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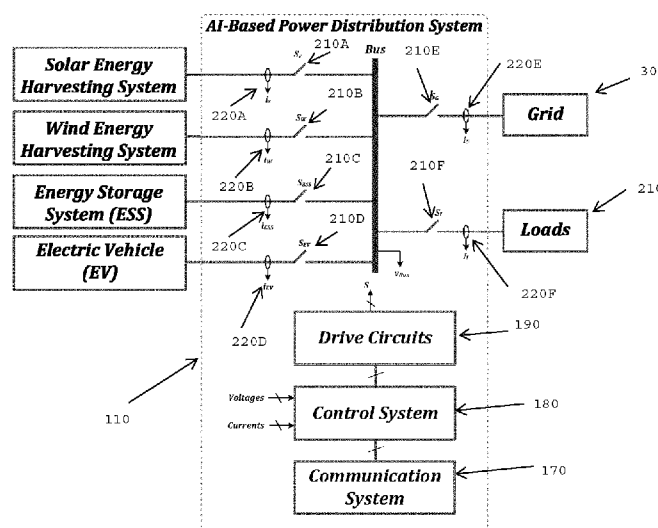


FIGURE 5

(57) Abstract: An artificial intelligence based power distribution system using a controller that receives relevant power data from dynamic observer modules that monitor the various components of a Nano /micro power grid. The dynamic observer modules monitor the power parameters of various energy sources as well as power loads and the main power grid. Based on data from the modules, the controller uses an artificial intelligence based techniques to control and manage power flow within the Nano/micro grid to work towards optimal power flow and resource utilization.

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NANO/MICRO-GRID POWER DISTRIBUTION SYSTEM

TECHNICAL FIELD

[0001] The present invention relates to systems, methods, and devices relating to power distribution in nano/micro-grids. More specifically, the present invention relates to managing the power flow both within a nano/micro-grid and between the nano/micro-grid and other systems or devices.

BACKGROUND

[0002] Global power generation is experiencing a massive shift towards using renewable energy systems. Conventional power generation relies on centralized generators to produce power on a large scale. The centralized system consists of large remotely-located central generators that produce power and a transmission system that delivers power to different loads and consumers. While the current power generation system has been refined over many years to provide a fairly reliable and stable power grid, its structure is rapidly changing. Due to tightening regulations surrounding fossil fuels, global investment in renewable energy, power losses caused by transmission and distribution systems, and difficulties associated with system maintenance, the centralized power generation system is in the process of being replaced. What will take its place is called a "distributed power generation system" (DPGS).

[0003] Micro-grids and nano-grids are the main components of a DPGS. There are two general types of nano/micro-grids used in DPGSs: AC nano/micro-grids, and DC nano/micro-grids. The current power system provides AC power due to its advantages for long distance power transmission (i.e., transformers can be used to adjust optimal voltage levels). Thus, the development of nano/micro-grid technology has been mostly confined to AC nano/micro-grids. However, as the number of local nano/micro-grids increases the need for long distance power transmission will

significantly decline. Therefore, local DC nano/micro-grids can potentially be more efficient because many loads require DC power (e.g., LED lighting systems, electric vehicle charging, variable speed drives, monitors, computers, laptops, mobile phones, servers, batteries, etc.), and these loads need extra power conversion stages to operate in an AC system. Additionally, most renewable energy systems are either inherently DC in nature (batteries, solar panels) or incorporate a DC stage (inverter connected wind turbines).

[0004] Figure 1 shows a general block diagram of an AC nano/micro-grid. As can be seen, the AC nano/micro-grid includes a common AC bus that distributes power within the system. The grid includes DC/AC converters that couples DC power sources (e.g. wind turbines, solar energy cells, energy storage units, etc.) to the AC bus. The AC bus also couples to AC loads and, by way of a breaker, to the main AC power grid. Thus, as can be seen, all the components of the nano/micro-grid are connected to this AC bus.

[0005] Figure 2 shows a general block diagram of a DC nano/micro-grid. As can be seen, a common DC bus distributes power within the system. The DC bus couples to DC power sources (e.g. a battery, wind turbines, and solar power cells) by way of DC/DC converters. Similarly, the DC bus couples to the main power grid by way of a DC/AC converter. DC loads are also coupled to this common DC bus. Various components of the DC nano/micro-grid are connected to this DC bus through appropriate power converters.

[0006] The main issue with existing AC and DC nano/micro-grids is that the energy distribution is not optimal. In these systems, the energy management is suboptimal, and the overall efficiency of the system can be low. A more optimal and more efficient distribution of power within the nano/micro-grid would be of advantage as this would lead to less losses and more efficient use of resources.

[0007] Based on the above, there is therefore a need for systems and devices which mitigate if not avoid the shortcomings of the prior art.

SUMMARY

[0008] The present invention provides systems and methods relating to an AI-based power distribution system. The power distribution system uses a controller that receives relevant power data from dynamic observer modules that monitor the various components of a nano/micro power grid. The dynamic observer modules monitor the power parameters of various energy sources as well as power loads and the main power grid. Based on data from the modules, the controller uses AI-based methods and techniques to control and manage power flow within the nano/micro grid to work towards optimal power flow and resource utilization.

[0009] In one aspect, the present invention provides a control subsystem for managing a distribution of power in an energy network, the subsystem comprising:

- a dynamic grid observer module receiving voltage and current data from a power grid;
- at least one dynamic power source observer module receiving voltage and current data from at least one power source;
- a dynamic load observer module receiving voltage and current data from at least one power load;
- a power flow controller receiving data from said load observer module, said grid observer module, and said at least one power source observer module, said power flow controller controlling a flow of power between said grid, said at least one power load, and said at least one power source;

wherein said power flow controller uses artificial intelligence-based methods to determine and adjust said flow of power.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The embodiments of the present invention will now be described by reference to the following figures, in which identical reference numerals in different figures indicate identical elements and in which:

FIGURE 1 is a block diagram of an AC bus-based nano/micro-grid according to the prior art;

FIGURE 2 is a block diagram of a DC bus-based nano/micro-grid according to the prior art;

FIGURE 3 illustrates a block diagram for an AI-based power distribution system using an AC bus;

FIGURE 4 is a block diagram for an AI-based power distribution system using a DC bus;

FIGURE 5 is a block diagram illustrating the components in an AI-base power distribution component;

FIGURE 6 is a block diagram of the modules in a control subsystem according to one aspect of the invention;

FIGURE 7 is a schematic diagram illustrating the source of data for some of the dynamic observer modules;

FIGURE 8 is a diagram of inputs and output s of the dynamic observer blocks noted for Figure 7; and

FIGURE 9 is a diagram of an AI-based power flow controller that receives the output of the dynamic observer blocks illustrated in Figure 8.

FIGURE 10 illustrates the concept of design layers of a Smart Junction Box (SJB)/AI-based power distribution system according to one aspect of the present invention;

FIGURE 11 is flowchart of applied supervised machine learning on the system according to one aspect of the present invention; and

FIGURE 12 block diagram of an output provider for one aspect of the present invention.

DETAILED DESCRIPTION

- [0011] Referring to Figure 3, shown is an artificial intelligence (AI)-based AC power distribution system 10 for AC nano/micro-grids. As can be seen, the grid architecture is based on a smart power distribution system component 20 that optimally distributes power within the system 10. The component 20 couples to the main AC power grid 30 and to AC loads 40. Also coupled to the component 20 are power sources 50A, 50B, 50C, 50D. These power sources are illustrated as solar energy cells 50A, wind turbines 50B, and energy storage modules (e.g. batteries) 50C. A generator 50D is also illustrated. For the most part, these energy sources are coupled to the component 20 by way of DC/AC converters 60A, 60B, 60C.
- [0012] The AI-based power distribution component 20 effectively optimizes the power flow within the grid in the islanded mode of operation. It controls both the power flow within the grid as well as the power flow between the smaller grid and the main power grid in the grid-connected mode. In addition, in the islanded mode, the AI-based power distribution component adjusts the settings for the power generation side and load balances such that the maximum efficiency is achieved. This component 20 also increases the reliability of the nano/micro grid by intelligently distributing power within the grid. In addition to its power distribution and management capabilities, the AI-based power distribution component also distributes various grid related power data as may be necessary to various other modules and components. Because of this capability, the component 20 can be integrated with and be advantageous for future smart-grid applications.
- [0013] Referring to Figure 4, illustrated is a similar AI-based power distribution component for DC nano/micro-grids. As can be seen, the nano/micro-grid system 100 in Figure 4 includes a suitable AI-based power distribution component 110 similar to the component 20 in Figure 3. In Figure 4, this component 110 is for use with a DC-bus based grid system 100. The component 110 is coupled to the main power grid 30 by way of a DC/AC converter 120. The component 110 is coupled to power sources 130A, 130 B, 130 C by way of suitable DC/DC converters 140A, 140B, 140C.

Similar to Figure 3, the power sources are solar energy cells 130A, wind turbines 140B, and energy storage module 140C. An AC/DC converter 150 may be used with the wind turbine 140B. DC load 160 is also coupled to the component 110.

[0014] Figure 5 is a block diagram illustrating the internal structure of the AI-based power distribution component that forms part of the grids in Figures 3 and 4. As can be seen, the component 110 includes a communications subsystem 170, a control subsystem 180, and drive circuits 190. The bus 200 couples the various power sources (shown as solar power generation, wind power generation, and energy storage in Figure 5) to the control circuitry as well as to the loads 210 and to the main power grid 30. As can be seen, the coupling to the bus 200 is done by way of suitable switches 210A-210F, each of which is controlled by the control subsystem 180. Sensors 220A-220F, schematically shown in Figure 5, measure and sense relevant parameters of power coming from or going to the various power sources/loads coupled to the bus 200. These parameters are received by the control subsystem 180 and are used to determine the power flow and the power distribution within the nano/micro-grid to ensure optimal efficiency and utilization of resources.

[0015] Figure 6 shows an exemplary arrangement for the internal modules of the control subsystem illustrated in Figure 5. As can be seen, the control subsystem 180 includes an AI-based power flow controller 230. Coupled to this controller 230 and sending relevant power data (including voltage and current measurements) to the controller 230 are a dynamic grid observer module 240, a dynamic power generation observer module 250, a dynamic storage observer module 260, and a dynamic load observer module 270. Each of these modules receives real-time or near real-time voltage and current readings from their relevant sources. As such, the grid observer module 240 receives data regarding the main power grid, the power generation observer module 250 receives data regarding the various power sources that generate power (e.g. the solar energy cells and the wind turbines), the dynamic storage observer module 260 receives data regarding the energy storage components coupled to the common bus (e.g. the batteries), and the dynamic load observer module receives data regarding the various loads coupled to the nano/micro-grid system.

These dynamic observer modules dynamically estimate the relevant data regarding load, generation capability, storage status, and grid status. These observer modules provide the required information to the controller 230 to allow the controller to calculate, estimate, and control power flow within the nano/micro-grid system such that optimal power flow and/or optimal resource utilization/management is achieved.

- [0016] It should be noted that there exists a number of techniques that may be used to analyse various signals from different components (e.g., renewable energy harvesting systems, utility grid, etc.) of the nano-grid system. A common technique is the well-known Fast Fourier Transform (FFT). Even though this technique is very effective for steady-state analysis of fairly regular signals, it is not very appropriate for extracting the dynamic behaviour of the system. Although FFT includes all the information about a signal, much of the information is hidden. For instance, if there is a singularity in the signal, the time of the singularity is hidden in the Fourier transform. Thus, there is a need for an effective technique to dynamically observe the respective signals from different components of the nano-grid.
- [0017] It should be clear that, in nano/micro-grids, the required data for the dynamic observers is not usually on a linear Euclidean space. The data usually lies on a Riemannian Manifold (i.e., roughly, manifolds equipped with an inner product). Thus, the computational methods that rely on well-known Euclidean metrics are generally inefficient and suboptimal. This issue stems from the fact that these methods are simply unable when dealing with the underlying structure of the Riemannian Manifolds on which the data resides. Therefore, Euclidean-based system identification techniques for the dynamic observers are usually computationally intensive and not very appropriate for real-time applications. These dynamic observer modules are therefore based on various machine learning techniques on Riemannian Manifolds. We call these observers "Nano/Micro-Grid Learning on Riemannian Manifolds". This "nano/micro-grid learning" utilizes appropriate Riemannian metrics for different components and results in optimal observer algorithms with a low level of complexity tailored for real-time nano/micro-grid identification. The selected Riemannian metric directly affects the performance

of the observer modules. The Riemannian metric determines the complexity of the calculations, the speed of convergence, and the accuracy of the estimated states. The selection of the metric is of paramount importance in order to take advantage of the underlying structures on the corresponding Riemannian manifold and produces simple and practical dynamic observers. Figure 7 shows the conceptual design of dynamic observers based on nano/micro-grid learning on Riemannian Manifolds.

[0018] Figure 8 shows a block diagram of the dynamic observer blocks noted above. The main block receives the current and voltage from the respective components and generates a vector identifying the required parameters. The dynamic observers for the components have similar structures with only the output vector (parameters) being different for each observer. The Riemannian metrics for different components will be different and will be determined based on the underlying structure of the dynamics for each component.

[0019] Figure 9 shows a block diagram of the AI-Based Power Flow Controller block. This block receives the signals from dynamic observer blocks noted in Figure 8 (i.e., the dynamic grid observer, the dynamic generation observer, the dynamic storage observer, and the dynamic load observer). Each dynamic observer block produces a vector of signals, which will be the inputs to an AI-based method or algorithm used by the controller block in Figure 9. The output of the AI-Based Power Flow Controller block are the switching signals for the AI-Based Power Distribution System. In Figures 8 and 9, a number of vectors output by the block in Figure 8 operate as inputs to the main controller block in Figure 9. Grd_o is an input vector to be used by the AI-based method or algorithm and this input vector includes the grid parameters. Gen_o is also an input vector to the AI-based method or algorithm and this input vector includes the parameters for the renewable energy sources. Another of these input vectors to the AI-based method or algorithm is ESS_o . This input vector to the AI-based method includes the ESS parameters. Ld_o is another input vector to the AI-base method or algorithm and this input vector includes the load parameters. In Figure 9, S_s , S_w , S_{ESS} , S_{EV} , S_G , and S_L , are the output vectors of the

AI-based method or algorithm and these output vectors show the switch conditions/settings for different components.

[0020] In one embodiment, the system of the present invention is designed as a Smart Junction Box (SJB) or as an AI-based AC power distribution system. This system is conceptually designed as a three layer design as shown in Figure 10. In the base-layer (or bottom-most layer) there are two parts: the software and the hardware of the smart junction box. The middle layer consists of communication solution components including protocols, security, and data package arrangements. Finally, the third layer or top-most layer is an Artificial Intelligence (AI) component that acts as a ruling or controlling layer that determines and controls the behavior of the system. All the relay states are decided by this top-most layer.

[0021] The Artificial Intelligence (AI) component in the system is achieved by machine learning. As is well-known, two major categories for machine learning are supervised and unsupervised machine learning. Supervised machine learning is used for the system of the present invention due to the usefulness of the teaching or training dataset in supervised machine learning. Referring to Figure 11, a data flow diagram illustrates the logic and data flow for the system. As shown in Figure 11, a teaching or training dataset is sent to a machine learning subsystem to be trained. The training data set, labelled as "experience" in Figure 11, is used to train the machine learning subsystem. The output of the machine learning subsystem is sent to a cost function block and these two blocks form the model representation stage of the process. As is known, the training datasets or the "experience" datasets are gathered from experience or from previous instances of the system. For this system, it is known that the system must learn or be trained to decide which relay combination (n.b. : relay combination means which relays should be on or off) is applicable for a given current state. Therefore, the system output is the state of all relays. As input, the system can be fed data that includes the instant amount of power from a wind turbine, a solar cell, a power grid, and other power/voltage/current sinks and sources that are connected to the system. Other possible inputs to the system include the status of any and relays. Based on these

inputs, the best next state of the relays are output by the system. By defining each set of inputs and resulting output for the system, one training dataset or teaching dataset is defined. The collection of these experiences or datasets is called the system's overall dataset. Based on the overall dataset, the system is designed to learn to determine what is the optimal state for the various relays given the current state of the system.

[0022] Referring to Figure 11, after gathering a reasonable set of training datasets, the representation of the model for the system is obtained and the hypothesis for a decision function is generated in the next step of the process. Given that the output of the system is a binary output for the relays (i.e. each relay is to be set as either on or off), then the problem to be solved by the system is a classification problem, i.e., which set or sets of input data is/are to be mapped to which set or sets of output data. Based on problem specification, the system can use logistic regression for the model representation step (see Figure 11). Using a sigmoid function as a hypothesis and finding a suitably related cost function leads to completing the model representation step. In the next step, the learned hypothesis is obtained by optimizing the cost function. This learned hypothesis provides the coefficients for the decision function, and, by having these coefficients, the system now has what is required to know how to act in a new situation. It should be noted that decision function calculations are done offline by mathematical tools to ensure fast and accurate system results. After such calculations, the coefficients are extracted and provided to the decision functions on the system. To render the system more accurate, a recursive method such as the Gradient Boosting Algorithm (GBA) can be used during the learning process/learning/training phase of the process. The GBA improves the accuracy of the hypothesis generated by optimizing errors based on inputs to thereby reduce the uncertainty.

[0023] To apply the AI decision on the system output, a logic verification unit can be used. The logic verification unit can function to supervise the system's stability. In addition, user preferences may be considered when determining the system output. Therefore, as illustrated in Figure 12, the output of the trained system (listed as

"taught machine" in Figure 12) along with user preferences are both fed into logic check/verification unit. This logic verification/check unit can test/determine if the new settings will/can affect system stability. If the new settings are not suitable (e.g. the new settings will cause system instability), the logic verification unit can ignore the changes and can reports a fault/error. This logic verification unit can also consider user preferences for other possible situations. In one implementation, the logic verification unit may enter safe mode after the number of faults detected has reached a threshold number. This hybrid solution involving the logic verification unit and the threshold number of faults can contribute to a working system in all states.

[0024] As a summary of the system architecture, it should be clear that the system AI is a hybrid solution which uses a classification solution based on supervised machine learning along with a logic verification unit prior to a final output stage. As noted above, the system inputs include the instant power for sinks and sources where such data implicitly has time and relay status information. User preferences are also considered in the final stage where it will be applicable.

[0025] As a summary of the system architecture, it should be clear that the system AI is a hybrid solution which uses a classification solution based on supervised machine learning along with a logic verification unit prior to a final output stage. As noted above, the system inputs include the instant power for sinks and sources where such data implicitly has time and relay status information. User preferences are also considered in the final stage where it will be applicable.

[0026] In one simulation, a dataset was produced by gathering real-world available power analysis of sources and sinks. For example, to find available wind power, the wind profile obtained from an airport was used and, for this dataset, the wind speed was converted to a power rate based on a generic 1KW wind turbine. The house load was estimated based on the usage of two residential units. All other assumptions were made on the same bases. After input/output power calculations and preparations, the relays were assigned by considering following rules:

- * There is a restriction on the total power on the BUS.
- * The main source of input power is SOLAR.
- * The last input source is GRID.
- * Energy Storage System (ESS) could be sink/source of power based on its reported state of charge.

Known rules in machine states:

- * Instantaneous power at any input or output when those are connected (i.e., no delay).
- * State of charge of ESS.
- * Maximum possible amount of power of WIND and SOLAR sources.
- * GRID can deliver specified amount of power each moment (Most often).
- * LOAD should be the last thing that can be disconnected.
- * Preference is to lower usage of GRID.
- * In particular time (night), SOLAR is not available. At other times power from SOLAR may vary.
- * WIND is not main source of power but it could provide some power.

[0027] In one implementation, the system has the capability to communicate with a PC and with Android-based devices. The communications interface on third party devices are informed about the internal state of the system. Those interfaces are designed to show voltage, current, and relay status. This information will be available through wireless serial connection. The Zigbee protocol is used in the system's communication section which provides a reliable wireless communication in a wide

range of frequency options and with a wide range of free wireless channels in each region of the world.

[0028] In a PC implementation, data can be retrieved from a serial Comm port. The Comm port setting is, preferably, set on 115200-8-n-1 (baud-bits-parity-stop). The same data packet can be received on Android based devices which are equipped with an OTG communication port. Handshaking is not used in one implementation that uses serial communication. The data packet structure may be as follows:

* Receiving packet in application side includes 33 bytes of data. Additionally, the packet starts with an "@" symbol and ends with a "#" symbol. Also, packets would include "," as a delimiter between information fields.

* The system may report 10 channels of Analog to Digital Converter (ADC) results. These channels are connected to different sensors and the data being sensed correspond with desired data input points. In one implementation, 6 current sensors + 3 voltage sensors + 1 reserved will be reported to the system.

* Relays status also be represented by an included status register in a packet conforming to the above specifications. Therefore, each bit of a relay status byte representing the status of the relay in a packet will represent a closed relay contact by a one (1) in the data while an open relay contact will be represented by a zero (0) in the data.

[0029] A person understanding this invention may now conceive of alternative structures and embodiments or variations of the above all of which are intended to fall within the scope of the invention as defined in the claims that follow.

What is claimed is:

1. A control subsystem for managing a distribution of power in an energy network, the subsystem comprising:
 - a dynamic grid observer module receiving voltage and current data from a power grid;
 - at least one dynamic power source observer module receiving voltage and current data from at least one power source;
 - a dynamic load observer module receiving voltage and current data from at least one power load;
 - a power flow controller receiving data from said load observer module, said grid observer module, and said at least one power source observer module, said power flow controller controlling a flow of power between said grid, said at least one power load, and said at least one power source;

wherein said power flow controller uses artificial intelligence-based methods to determine and adjust said flow of power.

2. The subsystem according to claim 1, wherein said at least one power source generates power.
3. The subsystem according to claim 1, wherein said at least one power source is a renewable energy based power source.
4. The subsystem according to claim 1, wherein each of said at least one power source observer is coupled to said at least one power source by way of a power converter.
5. The subsystem according to claim 4, wherein said power converter is at least one of:
 - a DC/AC converter; and
 - a DC/DC converter.

6. The subsystem according to claim 1, wherein said grid observer module is coupled to said grid by way of a DC/AC converter.
7. The subsystem according to claim 1, wherein said controller is coupled to a communications subsystem to allow said controller to communicate with outside devices.
8. The subsystem according to claim 1, wherein at least one of said dynamic observer modules is based on machine learning techniques on Riemannian manifolds.
9. The subsystem according to claim 1, wherein said subsystem includes a dynamic storage observer receiving voltage and current data from at least one power storage device.
10. The subsystem according to claim 1, wherein each of said observer modules receives real-time or near real-time voltage and current readings from at least one component being monitored by said module.
11. The subsystem according to claim 1, wherein said artificial intelligence-based methods are implemented by way of machine learning enabled components.
12. The subsystem according to claim 1, wherein said artificial intelligence-based methods are implemented by using trained components, said trained components being trained using machine learning and at least one training dataset.
13. The subsystem according to claim 12, wherein said at least one training dataset is derived from experience or from previous instances of said subsystem.
14. The subsystem according to claim 1, comprising an artificial intelligence component that operates as a controlling layer that determines and controls a behaviour of said subsystem.
15. The subsystem according to claim 14, wherein said artificial intelligence component outputs a plurality of relay states that are determined by said component as being applicable for a given state.
16. The subsystem according to claim 14, wherein input to said component includes input from at least one renewable energy source.

17. The subsystem according to claim 1, wherein said subsystem comprises a logic verification unit, said logic verification unit being for determining if projected changes to a state of said system will affect system stability.

18. The subsystem according to claim 17, wherein when said logic verification unit determines that projected changes to said state of said system will affect system stability, said logic verification unit discards said projected changes.

19. The subsystem according to claim 17, wherein said logic verification unit enters a safe mode after detecting a predetermined number of changes to said state that will affect system stability.

20. The subsystem according to claim 3, wherein said renewable energy based power source is at least one of:

- a solar energy-based power source;
- a wind-based power source;
- an energy storage device; and
- an electric vehicle.

21. The subsystem according to claim 14, wherein an input to said component is at least one of:

- an instant amount of power from at least one wind turbine;
- an instant amount of power from at least one solar cell;
- an instant amount of power from at least one power grid;
- an instant amount of power from at least one source of power;
- an instant amount of power going to at least one power sink; and
- a state of at least one relay.

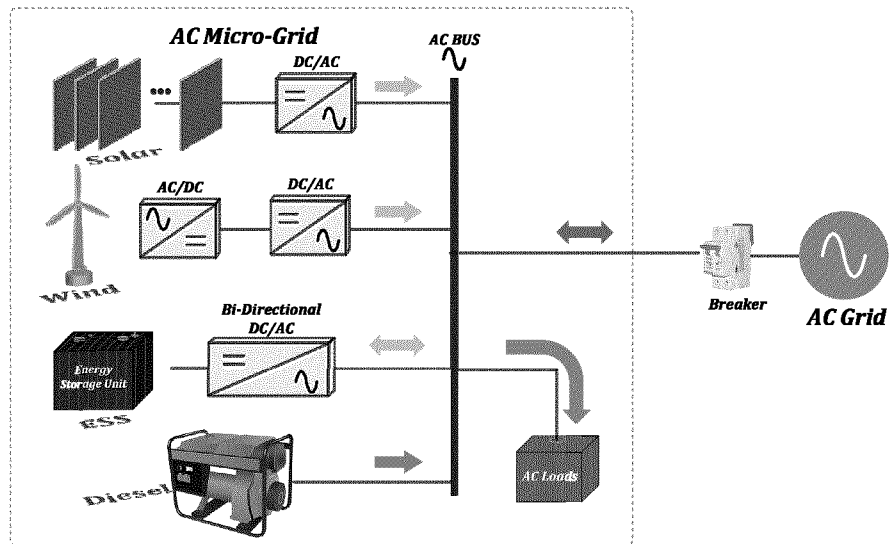


FIGURE 1
(PRIOR ART)

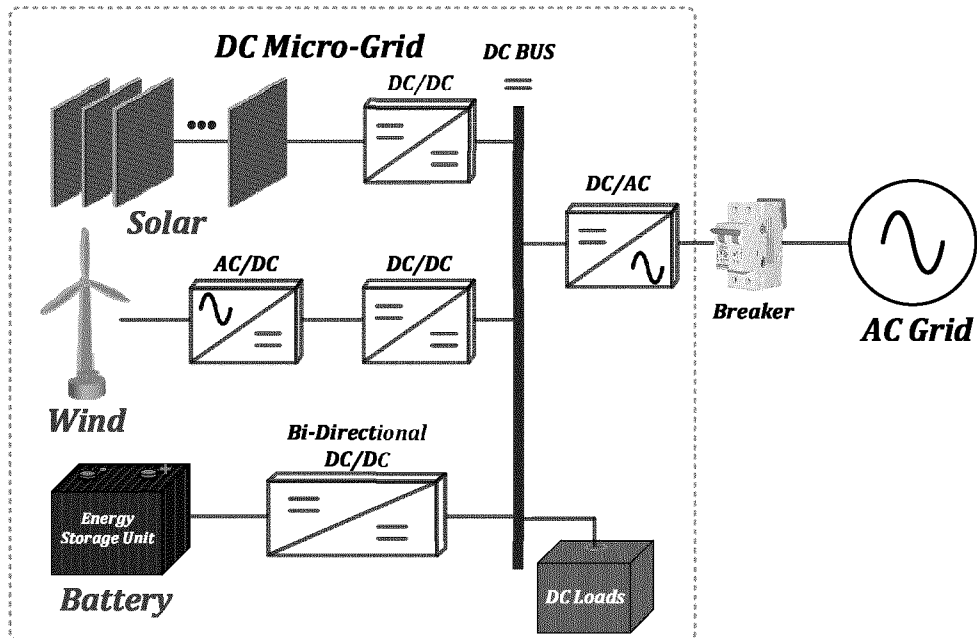


FIGURE 2
(PRIOR ART)

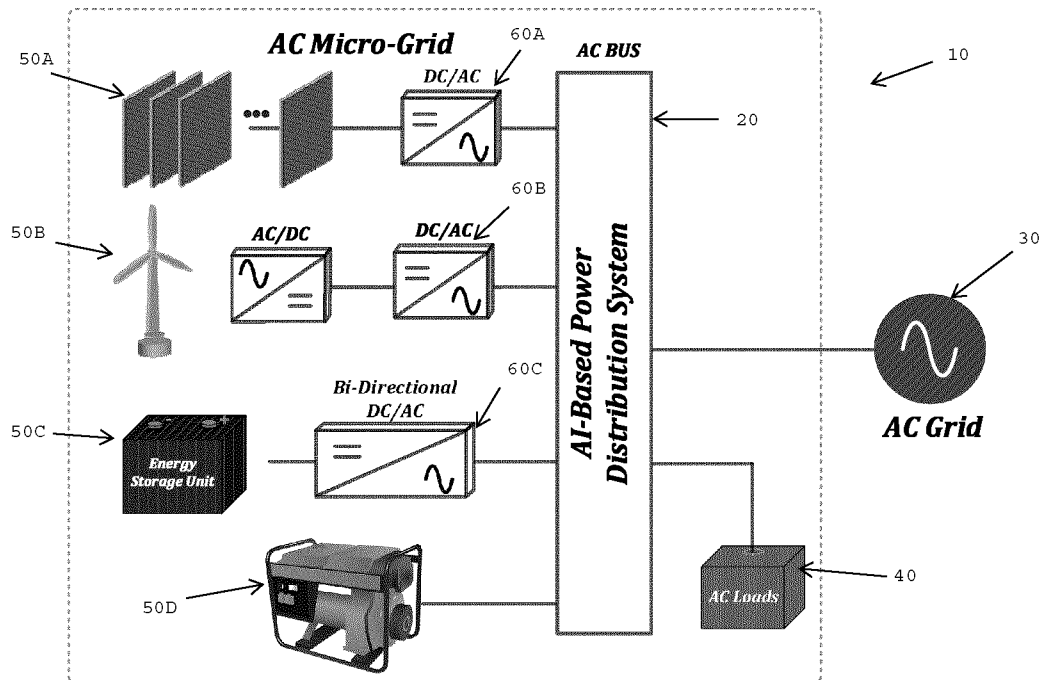
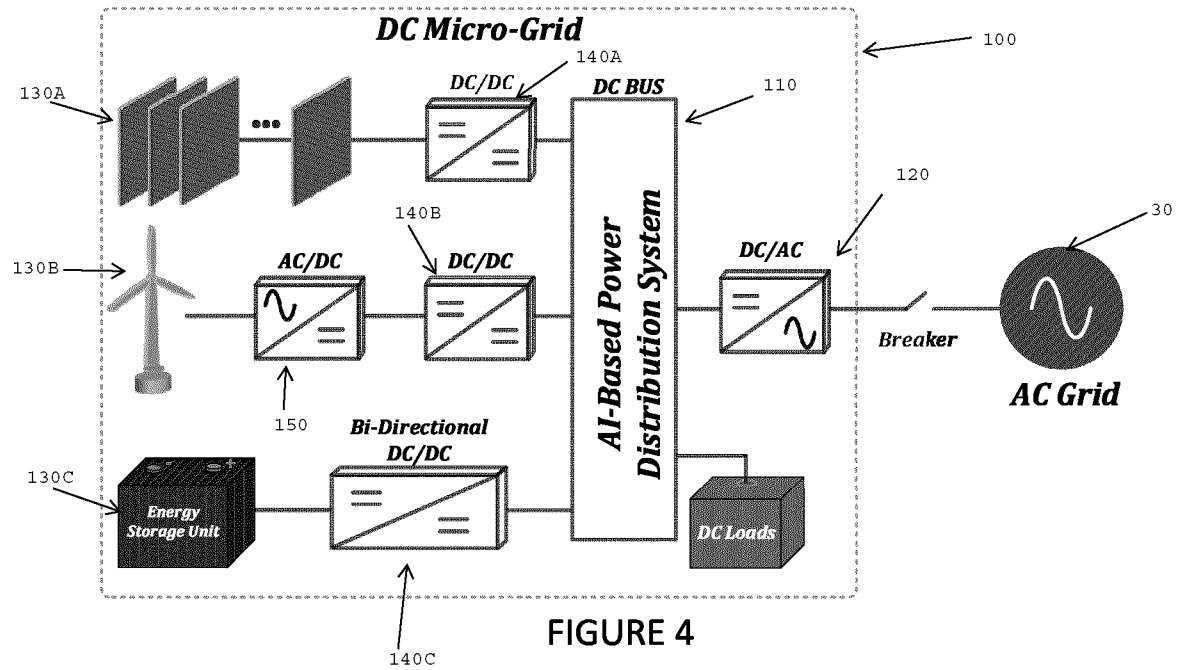


FIGURE 3



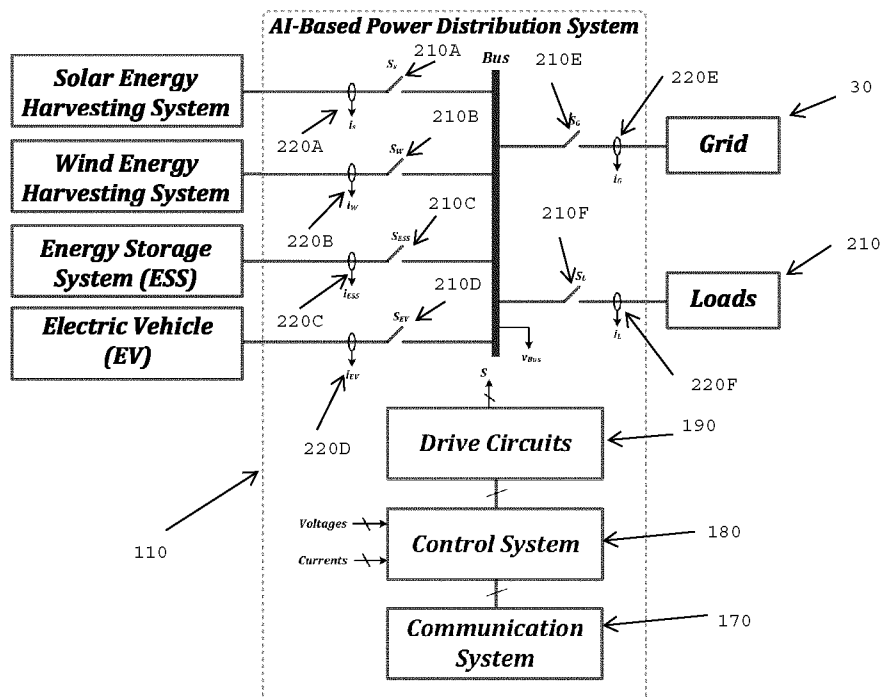


FIGURE 5

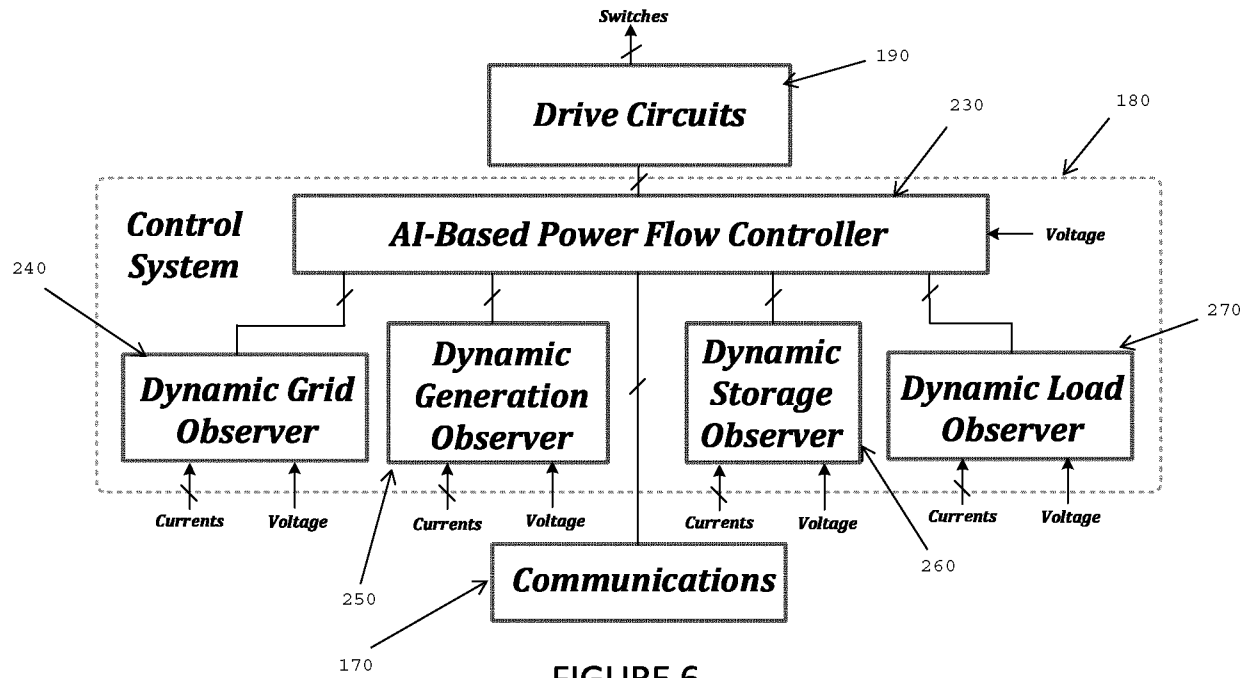


FIGURE 6

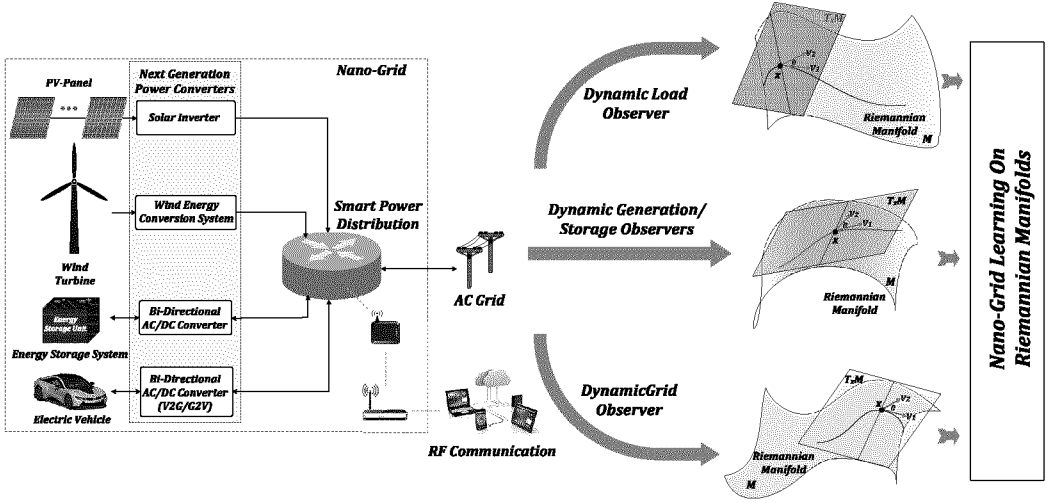


FIGURE 7

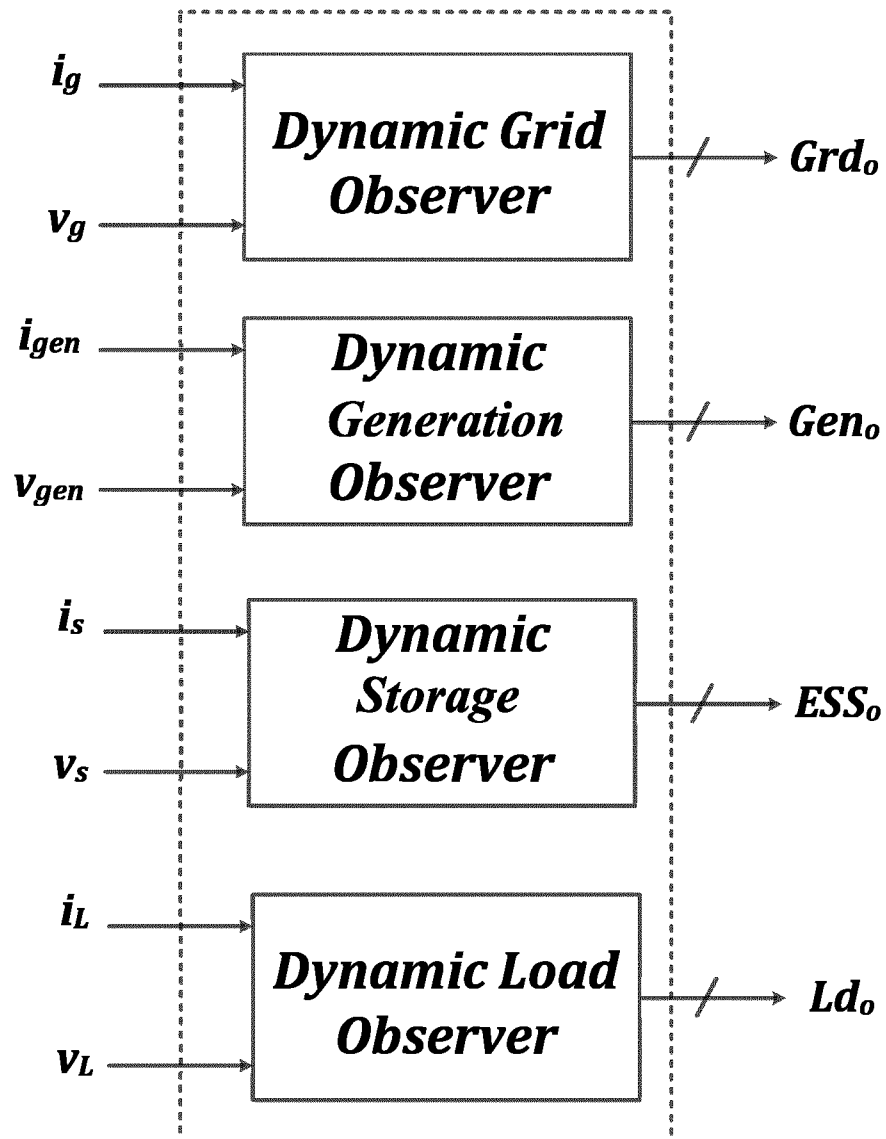


FIG. 8

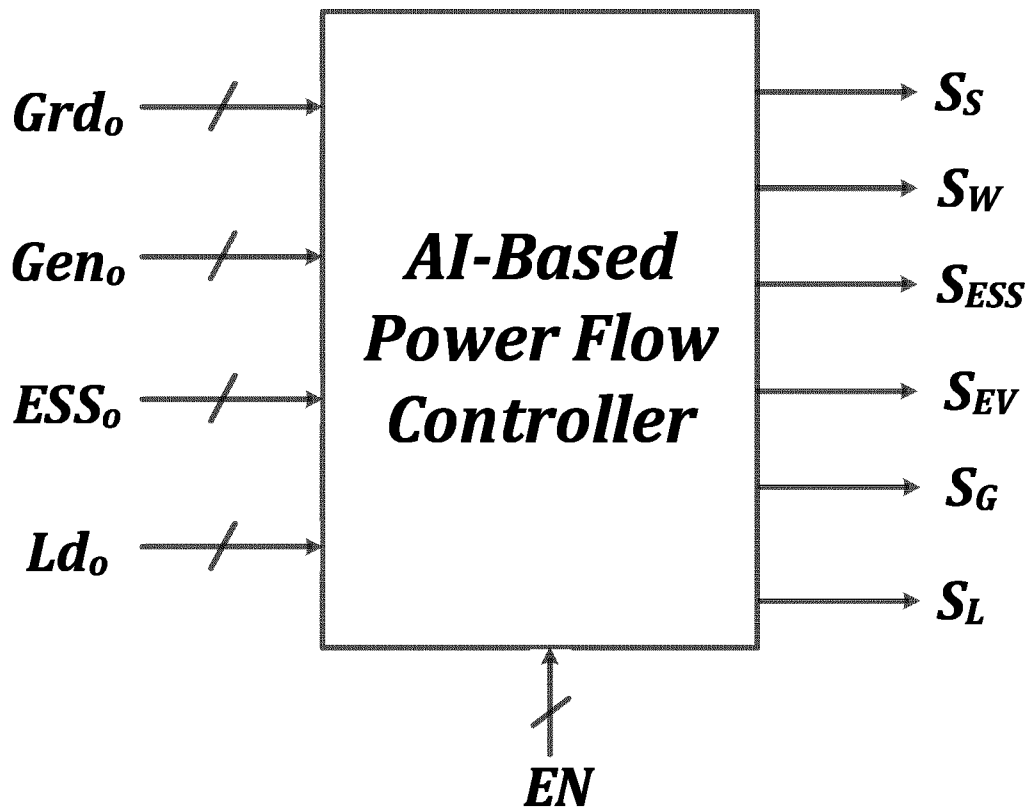


FIG. 9

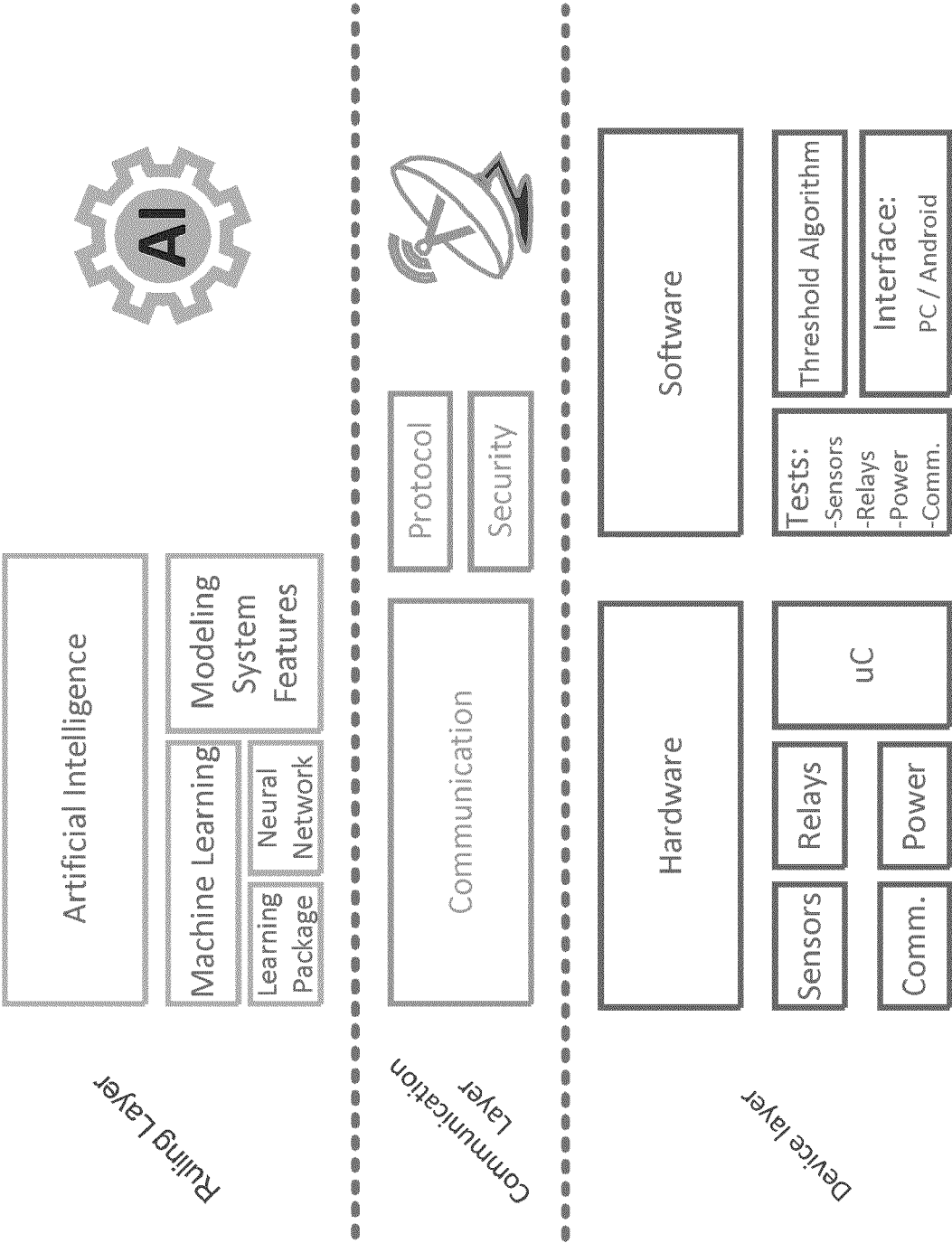


FIG. 10

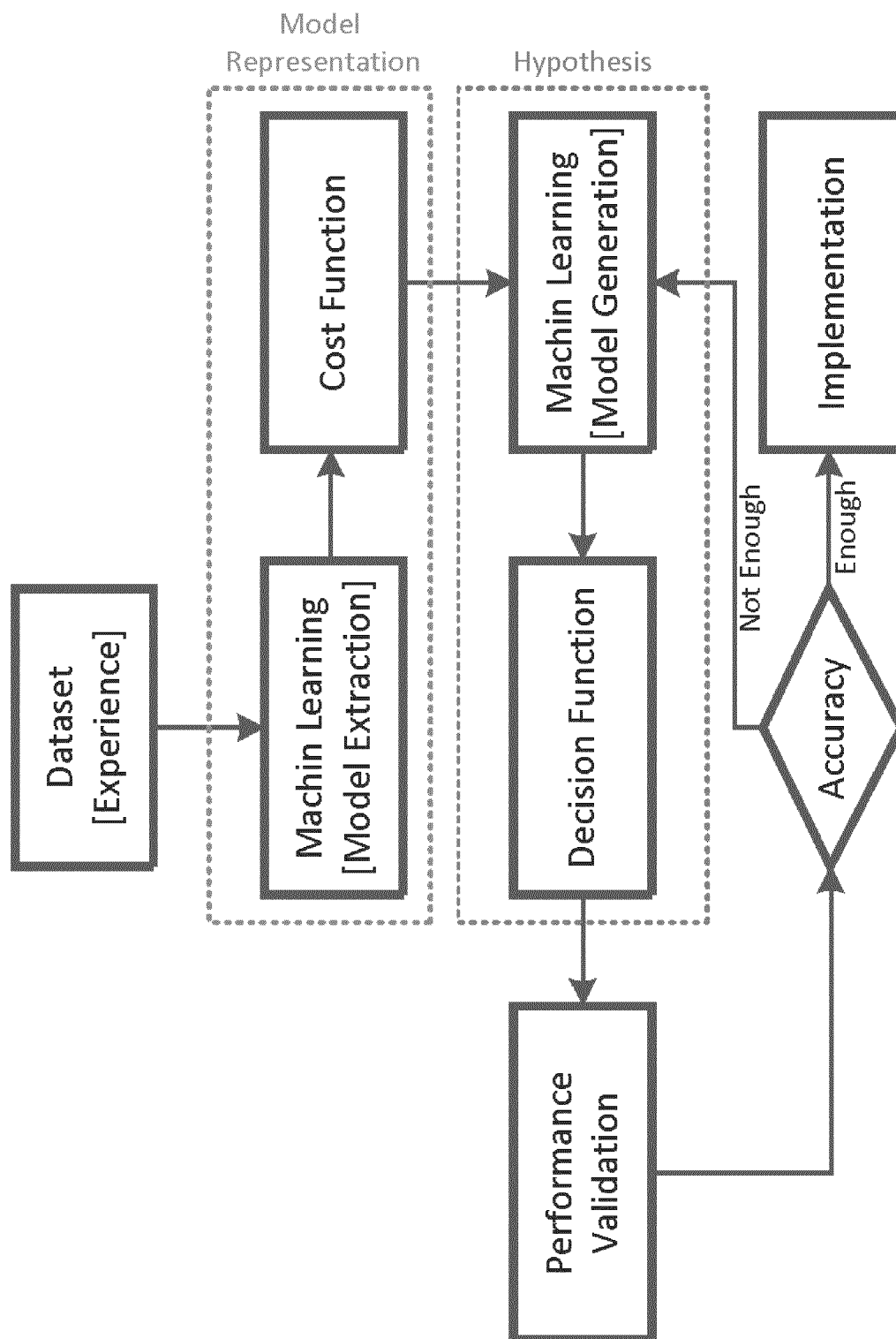


FIG. 11

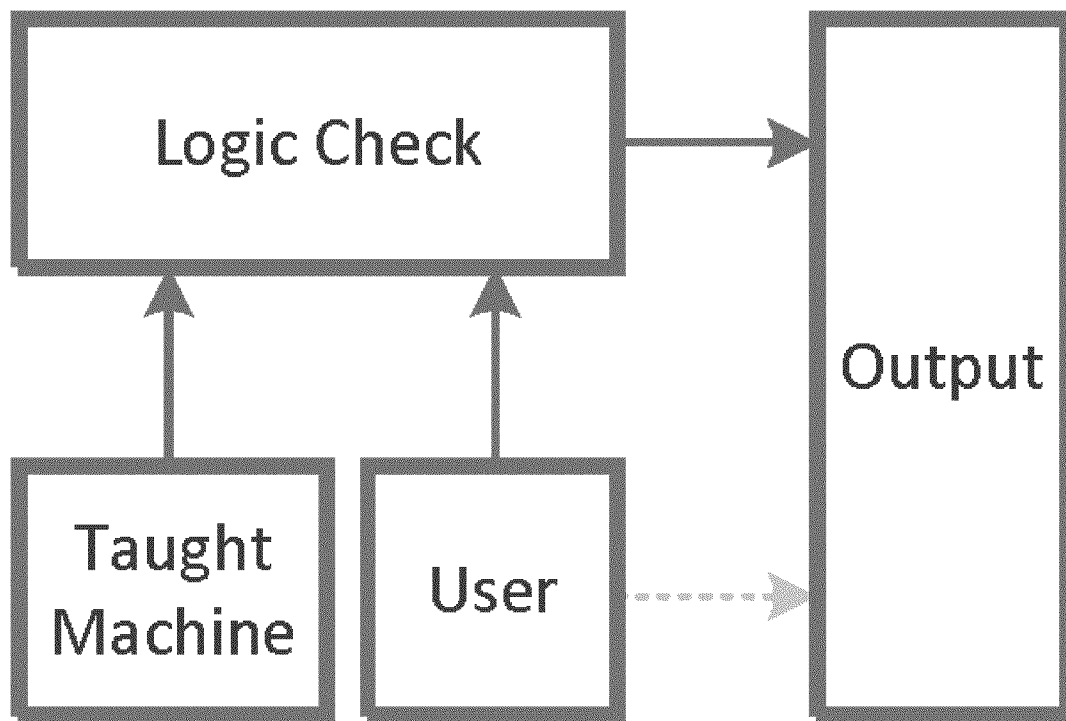


FIG. 12

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CA2019/051224

A. CLASSIFICATION OF SUBJECT MATTER

IPC: **H02J 13/00** (2006.01), **G06N 20/00** (2019.01), **H02J 15/00** (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H02J* (2006.01), **G06N*** (2019.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)

Databases searched: Canadian Patent Database, Questel Orbit, European Patent Database, Patent Abstracts of Japan (PAJ), US Patent Database, WIPO-PCT Publications (Full text), IEEE publications, STN (Scientific & Technical Network) and Google Patents.

Keywords/Search Terms: Power Flow Controller AND (Load Control OR Load Observer OR Load Monitor) AND (Dynamic OR Real-time)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US2011/0106321A1 (Cherian et al.), 05 May 2011 (05-05-2011) -see abstract; figs. 1-9; whole document;	1 – 21
A	US9590421 (Divan et al.), 07 March 2017 (07-03-2017) -see abstract; figs. 1-8; whole document;	1 – 21

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* “A” “D” “E” “L” “O” “P”	Special categories of cited documents: document defining the general state of the art which is not considered to be of particular relevance document cited by the applicant in the international application earlier application or patent but published on or after the international filing date document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) document referring to an oral disclosure, use, exhibition or other means document published prior to the international filing date but later than the priority date claimed	“T” “X” “Y” “&”	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art document member of the same patent family
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Date of the actual completion of the international search

Date of mailing of the international search report
18 November 2019 (18-11-2019)Name and mailing address of the ISA/CA
Canadian Intellectual Property Office
Place du Portage I, C114 - 1st Floor, Box PCT
50 Victoria Street
Gatineau, Quebec K1A 0C9
Facsimile No.: 819-953-2476

Authorized officer

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2019/051224

Patent Document Cited in Search Report	Publication Date	Family Members(s)	Publication Date
US2011/0106321A1	05 May 2011 (05-05-2011)	US2011106321A1 US8401709B2 CA2779307A1 CN102725933A CN102725933B DK2599183T3 EP2497177A2 EP2497177B1 EP2599182A1 EP2599183A1 EP2599183B1 ES2617753T3 JP2013510545A JP5896420B2 US2013166085A1 US8825218B2 US2012029897A1 US9300137B2 US2012029720A1 US2015012146A1 WO2012008979A2 WO2012008979A3 WO2012015507A1 WO2012015508A1	05 May 2011 (05-05-2011) 19 March 2013 (19-03-2013) 19 January 2012 (19-01-2012) 10 October 2012 (10-10-2012) 10 February 2016 (10-02-2016) 27 February 2017 (27-02-2017) 12 September 2012 (12-09-2012) 12 June 2019 (12-06-2019) 05 June 2013 (05-06-2013) 05 June 2013 (05-06-2013) 30 November 2016 (30-11-2016) 19 June 2017 (19-06-2017) 21 March 2013 (21-03-2013) 30 March 2016 (30-03-2016) 27 June 2013 (27-06-2013) 02 September 2014 (02-09-2014) 02 February 2012 (02-02-2012) 29 March 2016 (29-03-2016) 02 February 2012 (02-02-2012) 08 January 2015 (08-01-2015) 19 January 2012 (19-01-2012) 12 April 2012 (12-04-2012) 02 February 2012 (02-02-2012) 02 February 2012 (02-02-2012)
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