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(54) **SYSTEM FOR DISTRIBUTING DC POWER TO AND CONTROLLING BUILDING DEVICES**

(71) Applicant: **The Watt Stopper, Inc.**, Carlsbad, CA (US)

(72) Inventors: **Jeffrey T. Davis**, Carlsbad, CA (US);
Jonathan P. Cartrette, Carlsbad, CA (US)

(73) Assignee: **The Watt Stopper, Inc.**, Carlsbad, CA (US)

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H05B 37/02 (2006.01)
H02J 1/00 (2006.01)
H02M 7/04 (2006.01)
H02J 1/08 (2006.01)
H02J 5/00 (2016.01)
H05B 45/37 (2020.01)

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H05B 47/19 (2020.01)

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CPC **H02J 1/00** (2013.01);
H02J 1/08 (2013.01); **H02J 5/00** (2013.01);
H02M 7/04 (2013.01); **H05B 45/37** (2020.01);
H05B 47/18 (2020.01); **H05B 47/19** (2020.01)

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See application file for complete search history.

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Primary Examiner — Alfonso Perez Borroto

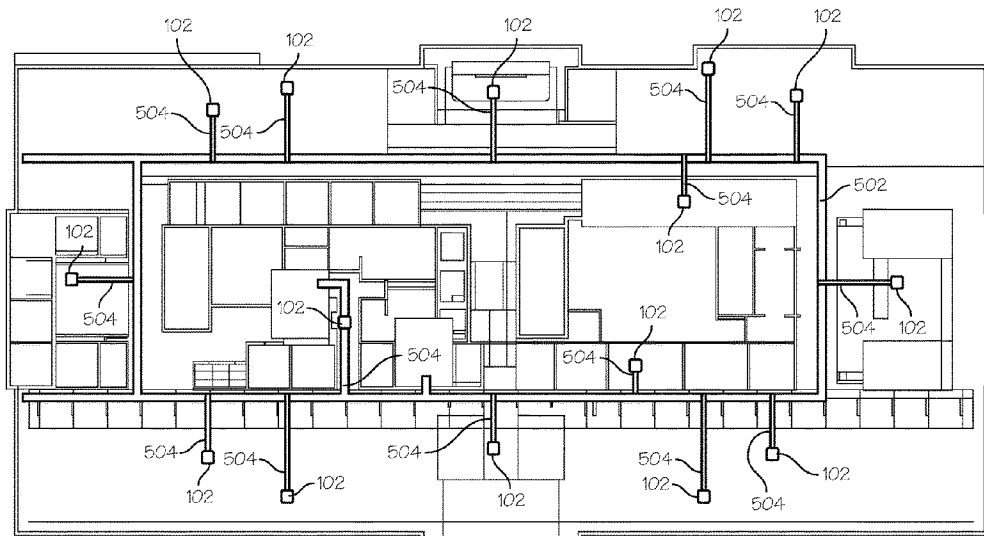
Assistant Examiner — Esayas G Yeshaw

(74) *Attorney, Agent, or Firm* — Crockett & Crockett, PC; K. David Crockett, Esq.; Niky Economy Syrengelas, Esq.

(57) **ABSTRACT**

A scalable DC power distribution and control system suitable for commercial buildings includes one or more power and control hubs. Each DC power and control power hub provides power and control for any suitable distributed DC loads such as light-fixtures. AC power from the electric utility is applied to the power and control hub and is converted to DC power for distribution to DC loads within the space using low-voltage cables.

8 Claims, 6 Drawing Sheets



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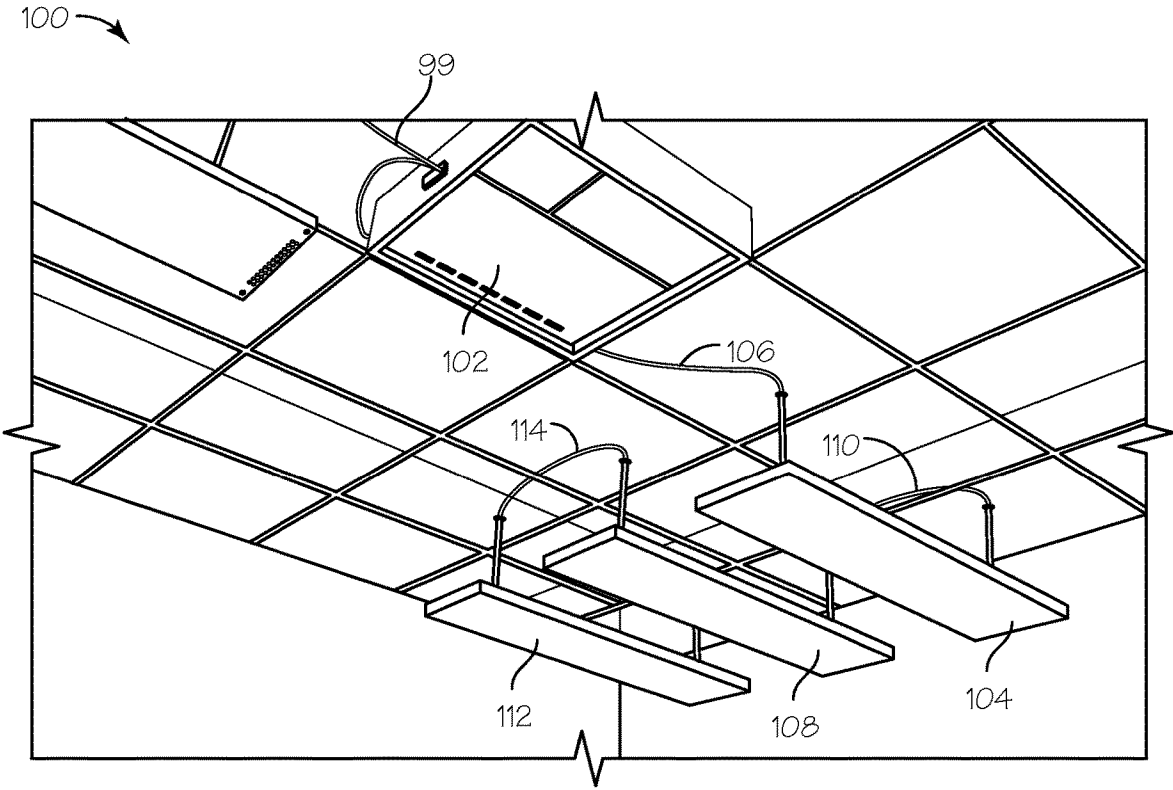


Fig. 1

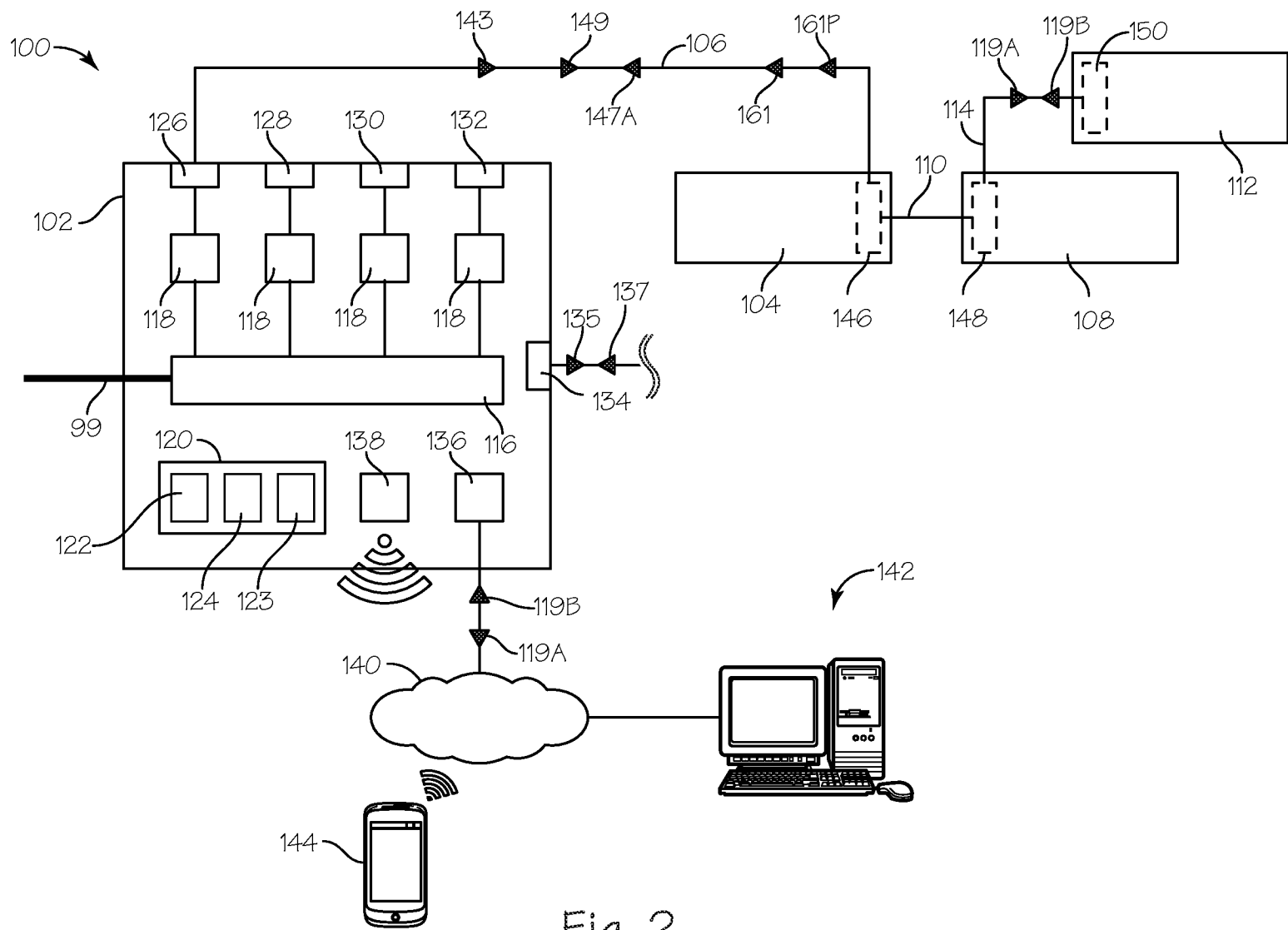


Fig. 2

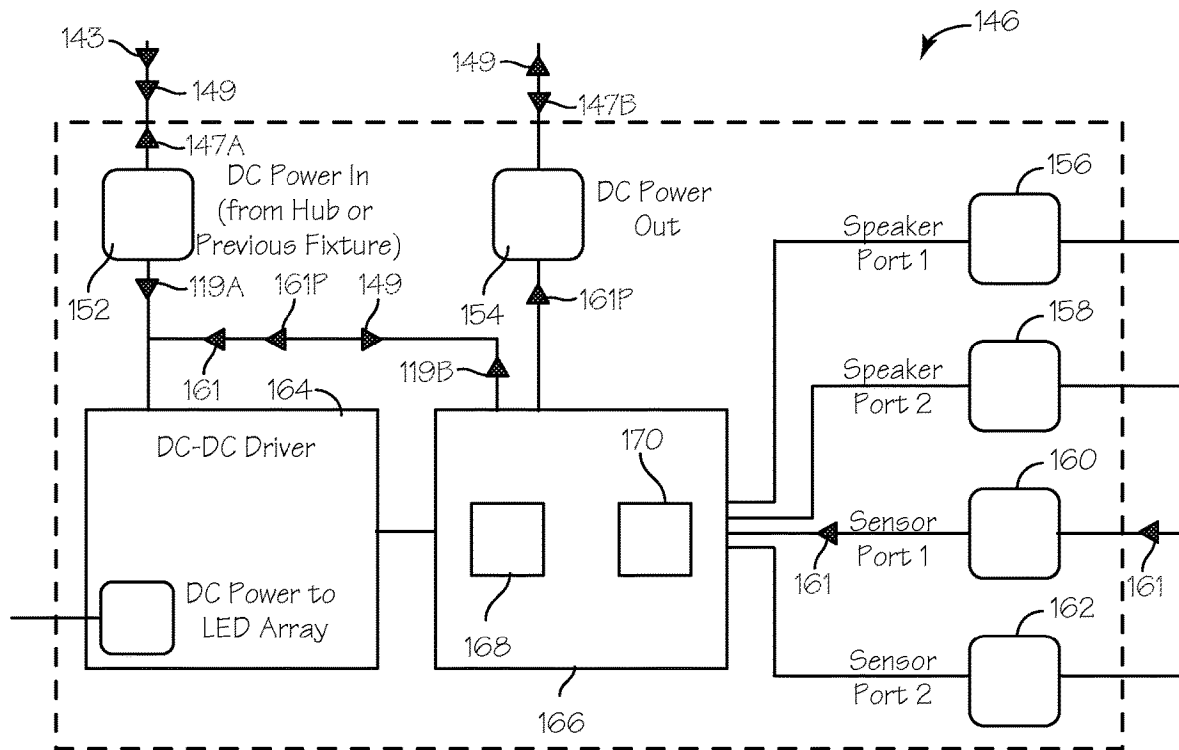


Fig. 3

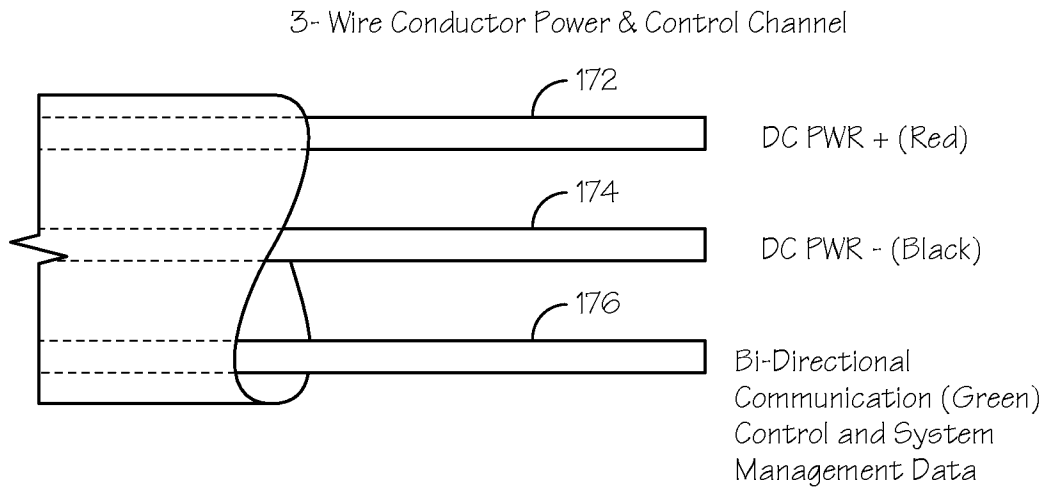


Fig. 4A

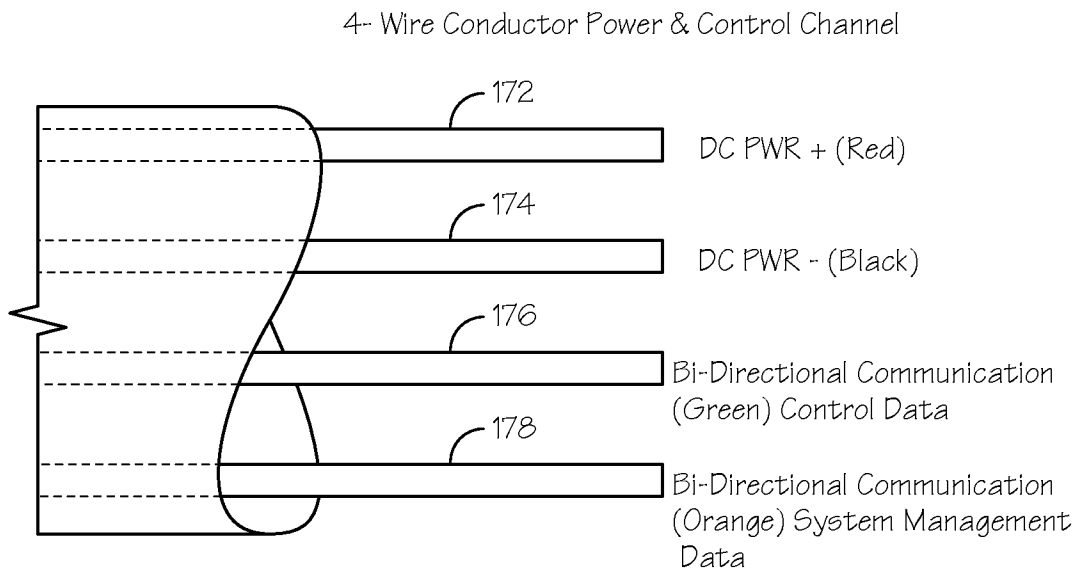


Fig. 4B

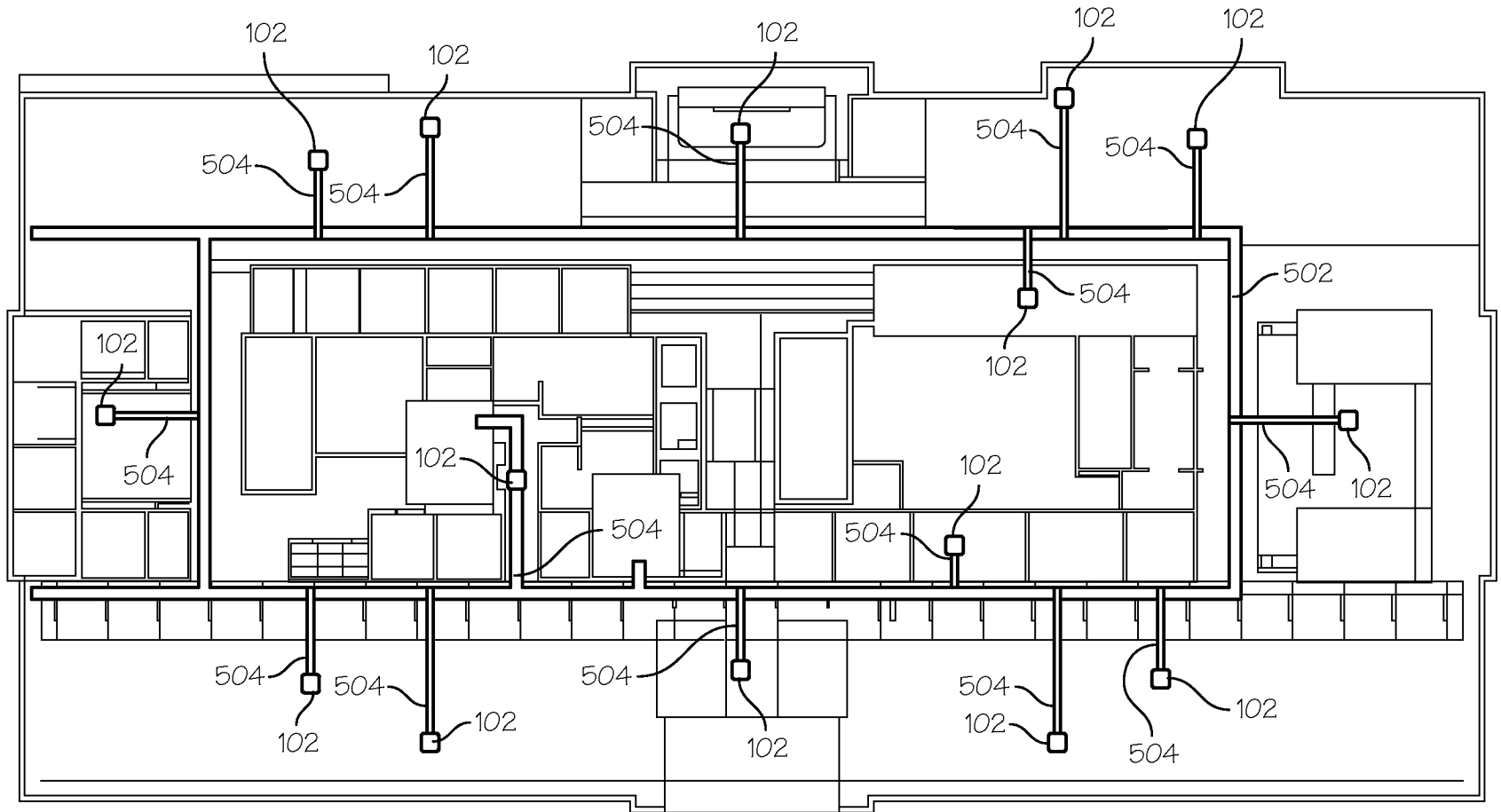


Fig. 5

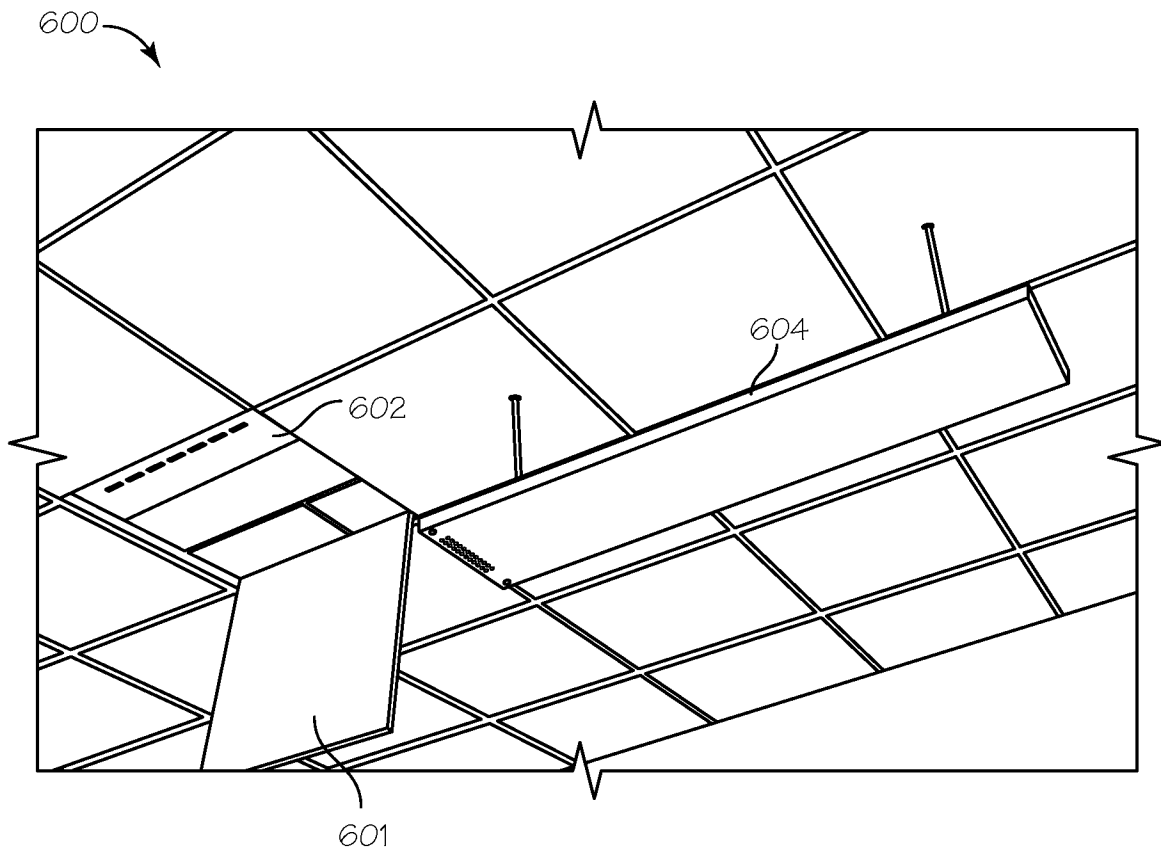


Fig. 6

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SYSTEM FOR DISTRIBUTING DC POWER TO AND CONTROLLING BUILDING DEVICES

RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 15/166,078, filed May 26, 2016, now U.S. Pat. No. 10,141,739, which in turn claims priority to U.S. Provisional Application 62/166,512 filed May 26, 2015.

FIELD

The inventions described below relate to the field of powering and controlling devices located in building spaces.

BACKGROUND

Building power systems typically distribute alternating-current (AC) electrical power that is delivered by an electric utility. Some electrical devices inside the building are design to operate based upon AC electrical power, for example incandescent light fixtures. Many electrical devices within a building require direct-current (DC) electrical power to operate. A typical example is a lamp constructed using light emitting diodes (LEDs). Because most building power systems distribute AC power, devices requiring DC power typically are associated with a device-specific AC/DC converter. AC/DC converters, however, generate power losses and using a dedicated AC/DC converter for each device that runs on DC power multiplies the power loss. Additionally, when the power distribution within a building is AC, the power wires must generally be housed in conduits and raceways as a safety measure increasing complexity and expense as well as potentially detracting from room aesthetics.

SUMMARY

The devices and methods described below provide for a scalable DC power distribution and control system suitable for commercial buildings. A DC power and control power hub provides power and control for any suitable distributed DC loads such as light-fixtures. AC power from the electric utility is applied to the power and control hub and is converted to DC power for distribution to DC loads within the space using low-voltage cables. Thus, the power loss due to many different and inefficient AC/DC converters can be consolidated into a single, more efficient conversion to save energy and conduits and raceways can be omitted.

Low-voltage cables are also used to transmit data signals. The devices and methods described below provide an opportunity to both power and control a device with a single cable more efficiently than existing approaches such as Power over Ethernet (POE).

A system for controlling and distributing DC power includes a power hub having a hub controller, a power converter converting AC power to DC power, one or more variable voltage regulators operatively connected to the power converter and controlled by the hub controller, or more output ports, each of the one or more output ports operatively connected to each of the one or more variable voltage regulators for providing regulated DC power and for receiving and transmitting data and control signals to one or more primary loads, one or more communication interfaces operatively connected to the hub controller for transmitting and receiving data and control signals over a network.

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Connected to the power hub are one or more primary loads, each primary load operatively connected to one of the one or more output ports, each primary load having a load control module, the load control module having a load controller operatively connected to the hub controller for receiving and transmitting data and control signals to the hub controller, a plurality of output ports operatively connected to the load controller, the plurality of output ports providing DC power to secondary loads and transmitting and receiving data and control signals to and from the load controller and a load driver for distributing DC power to the primary load, the load driver operatively connected to and under control of the load controller.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a power-distribution and control system.

FIG. 2 is a schematic representation of the power-distribution and control system shown in FIG. 1.

FIG. 3 is a schematic representation of a load control module in the power-distribution and control system shown in FIG. 1.

FIGS. 4A and 4B are schematic representations of the conductors inside the cables connecting components in the power distribution and control system of FIG. 1.

FIG. 5 is an exemplary building floor plan that depicts how the power-distribution and control system shown in FIG. 1 is connected to the AC power-distribution system running through the building.

FIG. 6 is a perspective view of another power-distribution and control system.

DETAILED DESCRIPTION OF THE INVENTIONS

FIG. 1 shows a perspective view of power-distribution and control system 100. The power-distribution and control system includes one or more power distribution hubs such as hub 102. Power distribution hubs such as hub 102 may be located in any suitable location such as on a ceiling, in a ceiling plenum, under a raised floor, on a wall, in a rack or enclosure mounted, or placed in a distribution closet for electrical or telecom equipment. Hub 102 is connected to AC power wires that are connected to the building AC power distribution system. An LED light fixture 104 is connected to the hub 102 through cable 106. As described in more detail below, cable 106 transmits both power and control signals from hub 102 to any suitable distributed DC loads such as light fixture 104. An LED light fixture 108 is connected to light fixture 104 through another cable 110. Cable 110 has the same construction as cable 104 but may differ in its length. An LED light fixture 112 is connected to light fixture 108 through cable 114. Cable 114 has the same construction as cables 106 and 110 but may differ in its lengths. The structure of cables 106, 110 and 114 is described in more detail below with reference to FIGS. 4A and 4B. Additional light fixtures or other DC loads can be added in a daisy-chain configuration with cables having the same construction as cables 106, 110, and 114. Distributed DC loads may be sensors, sound masking components, sub-metering components, emergency lighting components and occupancy density mapping components. Additionally, one or more additional light fixtures can be connected directly to hub 102 and additional light fixtures can be daisy-chained to the additional light fixtures that are directly connected to the hub using additional cables having the

same construction as cables **106**, **110**, and **114**. While the system **100** is shown and described as powering and controlling LED light fixtures, it should be understood that a system according to the present disclosure can control and power other types of light fixtures as well, for example, fluorescent light fixtures. Additionally, while system **100** is shown and described with one hub **102**, it should be understood that a system according to the present disclosure can include multiple interconnected hubs that can communicate through each other through a building computer network.

FIG. **2** shows a schematic representation of the power-distribution and control system shown in FIG. **1**. Hub **102** includes an AC/DC converter **116** that converts the AC power from the AC power wires **99** that are connected to Hub **102** into DC power that is used by the power-consuming devices in the system. Hub **102** also contains voltage regulators **118** that regulate the output voltage of the AC/DC converter. One voltage regulator stage per output connection is utilized to guarantee that amperage levels provided stay within safety NEC limits for Class 2 power. Voltage regulators **118** may be individual per port or combined on a common backplane or splitter board. Additionally each regulator stage utilizes current limiting to protect from both over current and short circuit events in a manner that does not damage the electrical components of hub **102** or any attached light fixtures or control devices.

Hub **102** also contains a controller **120** containing a memory **122** and one or more microprocessors such as microprocessor **124** and communication transceiver **123**. The controller **120** controls the AC/DC converter **116** and the voltage regulators **118**, and can also be used to control the entire system **100**. Controller **120** administrates communication between light fixtures or control accessory devices connected physically or logically to hub **102** through communication transceiver **123** and output ports **126**, **128**, **130** and **132**. Controller **120** also administrates wired and wireless communication with one or more network computers, other hubs and with workstations and mobile devices through communication transceiver **123** using wired network interface **136** and a wireless network interface **138** respectively. Having both wired and wireless communications capabilities enables the hubs and loads to determine which devices are physically close together as loads and controllers hard wired together are generally within 30-50 feet of each other and would be most likely to need to participate with the controller in application binding.

Controller **120** manages the list of control bindings that relate control accessory inputs to actuator events they assert including, but not limited to causing lights to turn on, off, or dim, and enabling or disabling other control accessory devices or subordinate systems such as sound masking or emergency signage. Communication addressing and message routing are able to work between a set of accessories, light fixtures, and other hub **102** functions without the requirement for a global or supervisory controller. Hub **102** also includes output ports **126**, **128**, **130**, and **132** for distributing the DC power output by the AC/DC converter. Each output port can provide, for example, 100 W of power and Class II circuits currently allow up to 60 VDC. The output ports can be programmed to provide voltages from 12-60 VDC and each output port can output power at different voltage levels. For example, output port **126** and **128** can output 24V and ports **130** and **132** can output 48V. For ease of reference, four output ports are shown, but it should be understood that hub **102** can have more or less than four output ports. Hub **102** can also include one or more connections **134** for providing power and content signals

such as power and content signal **135** to audio speakers as well as sending power and control signals **135** and receiving control signals and data **137** from secondary loads such as sensors or other suitable infrastructure components.

Hub **102** also includes a wired network interface **136** and a wireless network interface **138**. Interfaces **136** and **138** can be used to connect hub **102** to a computer network **140**. Network **140** can be a local area network (LAN) that utilizes the IEEE 802.11 or 802.3 standards family variants or a local control accessory device network utilizing IEEE 802.15.4 family technologies, sub Ghz RF, or Bluetooth variants including but not limited to Bluetooth Smart, Bluetooth Low Energy (BLE), and Bluetooth classic. Alternatively, the computer network **140** can be a wide-area network (WAN) such as the Internet. Through the computer network, hub **102** can communicate with other hubs or with a personal computer **142** or mobile device **144** running application software that performs one or more of the following functions: system configuration and management; real-time graphical display of system data (commonly referred to as “dashboarding”); data analytics; reporting; machine learning of the typical control functions of other hubs nearby to hub **102** for the purposes of real-time adaptive self programming of control operational sequences.

As shown in FIG. **2**, each LED fixture **104**, **108**, **112** respectively includes a load control module **146**, **148**, **150**. One end on each of cables **106**, **110**, **114** plugs directly into an input port on the respective one of load control modules **146**, **148**, **150** to connect the fixtures to the system. The opposite end of cable **106** also plugs directly into output port **126** of hub **102**, the opposite end of cable **110** plugs directly into an output port of control module **146** and the opposite end of cable **114** also plugs directly into an output port of control module **148**.

FIG. **3** shows a schematic representation of the load control module **146** shown in FIG. **2**. Load control modules **148**, **150** have the same or substantially the same construction as load control module **146**. Load control module **146** includes an input port **152** for receiving a cable (in this case, cable **106**). Load control module **146** receives DC power **143** and control signals **149** through input port **152** and also sends information monitoring signals **147A**, sensor data **161** and processed sensor data **161P** out from input port **152**. Load control module **146** uses all or a subset of output ports to apply DC power **145** to any suitable secondary loads that are operatively connected to the fixture such as LED lights, occupancy sensors, environmental sensors, speakers, IT equipment, personal computers, charging receptacles (USB and wireless charging), displays, and potentially any DC load that is 60 VDC and below and draws less than 100 W. Load control module also includes an output port **154** for receiving a cable (in this case cable **110**). Load control module serves as a conduit for transmitting DC power to one or more downstream devices (if such downstream devices are connected) through output port **154**. Load control module also serves as a conduit for transmitting control signals **149** to the downstream devices and receiving monitoring information signals **147B** from the downstream devices through output port **154**.

Load control module **146** also includes one or more output ports for secondary loads such as speaker ports **156**, **158** and sensor ports **160**, **162**. Each output port for secondary loads is for receiving a cable having the construction of cables **106**, **110**, **114** that is connected on its opposite ends to a secondary load such as a speaker, for example, a speaker that is used for sound-masking purposes in an office environment. Alternatively, output ports for secondary loads may

be configured to use category 5 or category 6 cables to connect secondary loads such as speakers and sensors that have low current demands. In this way secondary loads such as speakers can be powered and controlled through the overall control system **100**. Each sensor port is for receiving any suitable cable having the construction similar to cables **106**, **110**, **114** that is connected on its opposite ends to any suitable secondary load such as a sensor, for example, an occupancy, vacancy, daylight, or temperature sensor. In this way room monitoring sensors can be powered and controlled through the overall control system **100**, and sensor data **161** from the sensor can be processed, used, or reported externally by the control system **100**.

Load control module **146** further includes one or more primary load control drivers such as LED driver **164**. Primary load control driver **164** regulates the DC voltage that is output to the primary load such as the LEDs in the light fixture and protects against voltage fluctuations, which can impact the light output by the LEDs. The LED driver provides a constant current output typically (but not necessarily) within the range of 20 mA to 750 mA and at a voltage range typically (but not necessarily) 12 VDC-60 VDC. The output of the LED driver powers one or more LED arrays at a certain level of illumination. The output of the LED driver is tailored to the specific arrangement of LED arrays and the desired illumination level.

Load control modules such as modules **146**, **148** and **150** may include the primary load control drivers such as LED driver **164** as integrated components as illustrated or the load control drivers may be separate modular components that can be closely coupled or connected via a wire harness or any suitable bus interface that supports power & data such as a USB interface. The use of separate drivers permits pairing a load control module with a wider variety of dc/dc driver products that are either for LED arrays or powering other suitable loads.

Load control module **146** also includes a controller **166** having a memory **168** and one or more programmable microprocessors such as microprocessor **170**. The controller **166** receives and processes control signals through input port **152** and controls the LED driver **164**, any connected speaker, and any connected sensors accordingly. Additionally, controller **166** receives sensor data such as sensor data **161** from any sensors connected to the load control module and can process that data as desired or can forward processed sensor data **161P** to another device on the system. The controller **166** utilizes a hardware unique MAC address to indicate its model number, role, functionality, and logical hierarchy for digital communications within system **100**. Controller **166** is addressed within system **100** through its MAC address. Controller **166** can control the current and voltage output by LED driver **164** to change the brightness of the LEDs. This regulation can be based upon control signals received by the controller **166** that have been transmitted through system **100**. Illumination levels throughout the driver's full dynamic brightness range are commanded through means including 0-10V analog signals or direct digital communication to controller **166** or by methods such as universal asynchronous receiver/transmitter (UART), Serial Peripheral Interface (SPI), Inter-Integrated Circuit (I2C), Digital Addressable Lighting Interface (DALI), or Digital Multiplex (DMX) protocols.

FIGS. 4A and 4B schematically depict two different wire configurations for the cables used in system **100**, such as cables **106**, **110**, **114**. Unlike systems that use established standards, such as POE, for transmitting power and data over a single cable, system **100** does not use cables that are

widely used for data transmission, such as Category 5 or 6 cable. The Institute of Electrical and Electronics Engineers (IEEE) type 2 POE standard limits the current in Category 5 cables to 600 ma per pair with a maximum power available of 25.5 watts. Thus, POE is incapable of providing the DC power available from system **100**. The use of larger diameter conductors limit power loss in the cables of system **100** and thus permits daisy-chained configurations. The resistance of the wires in Cat 5 or 6 cable lead to unacceptable power losses in such a configuration.

FIG. 4A shows a three-wire configuration. First wire **172** is a positive power wire. Second wire **174** is a negative power wire. Third wire **176** conducts bidirectional communication of control signals and system-management data such as control signals **149**, information monitoring signals **147A**, sensor data **161** and processed sensor data **161P**. A fourth wire providing a ground for the communication and control channel is not required. Second wire **174** acts as a common ground for both the power circuit and the communication and control circuit. Preferably, wires **172-76** have a gauge of AWG **18** (wire diameter of 0.0403 in.) or larger. In comparison, Cat 5 and Cat 6 cables have wire diameters of 0.02503 in. and smaller.

FIG. 4B shows a four-wire configuration. In this configuration the control signals are delivered on wire **176** and the system management data is delivered on additional wire **178**. Wires **453** and **454** (as well as wire **451**) share wire **452** as a ground wire. Cables providing three or four AWG **18** wires can currently be purchased in bulk from a number of sources. An installer can then simply determine the amount of cable needed to connect two devices, cut out that length of cable, and then add connectors to the end of the cable on-site. The process of adding connectors to the end of a cable is known as "terminating" the cable. The use of field-terminable bulk cable in system **100** makes it possible to place devices in system **100** arbitrarily far apart from each other. The installer can simply cut out the length of bulk cable required to span the distance and then field-terminate that cable preventing or limiting service loops which can create power and communication-strength losses as well as have a negative effect on aesthetics.

FIG. 5 shows a schematic layout for a space **500**. Space **500** may be a building, a floor of a building or a portion of a floor of a building. In FIG. 5, space **500** is shown as an entire floor of a building. A primary AC power pathway **502** traverses the floor. Secondary AC power pathways **504** connect hubs **102** to the primary AC power pathway. For example, one hub could be installed for every 2,500 square feet of space.

FIG. 6 shows a perspective view of another power-distribution and control system **600**. This system is similar to system **100** shown in FIG. 1, except that the hub **602** is mounted above the ceiling instead of below the ceiling so that hub **602** can be hidden from view. Hub **602** is dimensioned so that it can be inserted into the ceiling through the space taken up by a standard ceiling tile **601** for a commercial space. In this manner, hub **602** can be inserted into the ceiling from within the room by first removing the ceiling tile **601** at the appropriate installation location. Once the hub is installed in the ceiling, the ceiling tile can be replaced to hide the hub from view. The cable connecting hub **602** to fixture **604** can also be hidden by routing it through the mounting structure for fixture **604**.

The disclosed power-distribution and control systems can route DC power, control signals, and sensor data among controllers regardless of how they are connected. The system is not topology-specific; it is topology agnostic. Devices

such as light fixtures do not need to be connected directly to the hub. They can, instead, be daisy-chained together so long as combined they do not draw more power than a particular hub output channel can provide. For example, if a hub output can provide 100 W, then four devices each drawing 25 W can be connected to that output in a series fashion. Adding a fifth device that normally draws 25 W, would overload the output unless the devices contain circuitry or software that permits them to reduce their power draw (resulting in less brightness, for example, for a light) or coordinate the timing of their loads to keep the peak below the output channel rating upon the detection of an overload condition.

Additionally, hubs in power distribution and control system 100 such as hub 102 can communicate with any controller in the system even if it is not directly connected to them. Packets such as packets 119A and 119B are addressed to the MAC addresses of particular controllers, and intermediate controllers along the path from the source to destination do not serve as a barrier to successful transmission. In this sense the communication channel logically acts as a single communication wire, even though it may be physically made up of several wires through the daisy-chain connections. The controllers use transceivers such as transceiver 123 that can monitor incoming data for packets such as packets 119A or 119B addressed to them. The communications protocol for system 100 uses first-come first-serve priority and employs random-times for attempted retransmission when two load control modules send a packet at the same time such that there is a collision. The controllers can self-organize and establish hierarchies according to the principles set forth in U.S. Pat. No. 8,487,474 titled Method and Apparatus for Electrical Load Control Network, which patent is hereby incorporated by reference in its entirety.

While the preferred embodiments of the devices and methods have been described in reference to the environment in which they were developed, they are merely illustrative of the principles of the inventions. The elements of the various embodiments may be incorporated into each of the other species to obtain the benefits of those elements in combination with such other species, and the various beneficial features may be employed in embodiments alone or in combination with each other. Other embodiments and configurations may be devised without departing from the spirit of the inventions and the scope of the appended claims.

We claim:

1. A system for controlling and distributing DC power comprising:
 a plurality of power hubs wherein each power hub comprises:
 a hub controller;
 a power converter adapted to convert AC power to DC power;
 one or more variable voltage regulators operatively connected to the power converter and controlled by the hub controller, the one or more variable voltage regulators are operable to provide regulated DC power to one or more primary loads and to receive and transmit data and control signals from and to the one or more primary loads;
 one or more communication interfaces operatively connected to the hub controller to transmit and receive data and control signals;
 one or more primary loads operatively connected to each of the plurality of power hubs, each primary load having a load control module, the load control module comprising:

a load controller operatively connected to the hub controller to receive and transmit data and control signals to the hub controller;
 a plurality of output ports operatively connected to the load controller, the plurality of output ports adapted to provide DC power to secondary loads and to transmit and receive data and control signals to and from the load controller;
 a load driver adapted to distribute DC power to the secondary loads, the load driver operatively connected to and under control of the load controller.

2. The system for controlling and distributing DC power of claim 1 wherein the one or more primary loads are selected from the group consisting of lights, sensors, shades, sound masking components, sub-metering components, emergency lighting components and occupancy density mapping components.

3. The system for controlling and distributing DC power of claim 1 wherein the plurality of power hubs and load controllers are operatively connected to each other via a network.

4. The system for controlling and distributing DC power of claim 3 wherein the network is exclusive to the plurality of power hubs.

5. The system for controlling and distributing DC power of claim 2 wherein at least one of the one or more primary loads is operatively connected to one or more secondary loads and the one or more secondary loads are selected from the group consisting of lights, sensors, shades, sound masking components, sub-metering components, emergency lighting components and occupancy density mapping components.

6. A system for controlling and distributing DC power comprising:
 one or more power hubs wherein each power hub comprises:
 a hub controller;
 a power converter adapted to convert AC power to DC power;
 one or more variable voltage regulators operatively connected to the power converter and controlled by the hub controller, the one or more variable voltage regulators are operable to provide regulated DC power to one or more primary loads and to receive and transmit data and control signals from and to the one or more primary loads;
 one or more communication interfaces operatively connected to the hub controller to transmit and receive data and control signals;
 one or more primary loads, each primary load having a load control module and a load driver; and
 a plurality of secondary loads operatively connected to the load driver of at least one primary load.

7. The system for controlling and distributing DC power of claim 6 wherein the one or more primary loads and the plurality of secondary loads are selected from the group consisting of lights, sensors, shades, sound masking components, sub-metering components, emergency lighting components and occupancy density mapping components.

8. The system for controlling and distributing DC power of claim 1 wherein the one or more power hubs and the one or more load controllers are operatively connected to each other via a network.