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(71) Applicant: **KONINKLIJKE PHILIPS N.V.** [NL/NL]; High Tech Campus 5, NL-5656 AE Eindhoven (NL).

(72) Inventors: **SHROTRIYA, Ameya Dilip**; c/o High Tech Campus 5, NL-5656 AE Eindhoven (NL). **HILLAS, Nicholaos**; c/o High Tech Campus 5, NL-5656 AE Eindhoven (NL).

(74) Agents: **VAN EEUWIJK, Alexander Henricus Walterus** et al.; High Tech Campus Building 5, NL-5656 AE Eindhoven (NL).

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(54) Title: LIGHTING UNIT, LIGHTING DRIVER AND SYSTEM FOR DETECTING SIGNALING TRANSITIONS ON LINE VOLTAGE AND CONTROLLING DIMMING LEVEL OF LIGHT SOURCE

(57) Abstract: A lighting unit includes a lighting source and a lighting driver connected to the lighting source. The lighting driver is connected to a line voltage having a burst of signaling transitions that transition between a nominal line voltage and a signaling voltage. The lighting driver detects the signaling transitions on the line voltage, generates a dimming signal responsive to the detected signaling transitions, provides a driving current to the lighting source, and adjusts a level of the driving current responsive to the dimming signal.

Lighting Unit, Lighting Driver And System For Detecting Signaling Transitions On Line Voltage And Controlling Dimming Level Of Light Source

[0001] The present invention is directed generally to a lighting driver for controlling the dimming level of lighting sources. More particularly, various inventive methods and apparatuses disclosed herein relate to a lighting driver and system for detecting signaling transitions inserted onto a line voltage, and controlling the dimming level of lighting sources responsive to the detected signaling transitions.

[0002] Many lighting applications make use of dimmers. Dimming may be achieved by means of standard control interfaces such as a digitally addressable lighting interface (DALI), a digital multiplex (DMX) interface or 0-10V dimming interface, or by line-side control methods such as leading-edge and trailing-edge dimming schemes and a power-line communication scheme. Although well established, each of these interfaces and schemes have limitations and undesirable characteristics.

[0003] For example, control interface standards such as DALI, DMX or 0-10V require installation of control lines in addition to power lines. Most existing lighting infrastructure, particularly outdoor lighting infrastructure, is designed for use with conventional lighting sources and does not support additional control wiring. Also, such control interfaces necessitate the use of a controller located either remotely or at every lighting source. Isolation and safety are concerns.

[0004] Line-side control methods alleviate the need of control lines. However, leading-edge dimming (triac dimming) or forward-phase dimming schemes chop a leading-edge portion of the voltage signal waveform, and trailing-edge dimming or reverse-phase dimming schemes chop trailing edge portions of the voltage signal waveform. Consequently, it is difficult to meet power factor and total harmonic distortion (THD) requirements with these dimming schemes. The dimming percentage is limited and the hardware necessary to implement these schemes is complicated. Power-line communication schemes add noise to the power line, resulting in transmission of electromagnetic interference on the power lines.

[0005] Thus, it would be desirable to provide a lighting driver and line-side dimming scheme that adjusts the dimming level of lighting sources without the use or installation of control wires and standard line-side dimming schemes, and that may be easily installed and implemented in existing lighting infrastructure.

Summary

[0006] The present disclosure is directed to inventive apparatus and method for a lighting driver, and a lighting unit that includes the lighting driver, that detects signaling transitions inserted onto line voltage and controls the dimming level of a light source responsive to the detected signaling transitions.

[0007] Generally, in one aspect, the invention focuses on a lighting unit that includes includes a lighting source; and a lighting driver connected to a line voltage having signaling transitions that transition between a nominal line voltage and a signaling voltage, and that is configured to detect the signaling transitions on the line voltage, generate a dimming signal responsive to the detected signaling transitions, provide a driving current to the lighting source, and adjust a level of the driving current responsive to the dimming signal.

[0008] In another aspect, the invention relates to an electrical device that includes an electrical load; and a load driver connected to a line voltage having signaling transitions that transition between a nominal line voltage and a signaling voltage, and that is configured to detect the signaling transitions on the line voltage, generate a load shedding signal responsive to the detected signaling transitions, provide a driving current to the electrical load, and adjust a level of the driving current responsive to the load shedding signal.

[0009] In another aspect, a lighting driver includes a peak detector configured to detect a peak voltage of a line voltage, the line voltage having signaling transitions that transition between a nominal line voltage and a signaling voltage; a resistive divider configured to provide a divided voltage responsive to the detected peak voltage; a waveform discriminator configured to detect the signal transitions on the line voltage and time intervals between the signaling transitions responsive to the divided voltage, and provide a dimming signal according to the detected time intervals; and a power converter configured to provide a driving current to a lighting source, and adjust a level of the driving current responsive to the dimming control signal.

[0010] As used herein for purposes of the present disclosure, the term “LED” should be understood to include any electroluminescent diode or other type of carrier injection/junction-based system that is capable of generating radiation in response to an electric signal. Thus, the term LED includes, but is not limited to, various semiconductor-based structures that emit light in response to current, light emitting polymers, organic light emitting diodes (OLEDs), electroluminescent strips, and the like. In particular, the term LED refers to light emitting diodes of all types (including semi-conductor and organic light emitting diodes) that may be configured to generate radiation in one or more of the infrared spectrum, ultraviolet spectrum, and various portions of the visible spectrum (generally including radiation wavelengths from approximately 400 nanometers to approximately 700 nanometers).

[0011] For example, one implementation of an LED configured to generate essentially white light (e.g., a white LED) may include a number of dies which respectively emit different spectra of electroluminescence that, in combination, mix to form essentially white light. In another implementation, a white light LED may be associated with a phosphor material that converts electroluminescence having a first spectrum to a different second spectrum. In one example of this implementation, electroluminescence having a relatively short wavelength and narrow bandwidth spectrum “pumps” the phosphor material, which in turn radiates longer wavelength radiation having a somewhat broader spectrum.

[0012] The term “light source” should be understood to refer to any one or more of a variety of radiation sources, including, but not limited to, LED-based sources (including one or more LEDs as defined above), incandescent sources (e.g., filament lamps, halogen lamps), fluorescent sources, phosphorescent sources, high-intensity discharge sources (e.g., sodium vapor, mercury vapor, and metal halide lamps), lasers, other types of electroluminescent sources, pyro-luminescent sources (e.g., flames), candle-luminescent sources (e.g., gas mantles, carbon arc radiation sources), photo-luminescent sources (e.g., gaseous discharge sources), cathode luminescent sources using electronic satiation, galvano-luminescent sources, crystallo-luminescent sources, kine-luminescent sources, thermo-luminescent sources, triboluminescent sources, sonoluminescent sources, radioluminescent sources, and luminescent polymers.

[0013] The term “lighting fixture” is used herein to refer to an implementation or arrangement of one or more lighting units in a particular form factor, assembly, or package. The term "lighting unit" is used herein to refer to an apparatus including one or more light sources of same or different types. A given lighting unit may have any one of a variety of mounting arrangements for the light source(s), enclosure/housing arrangements and shapes, and/or electrical and mechanical connection configurations. Additionally, a given lighting unit optionally may be associated with (e.g., include, be coupled to and/or packaged together with) various other components (e.g., control circuitry) relating to the operation of the light source(s). An "LED-based lighting unit" refers to a lighting unit that includes one or more LED-based light sources such as one or more strings of LEDs as discussed above, alone or in combination with other non LED-based light sources. A "multi-channel" lighting unit refers to an LED-based or non LED-based lighting unit that includes at least two light sources configured to respectively generate different spectrums of radiation, wherein each different source spectrum may be referred to as a "channel" of the multi-channel lighting unit.

[0014] The term "controller" is used herein generally to describe various apparatus relating to the operation of one or more light sources. A controller can be implemented in numerous ways (e.g., such as with dedicated hardware) to perform various functions discussed herein. A "processor" is one example of a controller which employs one or more microprocessors that may be programmed using software (e.g., microcode) to perform various functions discussed herein. A controller may be implemented with or without employing a processor, and also may be implemented as a combination of dedicated hardware to perform some functions and a processor (e.g., one or more programmed microprocessors and associated circuitry) to perform other functions. Examples of controller components that may be employed in various embodiments of the present disclosure include, but are not limited to, conventional microprocessors, application specific integrated circuits (ASICs), and field-programmable gate arrays (FPGAs).

[0015] In various implementations, a processor or controller may be associated with one or more storage media (generically referred to herein as "memory," e.g., volatile and non-volatile computer memory such as RAM, PROM, EPROM, and EEPROM, floppy disks, compact disks, optical disks, magnetic tape, etc.). In some implementations, the storage media may be encoded with one or more programs that, when executed on one or more processors and/or controllers, perform at least some of the functions discussed herein. Various storage media may be fixed within a processor or controller or may be transportable, such that the one or more programs stored thereon can be loaded into a processor or controller so as to implement various aspects of the present invention discussed herein. The terms “program” or “computer program” are used herein in a generic sense to refer to any type of computer code (e.g., software or microcode) that can be employed to program one or more processors or controllers.

[0016] The term “network” as used herein refers to any interconnection of two or more devices (including controllers or processors) that facilitates the transport of information (e.g. for device control, data storage, data exchange, etc.) between any two or more devices and/or among multiple devices coupled to the network. As should be readily appreciated, various implementations of networks suitable for interconnecting multiple devices may include any of a variety of network topologies and employ any of a variety of communication protocols. Additionally, in various networks according to the present disclosure, any one connection between two devices may represent a dedicated connection between the two systems, or alternatively a non-dedicated connection. In addition to carrying information intended for the two devices, such a non-dedicated connection may carry information not necessarily intended for either of the two devices (e.g., an open network connection). Furthermore, it should be readily appreciated that various networks of devices as discussed herein may employ one or more wireless, wire/cable, and/or fiber optic links to facilitate information transport throughout the network.

[0017] It should be appreciated that all combinations of the foregoing concepts and additional concepts discussed in greater detail below (provided such concepts are not mutually inconsistent) are contemplated as being part of the inventive subject matter disclosed herein. In particular, all combinations of claimed subject matter appearing at the end of this disclosure are contemplated as being part of the inventive subject matter disclosed herein. It should also be appreciated that terminology explicitly employed herein that also may appear in any disclosure incorporated by reference should be accorded a meaning most consistent with the particular concepts disclosed herein.

Brief Description of the Drawings

[0018] In the drawings, like reference characters generally refer to the same parts throughout the different views. Also, the drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention.

[0019] Fig. 1 illustrates an example embodiment of a lighting system including controllers that control the dimming levels of lighting units.

[0020] Fig. 2 illustrates an example embodiment of a controller of the lighting system.

[0021] Fig. 3 illustrates an example embodiment of the line voltage having inserted signaling transitions.

[0022] Fig. 4 illustrates an example embodiment of a lighting unit.

[0023] Fig. 5 illustrates an example embodiment of a system that controls load shedding of electrical devices.

[0024] Fig. 6 illustrates an example embodiment of an electrical device.

Detailed Description

[0025] In the following detailed description, for purposes of explanation and not limitation, representative embodiments disclosing specific details are set forth in order to provide a thorough understanding of the present teachings. However, it will be apparent to one having ordinary skill in the art having had the benefit of the present disclosure that other embodiments according to the present teachings that depart from the specific details disclosed herein remain within the scope of the appended claims. Moreover, descriptions of well-known apparatuses and methods may be omitted so as to not obscure the description of the representative embodiments. Such methods and apparatuses are clearly within the scope of the present teachings.

[0026] Fig. 1 illustrates an example embodiment of a lighting system including controllers that control the dimming level of lighting units. Lighting system 10 includes an AC line source 100 which may be connected to a plurality of lighting units 120-1 and 120-2 and to controllers 130 and 150 by a cable 110 consisting of two wires. Controller 130 may be connected to a plurality of lighting units 120-3, 120-4,…120-n via cable 112 which may consist of two wires. Controller 150 may be connected to a plurality of lighting units 140-1, 140-2, 140-3,…140-n by a cable 114 which may consist of two wires. AC line source 100 may be mains voltage. In some embodiments AC line source 100 may provide 120 volts AC, 277 volts AC, or other values of AC voltage. Each of lighting units 120-1 – 120-n and 140-1 – 140-n may include one or more lighting sources. Each of lighting units 120-1 – 120-n and 140-1 – 140-n may also include one or more corresponding lighting drivers (ballasts) for driving the lighting sources.

[0027] Controllers 130 and 150 insert bursts of signaling transitions onto the line voltage provided from AC line source 100 via cable 110, to control the dimming level of the subsequently disposed lighting fixtures. The signaling transitions transition between a nominal line voltage and a signaling voltage. Controller 130 outputs the line voltage having signaling transitions inserted thereon along cable 112 to control the dimming level of lighting units 120-3, 120-4,... 120-n. Controller 150 outputs the line voltage having signaling transitions inserted thereon along cable 114 to control the dimming level of lighting units 140-1, 140-2, 140-3,... 140-n. As will be subsequently described, one or more of lighting units 120-3, 120-4,... 120-n disposed downstream relative to controller 130 and/or one or more of lighting units 140-1, 140-2, 140-3,... 140-n disposed downstream relative to controller 150 may include lighting drivers configured to detect the inserted signaling transitions and control the dimming level of the corresponding lighting sources responsive to the discriminated signaling transitions. That is, one or more of lighting units 120-3, 120-4,... 120-n disposed downstream relative to controller 130 and/or one or more of lighting units 140-1, 140-2, 140-3,... 140-n disposed downstream relative to controller 150 may not include lighting drivers configured to detect inserted signaling transitions, while other ones of the lighting units may include lighting drivers configured to detect signaling transitions. Lighting units that do not include lighting drivers configured to detect the signaling transitions will be unaffected by the inserted signaling transitions, and the dimming level of such lighting units will not be controllable. Lighting units 120-1 and 120-2 may or may not be configured as including lighting drivers configured to detect signaling transitions. However, since lighting units 120-1 and 120-2 are disposed upstream relative to controllers 130 and 150 so that the line voltage is provided directly from AC line source 100 without inserted signaling transitions, the dimming level of lighting units 120-1 and 120-2 are not controlled in this embodiment.

[0028] Although only two controllers 130 and 150 are shown, in other embodiments a plurality of additional controllers may be disposed in lighting system 10 to control various other lighting units. Also, in other embodiments all of the lighting units may include lighting drivers configured to discriminate inserted signaling transitions, and all of the lighting units may be disposed downstream relative to a controller configured to insert signaling transitions for controlling dimming level. In some embodiments, the lighting units including lighting drivers configured to detect signaling transitions for controlling dimming level may be connected in parallel to a controller such as controller 130, and will thus be responsive to signaling transitions inserted by controller 130. The configuration of lighting system 10 is merely exemplary. Lighting system 10 may include lighting units disposed to illuminate streets or highways, to provide general lighting within an outdoor facility, to provide exterior security lighting and/or to provide general lighting indoors within a facility. Plural controllers such as controllers 130 and 150 may be provided in a variety of locations including on outdoor structures or poles on which lighting units are mounted, and/or at various locations within an indoor facility such as at opposite ends of a large storage area, and/or at various control locations.

[0029] Fig. 2 illustrates an example embodiment of a controller of the lighting system. As shown in Fig. 2, controller 130 is connected to the line voltage provided by AC line source 100 via cable 110, and is configured to insert signaling transitions onto the line voltage and to provide the line voltage having the signaling transitions inserted thereon to lighting units 120-3, 120-4,…120-n via cable 112. Controller 130 includes an auto-transformer 132 having a first end terminal n1 connected to a first wire of cable 110, a second end terminal n3 connected to a second wire of cable 110, a first winding portion 132a connected between first end terminal n1 and transformer tap n2, and a second winding portion 132b connected between transformer tap n2 and second end terminal n3. Switch SW1 includes a first switch terminal connected to first end terminal n1, and a second switch terminal connected to the first wire of cable 112. Switch SW2 includes a first switch terminal connected to transformer tap n2, and a second switch terminal connected to the first wire of cable 112. Switches SW1 and SW2 may be relays, solid-state relays having extremely fast response time, thyristors or insulated gate bipolar transistors (IGBTs). If a high power rating is necessary, switches SW1 and SW2 may consist of solid-state relays which engage respective power relays scaled to handle the appropriate power levels. The second wire of cable 112 is connected to second end terminal n3 of auto-transformer 132.

[0030] Switch controller 134 is connected to the first wire of cable 110 and is powered by the line voltage. Switch controller 134 provides switch signal s1 for turning switch SW1 on/off, and switch signal s2 for turning switch SW2 off/on. Switch signals s1 and s2 are output by switch controller 134 so that switches SW1 and SW2 are respectively in an on state and an off state simultaneously, or respectively in an off state and an on state simultaneously. Although switches SW1 and SW2 may be simultaneously in an off state cutting off supply of the line voltage to cable 112, to prevent shorting of auto-transformer 132 switch controller 134 controls switch signals s1 and s2 so that switches SW1 and SW2 are not simultaneously in an on state. Switch controller 134 controls the on/off timing of switches SW1 and SW2 to insert signaling transitions onto the line voltage output to cable 112, responsive to control signal cont_sig. Switch controller 134 may include a micro-controller, an application-specific integrated circuit (ASIC), a field programmable gate array (FPGA), or any circuitry capable of generating switch signals s1 and s2.

[0031] In an embodiment, controller 130 may further include receiver 138 configured to receive an externally provided wireless signal from a server or central control unit, the wireless signal indicative of a desired dimming level of lighting units 120-3, 120-4,…120-n controlled by controller 130. The externally provided wireless signal may be a radio frequency (RF) signal such as a general packet radio service (GPRS) signal, an optical signal, or any wireless signal. In a further embodiments, controller 130 may be hardwired to directly receive control signal cont_sig indicative of the desired dimming level of lighting units 120-3, 120-4,…120-n. For example, control signal cont_sig may be provided manually by a user as a voltage level input from a potentiometer, a wall mounted dimmer or a switch disposed separately from controller 130. The voltage level may be input directly to an analog-digital converter (ADC) input terminal of switch controller 134. In such further embodiments, receiver 138 may be unnecessary and thus omitted from switch controller 134.

[0032] Controller 130 may further include a voltage dependent resistor (VDR) or varistor 136 as a protective element. VDR 136 has a first terminal connected to the first wire of cable 112 and the second switch terminals of switches SW1 and SW2, and also has a second terminal connected to the second wire of cable 112 and second end terminal n3 of auto-transformer 132. Controller 130 may be configured to provide switch signals s1 and s2 to insert the signaling transitions onto the line voltage by turning switches SW1 and SW2 on and off for short periods of time on the order of several msecs or a few tens of msecs. VDR 136 clamps the peak voltage provided to the wires of cable 112 by absorbing transient energy arising from voltage spikes introduced by switching of winding portions 132a and 132b, to prevent damage to downstream lighting units 120-3, 120-4,…120-n. In other embodiments, VDRs may be disposed in the front end of lighting units 120-3, 120-4,…120-n instead of in controller 130, or VDRs may be disposed in both the front end of lighting units 120-3, 120-4,…120-n and in controller 130.

[0033] While the configuration of controller 130 has been described above in detail with respect to Fig. 2, controller 150 may be configured in a similar manner. Controller 150 is connected to the line voltage provided by AC line source 100 via cable 110, and may be configured to insert signaling transitions onto the line voltage and to provide the line voltage as having the signaling transitions inserted thereon to lighting units 140-1, 140-2, 140-3,…140-n via cable 114.

[0034] Fig. 3 illustrates an embodiment of the line voltage having inserted signaling transitions, as output by the controller. The signaling transitions, and the manner in which they are inserted onto the line voltage by controller 130 to control the dimming level of lighting units 120-3, 120-4,…120-n will be described with reference to Figs. 1-3. The following is also descriptive of the line voltage with inserted signaling transitions as output by controller 150 to control the dimming level of lighting units 140-1, 140-2, 140-3,…140-n.

[0035] At some time t0 shown in Fig. 3, AC line source 100 may be operative to provide a line voltage of 120 volts AC to lighting units 120-1 and 120-2 and to controllers 130 and 150 via cable 110. Lighting units 120-1 and 120-2 as directly provided with the line voltage from AC line source 100 without signaling transitions will be maintained on responsive to the provided line voltage without dimming control.

[0036] At time t0, there is no signaling to control dimming level, and switch controller 134 within controller 130 outputs switch signals s1 and s2 to respectively close switch SW1 and to open switch SW2, so that the first and second wires of cable 112 are respectively connected to first and second end terminals n1 and n3 of auto-transformer 132. The line voltage of 120 volts AC from cable 110 is thus output to cable 112 and provided to lighting units 120-3, 120-4,…120-n which are maintained on without dimming. Subsequently at time t1, responsive to control signal cont_sig indicative of a desired dimming level of corresponding lighting units 120-3, 120-4,…120-n, switch controller 134 outputs switch signals s1 and s2 to respectively open switch SW1 and close switch SW2, so that the first and second wires of cable 112 are respectively connected to transformer tap n2 and second end terminal n3 of auto-transformer 132. The line voltage thus transitions from the nominal line voltage to a signaling voltage at time t1. This transition at time t1 may be characterized as a first transition.

[0037] In an embodiment, the signaling voltage may be set so that the value ΔV between the nominal line voltage and the signaling voltage as shown in Fig.3 is large enough to be easily distinguishable over nominal line voltage fluctuations, but also small enough so that the signaling voltage is greater than the drop-out voltage of the lighting drivers within lighting units 120-1 – 120-n and 140-1 – 140-n. In some embodiments, the signaling voltage may be set to be a percentage of the nominal line voltage. The signaling voltage may be set to a fixed percentage within a range of about 90% – 95% of the nominal line voltage. For a nominal line voltage of 120 volts AC, the signaling voltage may accordingly be set to be within a range of about 114 volts AC to 108 volts AC. In other embodiments, the signaling voltage may be set as other percentages of the nominal line voltage, such as 80% for example. Auto-transformer 132 within controller 130 is designed so that winding portions 132a and 132b have the necessary respective number of windings to provide the selected signaling voltage at transformer tap n2.

[0038] Returning to Fig. 3, after a predetermined first time interval PT1 has elapsed subsequent time t1, switch controller 134 outputs switch signals s1 and s2 to respectively close switch SW1 and open switch SW2 at time t2, so that the first and second wires of cable 112 are respectively connected to first and second end terminals n1 and n3 of auto-transformer 132 and so that the line voltage of 120 volts AC is again output to cable 112. The line voltage thus transitions from the signaling voltage to the nominal line voltage at time t2. This transition at time t2 may also be characterized as a first transition.

[0039] In some embodiments, the predetermined first time interval PT1 may be set as 20 msecs when the system is designed. In other embodiments different predetermined first time intervals PT1 may be set when the system is designed. The predetermined first time interval PT1 should however be set so that the response time of switches SW1 and SW2 is negligible compared to the predetermined first time interval PT1.

[0040] After a predetermined first time interval PT1 has elapsed subsequent time t2, switch controller 134 outputs switch signals s1 and s2 at time t3 to respectively open switch SW1 and close switch SW2, so that the first and second wires of cable 112 are respectively connected to transformer tap n2 and second end terminal n3 of auto-transformer 132. The line voltage thus again transitions from the nominal line voltage to the signaling voltage at time t3. This transition at time t3 may be characterized as another first transition.

[0041] As will be subsequently described, the lighting drivers within lighting units 120-3, 120-4,... 120-n subsequent controller 130 may be configured to enter a signaling mode upon detecting the above noted plurality of first transitions at times t1, t2 and t3 having the predetermined first time interval between each other. That is, the signaling mode begins at time t3. One of the reasons for having the time PT1 from time t2 to time t3 the same as the time PT1 from time t1 to time t2 is so that the lighting drivers can distinguish the signaling transitions from random line fluctuations in the same voltage range as the signaling voltage. This prevents false triggering of the signaling mode. If the time counted between voltage transitions detected by the lighting drivers at the lighting units does not match the predetermined time interval PT1, the lighting drivers will ignore the voltage transitions as random line fluctuations. Although three first transitions are described as indicating the start of the signaling mode, in other embodiments different numbers of first transitions greater than three, and/or transitions having four or more transitions may indicate the start of the signaling mode, and/or predetermined first time interval PT1 may be longer or shorter than 20 msecs as set during system design.

[0042] Upon entering the signaling mode, switch controller 134 of controller 130 determines a time interval Δt corresponding to the desired dimming level of lighting units 120-3, 120-4,... 120-n as indicated by the received control signal cont_sig. After the determined time interval Δt corresponding to the desired dimming level has elapsed subsequent occurrence of the last of the first transitions at time t3, switch controller 134 outputs switch signals s1 and s2 to respectively close switch SW1 and open switch SW2 at time t4. The first and second wires of cable 112 are respectively connected to first and second end terminals n1 and n3 of auto-transformer 132 at time t4 so that the line voltage of 120 volts AC is again output to cable 112. The line voltage thus transitions from the signaling voltage to the nominal line voltage at time t4. This transition at time t4 may be characterized as a second transition.

[0043] As shown in Fig. 3, the time interval Δt between the second transition at time t4 and the last of the first transitions at time t3 is Δt = t4 – t3. The timing of the second transition at time t4 is determined by switch controller 134 responsive to the control signal cont_sig so that time interval Δt has a length corresponding to the desired dimming level. In some embodiments, the range of the time interval Δt may be defined as 200 msecs ≤ Δt ≤ 400 msecs, where a time interval Δt of 200 msecs corresponds to a minimum dimming level (darkest) and a time interval Δt of 400 msecs corresponds to a maximum dimming level (brightest). The range of time interval Δt may be divided into discrete steps with each step representing a certain percentage of dimming level. Switch controller 134 may include a memory which stores or maps discrete time intervals Δt for various desired dimming levels, and may be configured to provide switch signals s1 and s2 at a corresponding time t4 in accordance with the stored or mapped discrete time intervals Δt. In other embodiments, different ranges of time interval Δt may be used. The range of time interval Δt should however be at least 400 msecs.

[0044] As further shown in Fig. 3, subsequent the second transition at time t4, after the signaling mode is complete, the line voltage is indefinitely maintained at the nominal voltage level by switch controller 134 of controller 130, until a new control signal cont_sig is received indicative of a new desired dimming level. In the above noted example embodiment, in a case where the first predetermined time interval PT1 is set to 20 msecs and the time interval Δt is a maximum of 400 msecs corresponding to a maximum dimming level, the line voltage is altered by the signaling transitions inserted at times t1-t4 over a very short period of time less than one second. During periods of time where the dimming level of the lighting units is to remain in a steady state, signaling transitions are not inserted by switching controller 134 and the line voltage remains unaltered at 120 volts AC. Dimming control can thus be provided and maintained using a single set of signaling transitions with minimum power consumption. As an error-detection method, the sequence of signaling transitions may be repeated once or twice in succession so that the lighting drivers within the lighting units may confirm that the same sequence of signaling transitions was repeated and therefore conclude that the sequence of signaling transitions was authentic.

[0045] In embodiments having a defined range of the time interval Δt as noted above, the time interval Δt may be set to a maximum time interval Δt_{max} of 400 msecs corresponding to a maximum dimming level. In a further embodiment, switch controller 134 may be configured to enter a standby mode responsive to control signal cont_sig. Upon receipt of the control signal cont_sig indicative of the standby mode, instead of outputting switch signals s1 and s2 at time t4 to provide the second transition within the defined range of the time interval Δt to be indicative of a corresponding dimming level, switch controller 134 outputs switch signals s1 and s2 after a predetermined second time interval PT2 has elapsed subsequent time t3 shown in Fig. 3. That is, switch signals s1 and s2 are instead output at time t5. The predetermined second time interval PT2 as shown in Fig. 3 may be defined as $PT2 = \Delta t_{max} + PT3$, wherein assuming the above noted defined range of the time interval Δt, Δt_{max} is 400 msecs and predetermined third time interval PT3 may be set as 20 msecs for example. That is, predetermined second time interval PT2 is set to be greater than Δt_{max}. Predetermined third time interval PT3 may be the same as or different in length than first predetermined time interval PT1.

[0046] The lighting drivers within lighting units 120-3, 120-4,... 120-n subsequent controller 130 may be configured to enter the standby mode upon detecting the second transition depicted by dashed lines at time t5. In the standby mode, the lighting drivers may be controlled to no longer output driving current to the lighting sources and to also power down non-essential circuitry within the lighting drivers. In the standby mode, minimal circuitry necessary to receive and detect a next set of signaling transitions remain powered on. By provision of the standby mode the lighting sources may be shut off by powering down the lighting drivers instead of mechanically switching circuit breakers or relays, thus preventing excessive in-rush currents and significantly minimizing wear of the circuit breakers and relays.

[0047] Fig. 4 illustrates an example embodiment of a lighting unit. Lighting unit 120-3 as shown in Fig. 4 may be representative of any of lighting units 120-1, 120-2, 120-4,... 120-n and 140-1 – 140-n, and includes lighting driver 200 and lighting source 300. As described previously, each of the lighting units such as lighting unit 120-3 may include one or more lighting sources 300 and one or more lighting drivers 200. Lighting drivers 200 may be configured as subsequently described to detect signaling transitions inserted onto the line voltage. It should be understood that lighting driver 200 may include additional circuitry and components not described in the following. Lighting source 300 may be e-fluorescent lighting, e-HID (electronic-high intensity discharge) lighting, LED lighting, or any suitable lighting.

[0048] Lighting driver 200 as shown in Fig. 4 includes resistor 202 having a first terminal connected to a first wire of cable 112, and resistor 204 having first and second terminals respectively connected to a second terminal of resistor 202 and a second wire of cable 112. Resistors 202 and 204 are together configured as a resistive divider. Nodes n4 and n5 of full wave bridge rectifier 206 are respectively connected to the first wire of cable 112 and the second wire of cable 112. Nodes n6 and n7 of full wave bridge rectifier 206 are respectively connected to power converter 240 and the ground node. Diode 208 has an anode connected to node n8 between resistors 202 and 204, and a cathode connected to first terminal of capacitor 216. Capacitor 216 has a second terminal connected to the ground node. Resistor 210 has a first terminal connected to the cathode of diode 208. Resistor 212 has first and second terminals respectively connected to the second terminal of resistor 210 and to ground. Capacitor 214 has a first terminal connected to the first terminal of resistor 212 and to an input terminal A/D of waveform discriminator 230, and has a second terminal connected to ground. Resistors 210 and 212 are together configured as a resistive divider.

[0049] Resistor 218 has a first terminal connected to the first terminal of capacitor 216. Resistor 220 includes first and second terminals respectively connected to a second terminal of resistor 218 and the ground node. Resistor 222 has a first terminal connected to the second terminal of resistor 218. N-channel FET 224 has a gate terminal connected to output terminal B of waveform discriminator 230, a drain terminal connected to a second terminal of resistor 222, and a source terminal connected to the ground node. Resistors 218 and 220 are together configured as a resistive divider, and divide a detected peak voltage provided by diode 208. When n-channel FET 224 is turned on responsive to an output of waveform discriminator 230, resistor 222 is switched into connection in parallel with resistor 220. When n-channel FET 224 is turned off responsive to an output of waveform discriminator 230, resistor 222 is disconnected from the resistive divider including resistors 218 and 220. N-channel FET (transistor) 226 has a gate (first) terminal connected to the second terminal of transistor 218, a drain (third) terminal connected to input terminal IN of waveform discriminator 230, and a source (second) terminal connected to the ground node.

[0050] Waveform discriminator 230 is configured to provide a dimming control signal via output terminal C to power converter 240 responsive to the voltage level at the drain terminal of n-channel FET 226 connected to input terminal IN. Waveform discriminator 230 is also configured to provide a switching signal s3 via output terminal B to the gate terminal of n-channel FET 224 responsive to the voltage level at the first terminal of capacitor 214 connected to input terminal A/D. Waveform discriminator 230 is further connected to the ground node. Power converter 240 adjusts the intensity of lighting source 300 by adjusting the amount of current driven into lighting source 300 in response to the dimming control signal output from waveform discriminator 230.

[0051] In operation, full wave bridge rectifier 206 within lighting driver 200 of lighting unit 120-3 shown in Fig. 4 rectifies the line voltage applied via cable 112, and provides the rectified voltage to power converter 240 and to power waveform discriminator 230. The line voltage applied via cable 112 is also peak detected by diode (peak detector) 208, and the detected peak voltage is connected to the first terminal of capacitor 216. Resistor 218 and capacitor 216 are together configured as an RC circuit with a time constant small enough to ensure that the voltage across capacitor 216 can follow the signaling transitions inserted onto the line voltage, but also large enough to filter out noise spikes so that a clean signal may be passed on to the resistive divider including resistors 218 and 220 and subsequently to waveform discriminator 230. The divided voltage at the midpoint of the resistive divider including resistors 218 and 220 drives n-channel FET 226 on and off. The ratio of resistors 218 and 220 are set such that during normal operation when the nominal line voltage is provided along cable 112, the divided voltage at the midpoint between resistors 218 and 220 maintains n-channel FET 226 on, so that input terminal IN of waveform discriminator 230 is connected to the ground node. When the line voltage drops to the level of the signaling voltage, the divided voltage at the midpoint of resistors 218 and 220 is unable to keep n-channel FET 226 on, so that input terminal IN of waveform discriminator 230 is connected to a higher first voltage relative to ground. In other embodiments, a resistor may be inserted between the drain of n-channel FET 226 and the power supply of waveform discriminator 230. This interconnection will pull the drain of n-channel FET 226 high. In this way, a defined “high” being the power supply voltage and a defined “low” being the ground voltage may be presented to input terminal IN of waveform discriminator 230.

[0052] Waveform discriminator 230 is configured to detect the signaling transitions inserted onto the line voltage responsive to the voltage level changes at input terminal IN, to count and determine the length of the time intervals between successively detected signaling transitions, and to recognize receipt of the first and second transitions responsive to the detected time intervals. Waveform discriminator 230 enters the signaling mode responsive to the first transitions. Waveform discriminator 230 is further configured to detect the time interval Δt indicative of the desired dimming level responsive to the second voltage transition, and to either generate and output the dimming control signal to power converter 240 via output terminal C or enter the standby mode.

[0053] The time interval Δt may also represent a specific “character” and therefore, a recurring string of such “characters” can be encoded on the line voltage to constitute a complex message or command. Therefore, a protocol can be designed which will make use of the “channel” discussed herein.

[0054] As described previously with respect to Fig. 1, AC line source 100 of lighting system 10 may provide a line voltage of 120 volts AC via cable 110 which is a two-wire cable. Other lighting systems may be powered by a three-phase line source that provides a line voltage of 480 volts AC via a three wire cable. In such other lighting systems, the line voltage of one phase to ground is 277 volts AC. For the purposes of convenience and cost effectiveness, lighting driver 200 shown in Fig.4 may be configurable to be operable responsive to a nominal line voltage (predetermined first line voltage) of 120 volts AC or a nominal line voltage (predetermined second line voltage) of 277 volts AC.

[0055] In greater detail, the detected peak voltage from diode 208 in lighting driver 200 shown in Fig. 4 is connected to the first terminal of resistor 210. The divided voltage at the midpoint of resistive divider including resistors 210 and 212 is connected to input terminal A/D of waveform discriminator 230. Waveform discriminator 230 is configured to detect whether the line voltage is 120 volts AC or 277 volts AC responsive to the voltage at input terminal A/D, and to provide switch signal s3 indicative of the detection result. When waveform discriminator 230 detects that the nominal line voltage is 277 volts AC, switch signal s3 is set to a high voltage level relative to ground to maintain n-channel FET 224 in an on state so that resistor 222 is connected to the resistive divider in parallel with resistor 220. When waveform discriminator 230 detects that the nominal line voltage is 120 volts AC, switch signal s3 is set to a low voltage level to maintain n-channel FET 224 in an off state so that resistor 222 is disconnected from the circuit. Resistor 222 is selected to have a resistance value so that when it is connected in parallel to resistor 220, the divided voltage at the midpoint of the voltage divider between resistors 218 and 220 when the nominal line voltage is 277 volts AC will be substantially the same as the divided voltage between resistors 218 and 220 when the nominal line voltage is 120 volts AC. N-channel FET 226 may thus be turned on at appropriate times responsive to applied voltage levels that are substantially the same regardless of whether the nominal line voltage is 120 volts AC or 277 volts AC, so that lighting driver 200 may be compatible for use with different nominal line voltages. In other embodiments, the value of resistor 222 may be selected to be compatible with nominal line voltages other than 277 volts AC.

[0056] Waveform discriminator 230 of lighting driver 200 shown in Fig. 4 may include a micro-controller, an ASIC, an FPGA, or any circuitry capable of detecting signaling transitions responsive to changes in voltage level at input terminal IN and detecting the time intervals between the transitions so as to correspondingly enter the signaling mode, generate the dimming control signal, and enter the standby mode. Waveform discriminator 230 may also include circuitry capable of detecting the voltage level at the input terminal A/D so as to generate switch signal s3. In some embodiments, waveform discriminator 230 may be programmable and may include a memory for storing software programming. In other embodiments, waveform discriminator 230 may be a micro-controller based circuit that is fast enough to detect the changes in voltage level of the divided voltage at the midpoint of the resistive divider including resistors 218 and 220, so that the divided voltage may be directly input to input terminal IN of waveform discriminator 230 and n-channel FET 226 may be omitted.

[0057] In further embodiments, the lighting units may be addressable responsive to the inserted transitions to selectively adjust dimming levels. For example, lighting driver 200 within lighting unit 120-3 may be addressable to enter the signaling mode responsive to the three first transitions at t1, t2 and t3 shown in Fig. 3, and lighting driver 200 within lighting unit 120-4 may be addressable to enter the signaling mode responsive to five first transitions, wherein each of the first transitions are separated from each other by the predetermined first time interval PT1. In other embodiments, lighting driver 200 within lighting unit 120-3 may be addressable to enter the signaling mode responsive to three first transitions that are separated from each other by predetermined first time interval PT1, and lighting driver 200 within lighting unit 120-4 may be addressable to enter the signaling mode responsive to three first transitions that are separated from each other by a predetermined time interval different than predetermined first time interval PT1. The lighting units may be grouped together to be addressable responsive to different respective sets of first transitions. Switch controller 134 shown in Fig. 2 may be configured or programmed to provide switch signals s1 and s2 at timings necessary to achieve addressability.

[0058] Fig. 5 illustrates an example embodiment of a system that controls load shedding of electrical devices. System 20 includes AC line source 100 which may be connected to a plurality of electrical devices 420-1 and 420-2 and controllers 430 and 450 by a cable 110 consisting of two wires. Controller 430 may be connected to a plurality of electrical devices 420-3, 420-4,... 420-n via cable 112 which may consist of two wires. Controller 450 may be connected to a plurality of electrical devices 440-1, 440-2, 440-3,... 440-n by a cable 114 which may consist of two wires. AC line source 100 may be mains voltage. The electrical devices may include electrical loads such as air conditioning units, heating units, blowers, fans, or any other electrical load, and may each include a load driver for driving the electrical load. In a similar manner as in lighting system 10 shown in Fig. 1, controllers 430 and 450 insert bursts of signaling transitions that transition between a nominal line voltage and a signaling voltage onto the line voltage provided from AC line source 100 via cable 110, to control load shedding of the loads in the subsequently disposed electrical devices. Although only two controllers 430 and 450 are shown in Fig. 5, a plurality of additional controllers may be disposed to control various other electrical devices and in various other configurations. The electrical devices may be disposed within various rooms or areas of an indoor facility, or at various locations in an outdoor facility. Controllers 430 and 450 may be disposed at various locations within the facilities, at various control locations, or at a central control location.

[0059] Fig. 6 illustrates an example embodiment of an electrical device of system 20. Electrical device 420-3 shown in Fig. 6 may be representative of any of electrical devices 420-1 – 420-n and 440-1 – 440-n in system 20 shown in Fig. 5, and includes load driver 500 and electrical load 600. Load drivers 500 may be configured in a similar manner as lighting driver 200 shown in Fig. 4, to detect signaling transitions inserted on the line voltage. The inserted signaling transitions are of the form described with respect to Fig. 3. In Fig. 6, circuit elements that are the same as in Fig. 4 have the same respective reference numerals, and description of such same circuit elements may be omitted from the following for the sake of brevity.

[0060] Load driver 500 as shown in Fig. 6 is configured in a similar manner as lighting driver 200 shown in Fig. 4, except for the following. Since electrical loads 600 may be an air conditioning unit, heating unit, blower, or fan driven by AC line voltage, load driver 500 does not include a full wave bridge rectifier. Waveform discriminator 230 may be configured similarly as described with respect to Fig. 4 to generate and provide a load shedding signal to power converter 550 via output terminal C responsive to the voltage level at input terminal IN. Power converter 550 is connected to a first wire of cable 112 and adjusts the amount of current driven into electrical load 600 responsive to the load shedding signal, to control load shedding of electrical load 600. The load shedding signal may automatically control the cooling rate of an air conditioning unit, the heating rate of a heating unit, and/or the speed of a blower or a fan during off peak hours for instance, to conserve energy. Waveform discriminator 230 may be configured similarly as variously described previously to enter a signaling mode, to enter a standby mode, and to be responsive to a nominal line voltage of 120 volts AC or a nominal line voltage of 277 volts AC.

[0061] In other embodiments, the concepts as described with respect to Figs. 1-4 may be used in retrofit applications to provide existing lighting systems or installations with cost effective dimming level control, without the necessity of running additional control wiring and/or extensive infrastructure. For example, in an embodiment where an existing lighting system including lighting units mounted on light poles at various locations along one or more streets, one or more controllers 130 such as described with respect to Fig. 2 may be interconnected into the existing two wire cable feeding line voltage to the light poles, to insert signaling transitions onto the line voltage. One or more of the existing lighting units may be retrofit to replace a legacy lighting driver with a retrofit lighting driver such as lighting driver 200 described with respect to Fig. 4 directly connected to the existing two wire cable and the light source within the existing lighting unit, to control the dimming level of the lighting unit and/or enable provision of a standby mode responsive to the inserted signaling transitions. In the alternative, one or more of the existing lighting units may be retrofit to replace a legacy lighting driver with a retrofit lighting driver similar to load driver 500 described with respect to Fig. 6. In other embodiments, one or more of the existing lighting units may be retrofit to respectively replace a legacy lighting driver and a legacy lighting source with a retrofit lighting driver such as lighting driver 200 and a retrofit lighting source such as lighting source 300 described with respect to Fig. 4. In a similar manner, the concepts as described with respect to Figs. 5-6 may be used in retrofit applications to provide existing air conditioning and/or heating systems or installations with load shedding control, also without the necessity of running additional control wiring and/or adding extensive infrastructure.

[0062] In a still further embodiment, lighting system 10 shown in Fig. 1 may be configured to provide a DC line voltage having signaling transitions inserted thereon to control dimming level of the lighting fixtures. For example, instead of an AC line source, the lighting system may be connected to a DC line source that provides a line voltage of 250 volts DC or 480 volts DC. In other embodiments, instead of including auto-transformer 132 and switches SW1 and SW2, controller 130 as shown in Fig. 2 may include an AC-DC DC-DC converter connected to the AC line voltage provided along cable 110. The AC-DC DC-DC converter may be configured to output a line voltage of 480 volts DC along cable 112 and to insert signaling transitions at a signaling voltage onto the output line voltage responsive to timing signals provided by switch controller 134. VDR 136 would be unnecessary in this and omitted in this embodiment. A lighting such as configured in load driver 500 shown in Fig. 6 may be used to detect the signaling transitions and provide a dimming control signal to power converter 550 to adjust the amount of current provided to a corresponding lighting source. In further embodiments, such a lighting system may be used to control dimming levels of 12 volt or 24 volt DC lighting systems.

[0063] While several inventive embodiments have been described and illustrated herein, those of ordinary skill in the art will readily envision a variety of other means and/or structures for performing the function and/or obtaining the results and/or one or more of the advantages described herein, and each of such variations and/or modifications is deemed to be within the scope of the inventive embodiments described herein. More generally, those skilled in the art will readily appreciate that all parameters, dimensions, materials, and configurations described herein are meant to be exemplary and that the actual parameters, dimensions, materials, and/or configurations will depend upon the specific application or applications for which the inventive teachings is/are used. Those skilled in the art will recognize, or be able to ascertain using no more than routine experimentation, many equivalents to the specific inventive embodiments described herein. It is, therefore, to be understood that the foregoing embodiments are presented by way of example only and that, within the scope of the appended claims and equivalents thereto, inventive embodiments may be practiced otherwise than as specifically described and claimed. Inventive embodiments of the present disclosure are directed to each individual feature, system, article, material, kit, and/or method described herein. In addition, any combination of two or more such features, systems, articles, materials, kits, and/or methods, if such features, systems, articles, materials, kits, and/or methods are not mutually inconsistent, is included within the inventive scope of the present disclosure.

[0064] All definitions, as defined and used herein, should be understood to control over dictionary definitions, definitions in documents incorporated by reference, and/or ordinary meanings of the defined terms.

[0065] The indefinite articles “a” and “an,” as used herein in the specification and in the claims, unless clearly indicated to the contrary, should be understood to mean “at least one.”

[0066] The phrase “and/or,” as used herein in the specification and in the claims, should be understood to mean “either or both” of the elements so conjoined, i.e., elements that are conjunctively present in some cases and disjunctively present in other cases. Multiple elements listed with “and/or” should be construed in the same fashion, i.e., “one or more” of the elements so conjoined. Other elements may optionally be present other than the elements specifically identified by the “and/or” clause, whether related or unrelated to those elements specifically identified. Thus, as a non-limiting example, a reference to “A and/or B”, when used in conjunction with open-ended language such as “comprising” can refer, in one embodiment, to A only (optionally including elements other than B); in another embodiment, to B only (optionally including elements other than A); in yet another embodiment, to both A and B (optionally including other elements); etc.

[0067] As used herein in the specification and in the claims, “or” should be understood to have the same meaning as “and/or” as defined above. For example, when separating items in a list, “or” or “and/or” shall be interpreted as being inclusive, i.e., the inclusion of at least one, but also including more than one, of a number or list of elements, and, optionally, additional unlisted items. Only terms clearly indicated to the contrary, such as “only one of” or “exactly one of,” or, when used in the claims, “consisting of,” will refer to the inclusion of exactly one element of a number or list of elements.

[0068] It should also be understood that, unless clearly indicated to the contrary, in any methods claimed herein that include more than one step or act, the order of the steps or acts of the method is not necessarily limited to the order in which the steps or acts of the method are recited.

[0069] In the claims, as well as in the specification above, all transitional phrases such as “comprising,” “including,” “carrying,” “having,” “containing,” “involving,” “holding,” “composed of,” and the like are to be understood to be open-ended, i.e., to mean including but not limited to. Only the transitional phrases “consisting of” and “consisting essentially of” shall be closed or semi-closed transitional phrases, respectively, as set forth in the United States Patent Office Manual of Patent Examining Procedures, Section 2111.03.

CLAIMS:

1. A lighting unit comprising:

a lighting source; and

a lighting driver connected to a line voltage having signaling transitions that transition between a nominal line voltage and a signaling voltage, and configured to detect the signaling transitions on the line voltage, generate a dimming signal responsive to the detected signaling transitions, provide a driving current to the lighting source, and adjust a level of the driving current responsive to the dimming signal.

2. The lighting unit of claim 1, wherein the lighting driver comprises a waveform discriminator configured to detect the signaling transitions, determine time intervals between the detected signaling transitions, and generate the dimming signal responsive to the determined time intervals.

3. The lighting unit of claim 2, wherein the lighting driver further comprises:

a peak detector configured to detect a peak voltage of the line voltage;

a resistive divider configured to divide the detected peak voltage and provide a divided voltage; and

a transistor having a gate terminal connected to the divided voltage, a second terminal connected to ground voltage, and a third terminal, the transistor configured as responsive to the divided voltage to output the ground voltage via the third terminal when the line voltage is at the nominal line voltage and to output a first voltage via the third terminal when the line voltage is at the signaling voltage,

wherein the waveform discriminator is further configured to generate the dimming signal responsive to the output of the transistor.

4. The lighting unit of claim 3, wherein the waveform discriminator is further configured to detect whether the nominal line voltage is a predetermined first line voltage or a predetermined second line voltage greater than the predetermined first line voltage, and to switch

a resistor into connection with the resistive divider when the nominal line voltage is the predetermined second line voltage.

5. The lighting unit of claim 4, wherein the predetermined first line voltage is 120 volts AC and the predetermined second line voltage is 277 volts AC.

6. The lighting unit of claim 2, wherein the signaling transitions include a plurality of first transitions having a predetermined first time interval between each other, and a second transition after the plurality of first transitions, and

wherein the waveform discriminator is further configured to enter a signaling mode responsive to detecting the first transitions, and set a value of the dimming signal responsive to a time interval between the second transition and a last of the first transitions.

7. The lighting unit of claim 6, wherein the waveform discriminator is further configured to enter a standby mode responsive to detecting the second transition at a predetermined second time interval after the last of the first transitions, and set a value of the dimming signal so that no light is emitted from the lighting source.

8. The lighting unit of claim 1, wherein the signaling voltage is a fixed percentage of the nominal line voltage.

9. The lighting unit of claim 8, wherein the fixed percentage is in a range of about 90% - 95%.

10. The lighting unit of claim 1, wherein the lighting driver is a retrofit lighting driver configured to replace a legacy lighting driver, and the lighting source is a retrofit lighting source configured to replace a legacy lighting source.

11. The lighting unit of claim 10, wherein the retrofit lighting source comprises e-fluorescent lighting, e-HID (electronic-high intensity discharge) lighting or LED lighting source.

12. The lighting unit of claim 1, wherein the lighting source comprises e-fluorescent lighting, e-HID (electronic-high intensity discharge) lighting or LED lighting source.

13. An electrical device comprising:

an electrical load; and

a load driver connected to a line voltage having signaling transitions that transition between a nominal line voltage and a signaling voltage, and configured to detect the signaling transitions on the line voltage, generate a load shedding signal responsive to the detected signaling transitions, provide a driving current to the electrical load, and adjust a level of the driving current responsive to the load shedding signal.

14. The electrical device of claim 13, wherein the load driver comprises a waveform discriminator configured to detect the signaling transitions, determine time intervals between the detected signaling transitions, and generate the load shedding signal responsive to the determined time intervals.

15. The electrical device of claim 14, wherein the signaling transitions include a plurality of first transitions having a predetermined first time interval between each other, and a second transition after the plurality of first transitions, and

wherein the waveform discriminator is further configured to enter a signaling mode responsive to detecting the first transitions, and set a value of the load shedding signal responsive to a time interval between the second transition and a last of the first transitions.

16. The electrical device of claim 15, wherein the waveform discriminator is further configured to enter a standby mode responsive to detecting the second transition at a predetermined second time interval after the last of the first transitions, and set a value of the load shedding signal so that no driving voltage is provided to the electrical load.

17. The electrical device of claim 13, wherein the electrical load comprises an air conditioning unit, a heating unit, a blower, or a fan.

18. A lighting driver comprising:

a peak detector configured to detect a peak voltage of a line voltage, the line voltage having signaling transitions that transition between a nominal line voltage and a signaling voltage;

a resistive divider configured to provide a divided voltage responsive to the detected peak voltage;

a waveform discriminator configured to detect the signal transitions on the line voltage and time intervals between the signaling transitions responsive to the divided voltage, and provide a dimming signal according to the detected time intervals; and

a power converter configured to provide a driving current to a lighting source, and adjust a level of the driving current responsive to the dimming control signal.

19. The lighting driver of claim 18, further comprising:

a transistor having a gate terminal connected to the divided voltage, a second terminal connected to ground voltage, and a third terminal, the transistor configured as responsive to the divided voltage to output the ground voltage via the third terminal when the line voltage is at the nominal line voltage and to output a first voltage via the third terminal when the line voltage is at the signaling voltage,

wherein the waveform discriminator is configured to detect the signaling transitions responsive to the output of the transistor.

20. The lighting driver of claim 19, wherein the waveform discriminator is further configured to detect whether the nominal line voltage is a predetermined first line voltage or a predetermined second line voltage greater than the predetermined first line voltage, and to switch a resistor into connection with the resistive divider when the nominal line voltage is the predetermined second line voltage.

21. The lighting driver of claim 20, wherein the predetermined first line voltage is 120 volts AC and the predetermined second line voltage is 277 volts AC.

22. The lighting driver of claim 18, wherein the signaling transitions include a plurality of first transitions having a predetermined first time interval between each other, and a second transition after the plurality of first transitions, and

wherein the waveform discriminator is further configured to enter a signaling mode responsive to detecting the first transitions, and set a value of the dimming signal responsive to a time interval between the second transition and a last of the first transitions.

23. The lighting driver of claim 22, wherein the waveform discriminator is further configured to enter a standby mode responsive to detecting the second transition at a predetermined second time interval after the last of the first transitions, and set a value of the dimming signal so that no light is emitted from the lighting source.

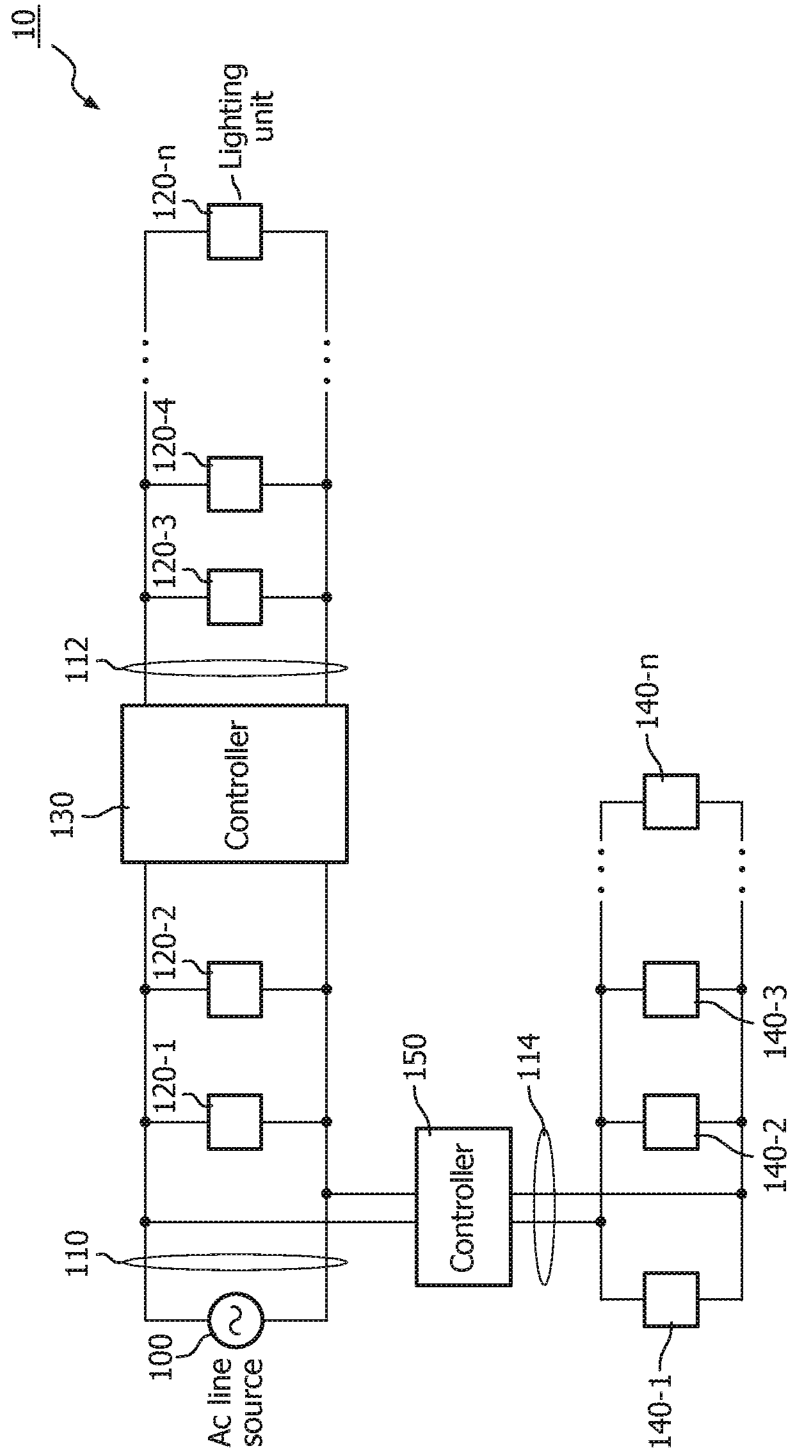
10
Lighting unit
120-n
120-4
120-3
112
130
Controller
120-2
120-1
150
Controller
114
110
100
Ac line source
140-n
140-3
140-2
140-1

FIG. 1

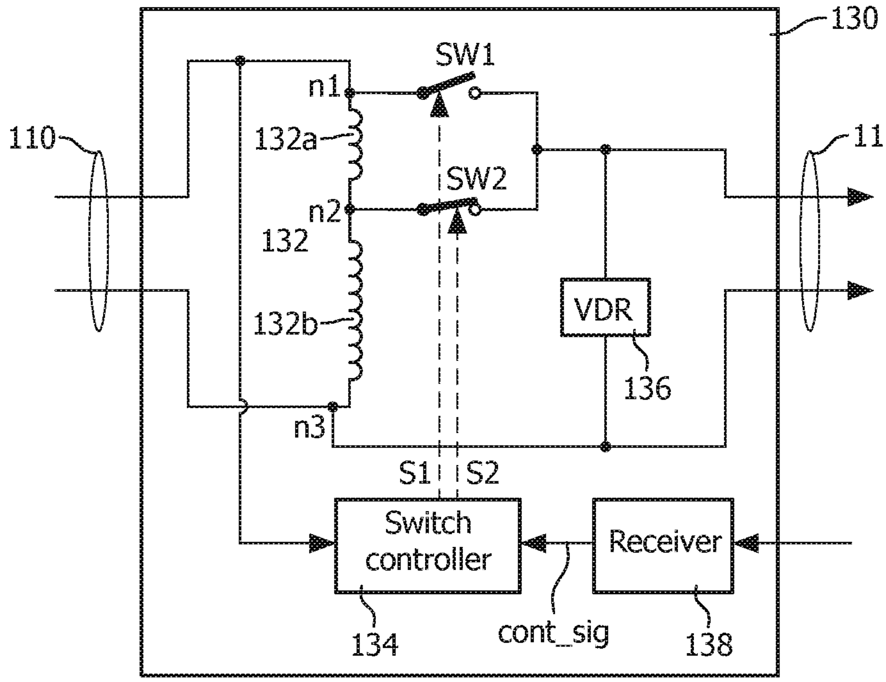
130
110
112
SW1
n1
132a
SW2
n2
132
132b
VDR
136
n3
S1
S2
Switch controller
Receiver
134
cont_sig
138

FIG. 2

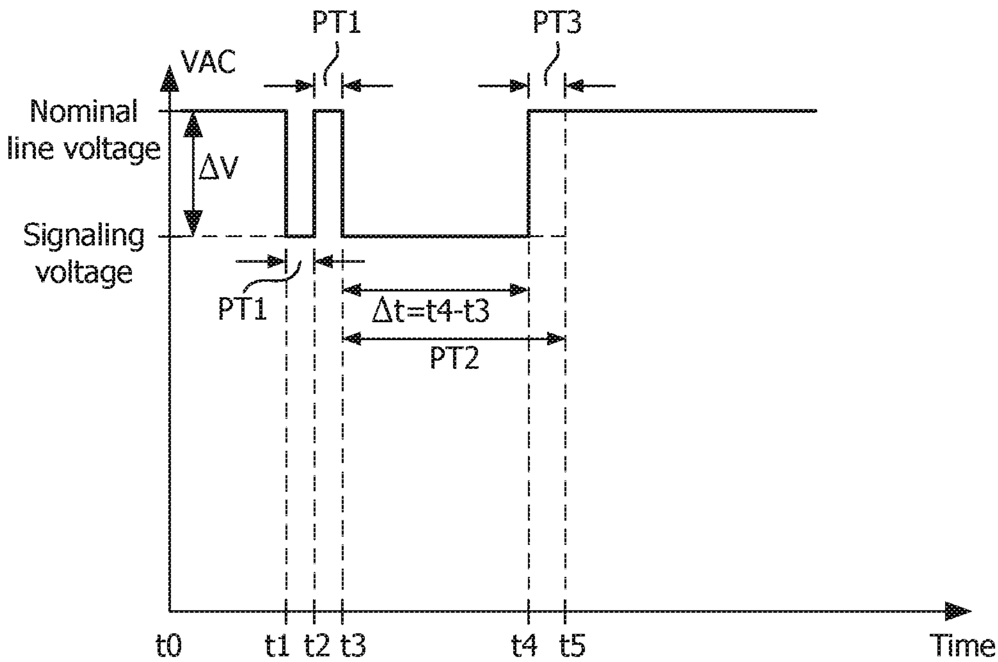
PT1
PT3
VAC
Nominal line voltage
ΔV
Signaling voltage
PT1
Δt=t4-t3
PT2
t0
t1
t2
t3
t4
t5
Time

FIG. 3

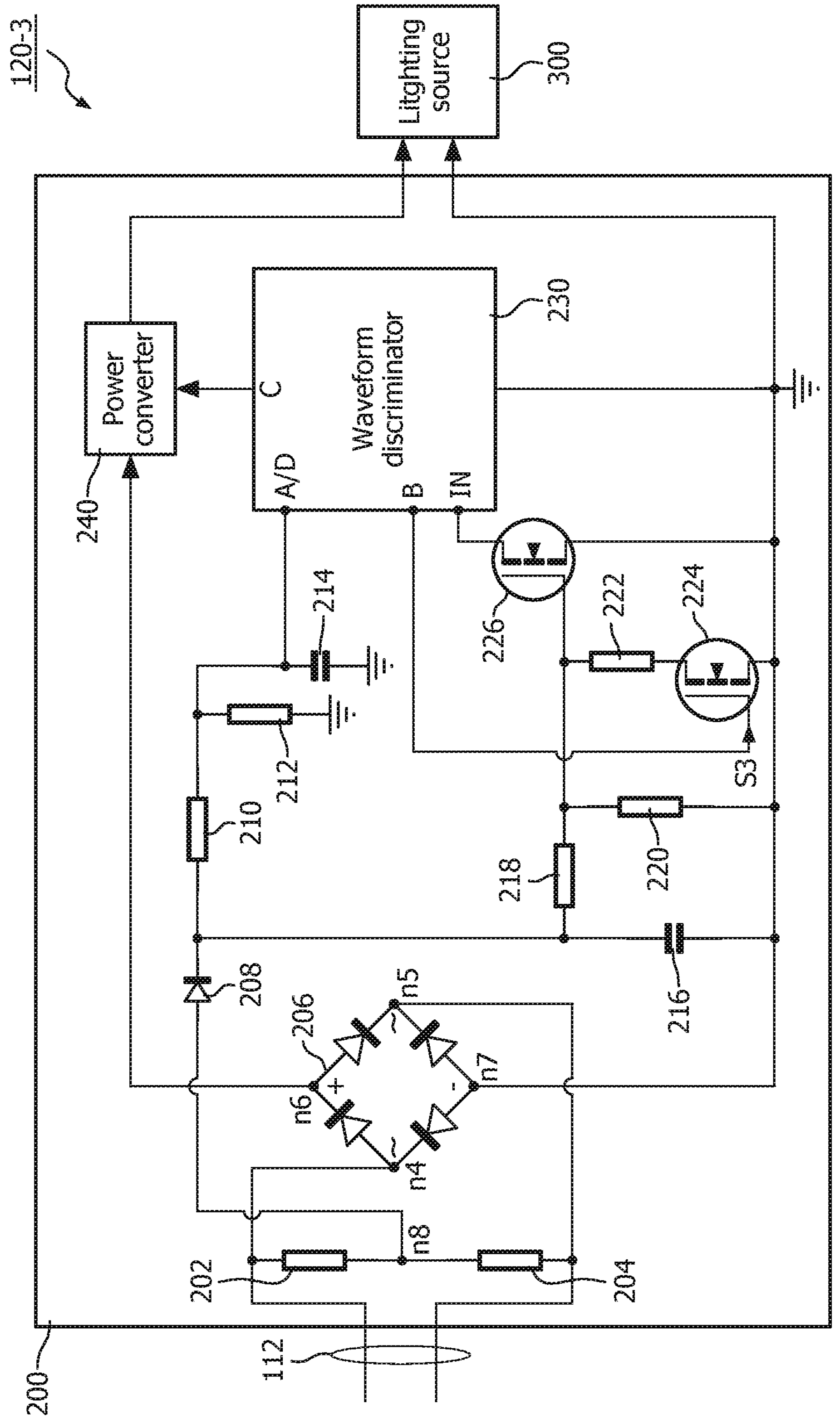
120-3
Litghting source
300
Power converter
240
Waveform discriminator
230
C
A/D
B
IN
214
212
210
208
206
226
222
224
S3
218
220
216
n4
n5
n6
n7
n8
202
204
112
200

FIG. 4

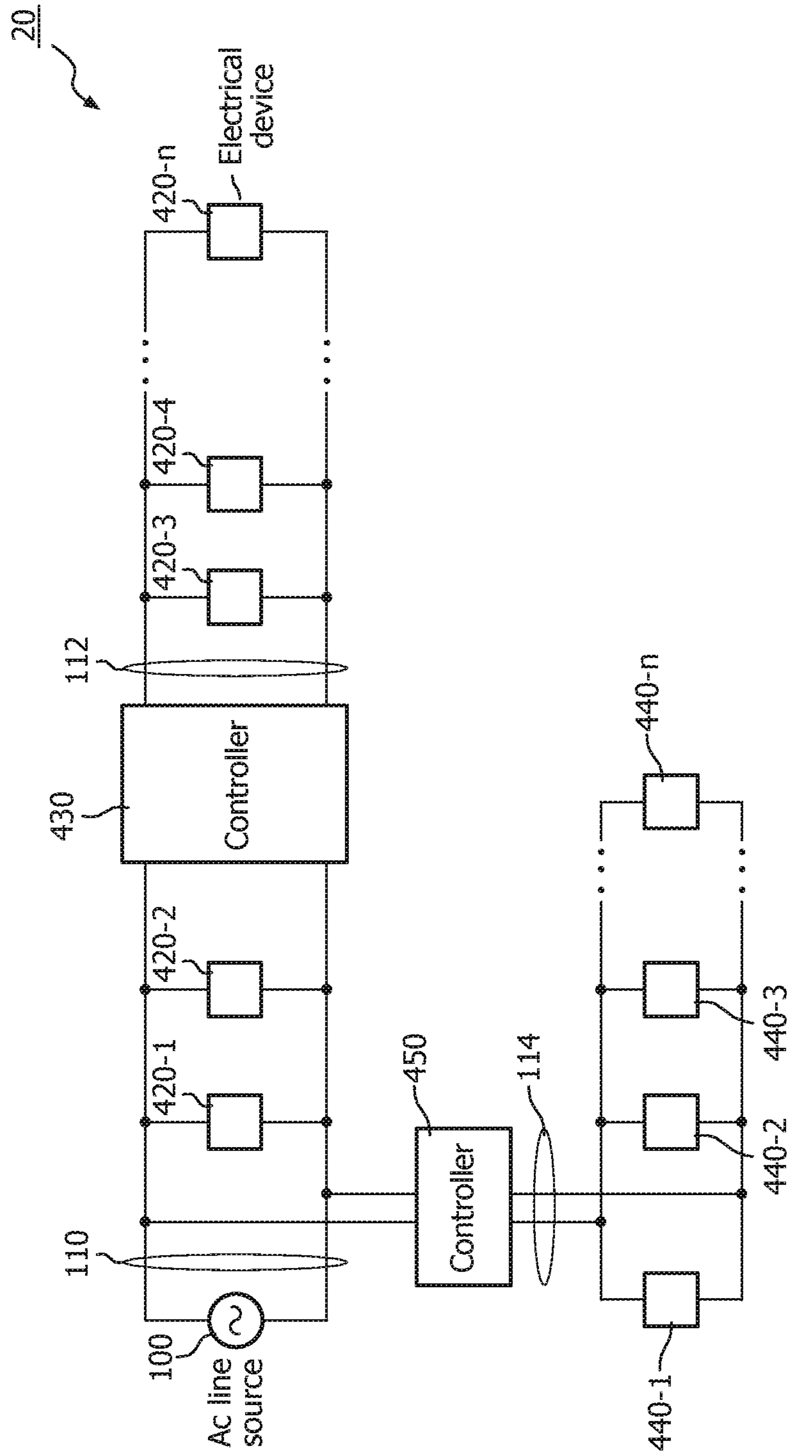
20
Electrical device
420-n
420-4
420-3
112
430
Controller
420-2
420-1
450
Controller
114
110
100
Ac line source
440-n
440-3
440-2
440-1

FIG. 5

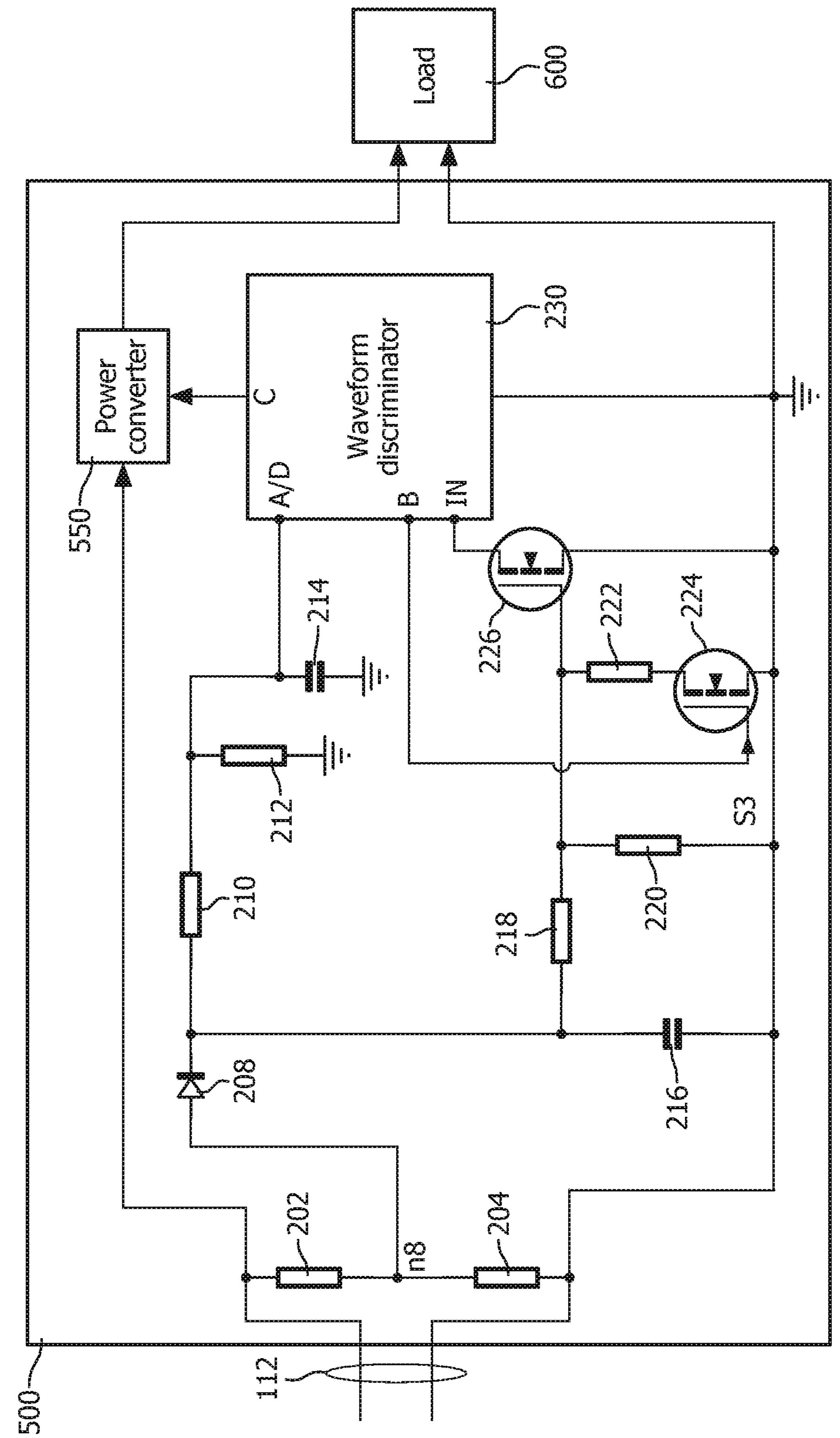
Load
600
Power converter
550
Waveform discriminator
230
C
A/D
B
IN
202
204
n8
208
210
212
214
216
218
220
222
224
226
S3
112
500

FIG. 6