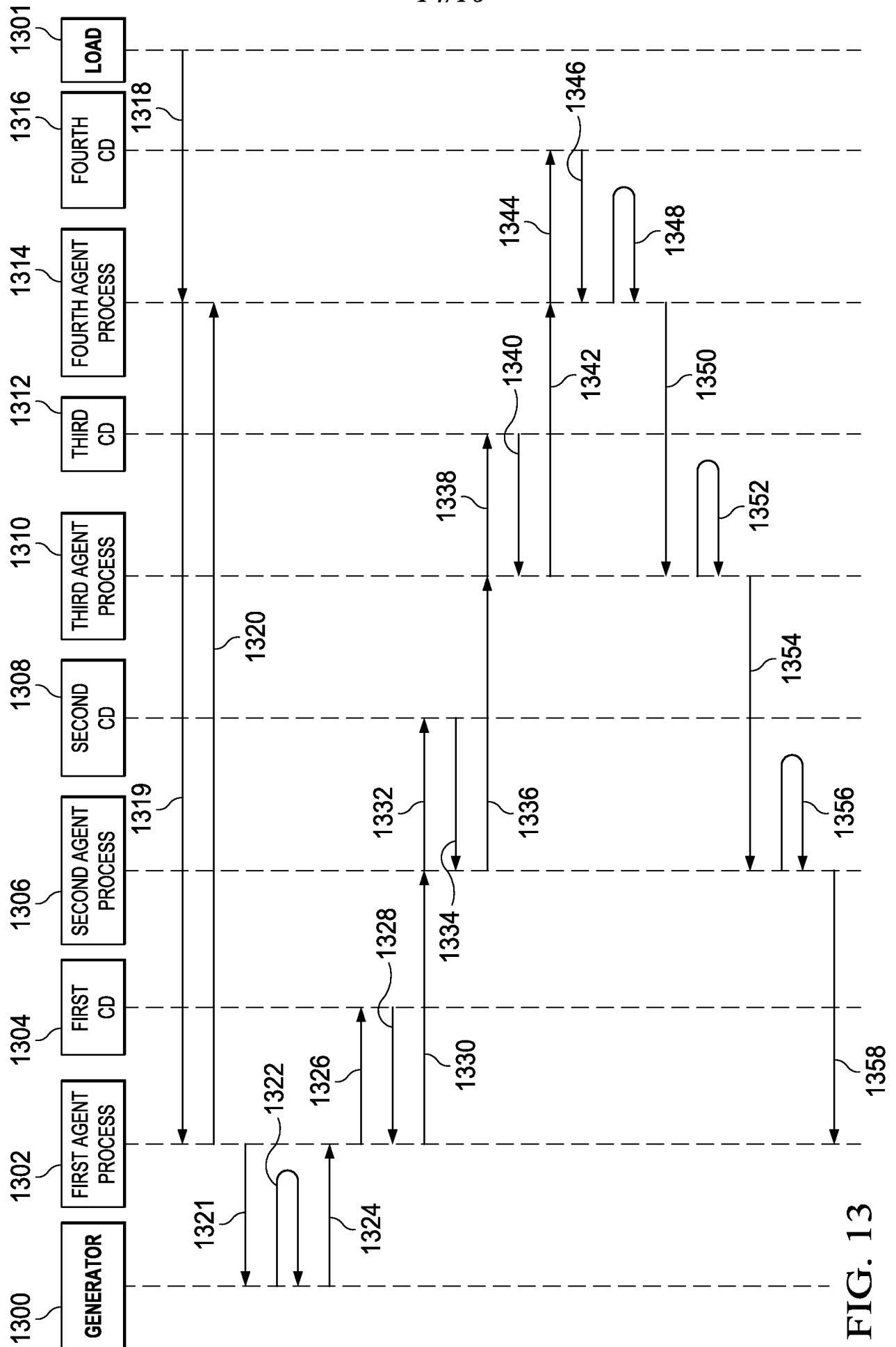


FIG. 13



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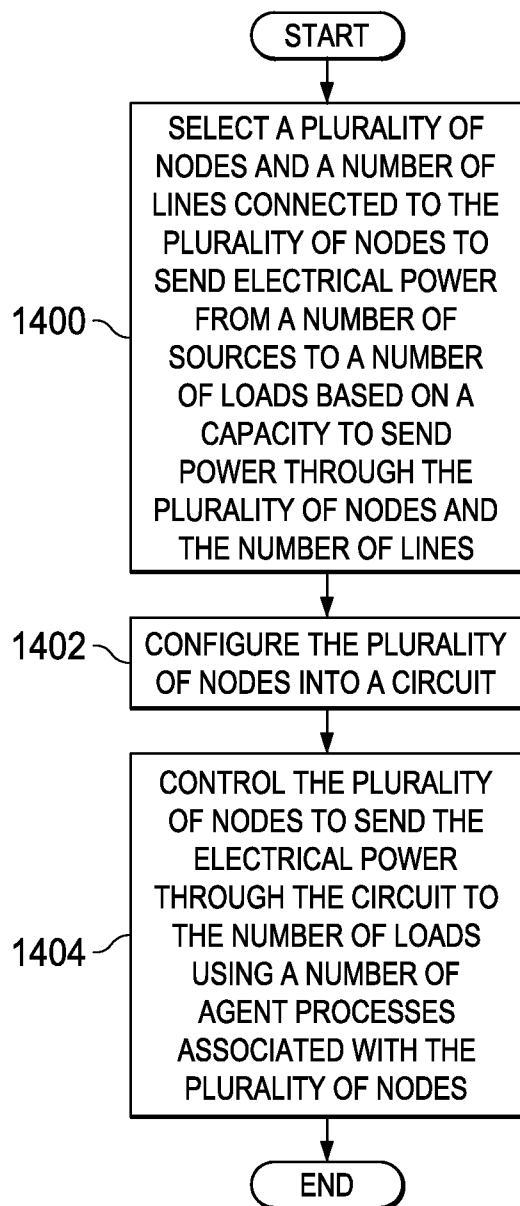


FIG. 14

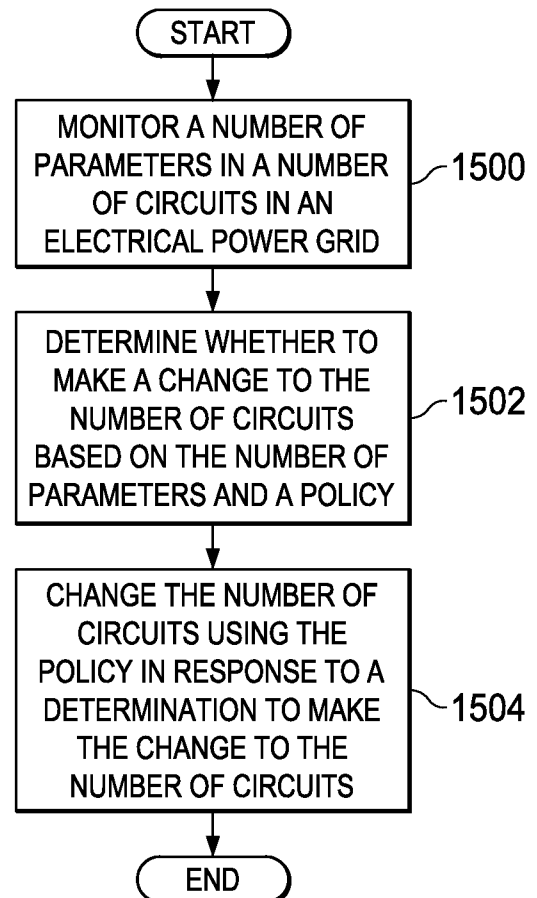


FIG. 15



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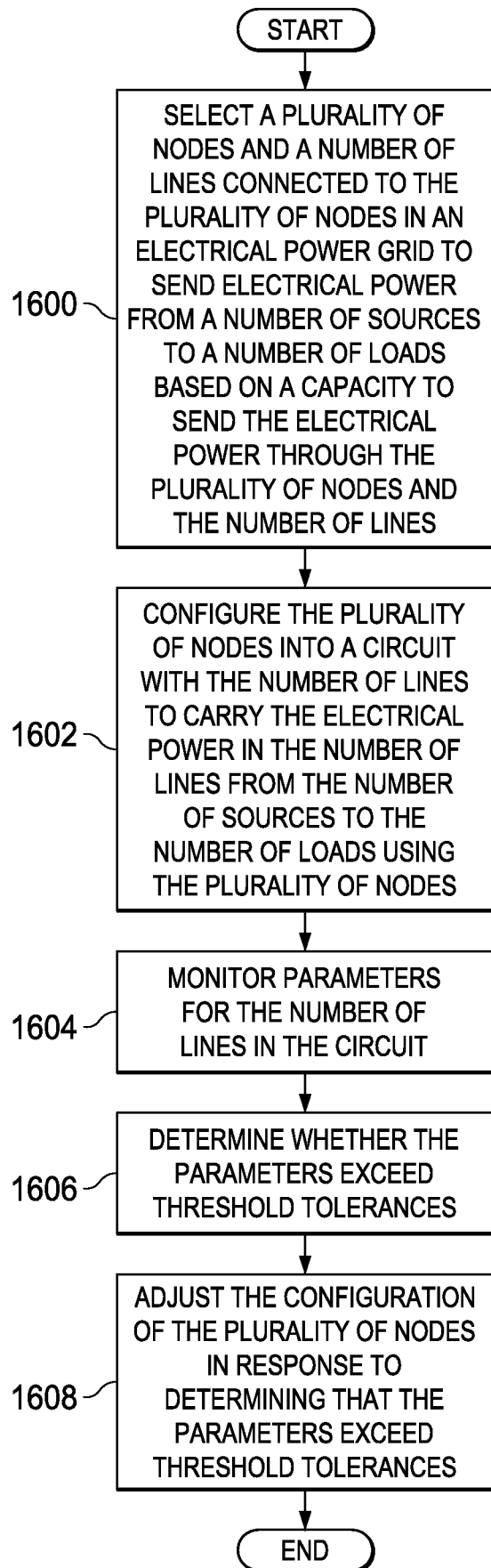


FIG. 16

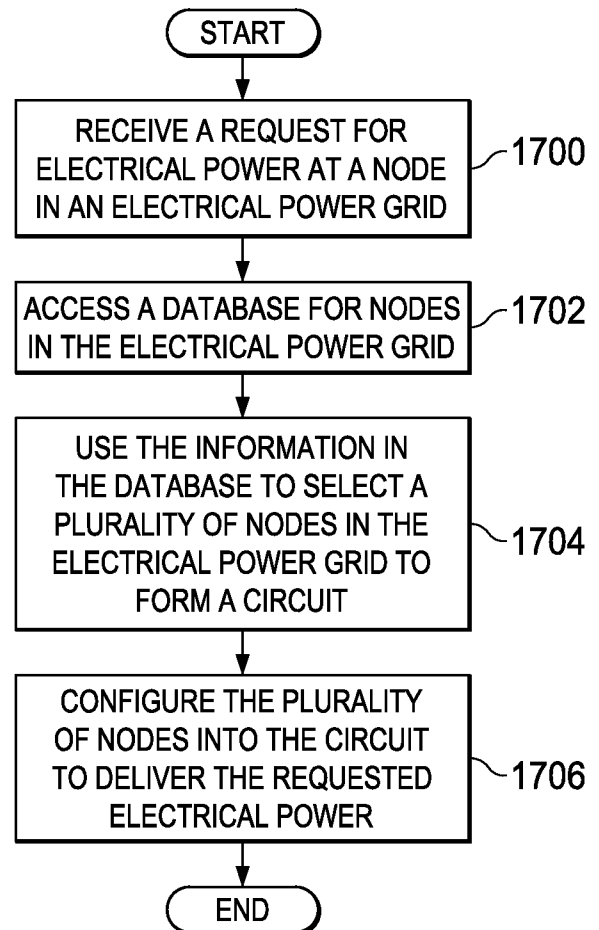


FIG. 17