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(54) Distributed wireless home network and commercial electrical automation system

(57) A central controller is disclosed to enable home and commercial automation for automatic, remote control of a wide variety of lights, appliances, HVAC and other systems utilizing a wireless distributed network. The central controller preferably employs a standard CPU and embedded operating system software. Graphical and audio user interfaces can be implemented. Harmonic distortion due to non-linear AC loads are mitigated in single-phase circuits through intelligent control of the loads and/or through intelligent complementary control of linear loads.

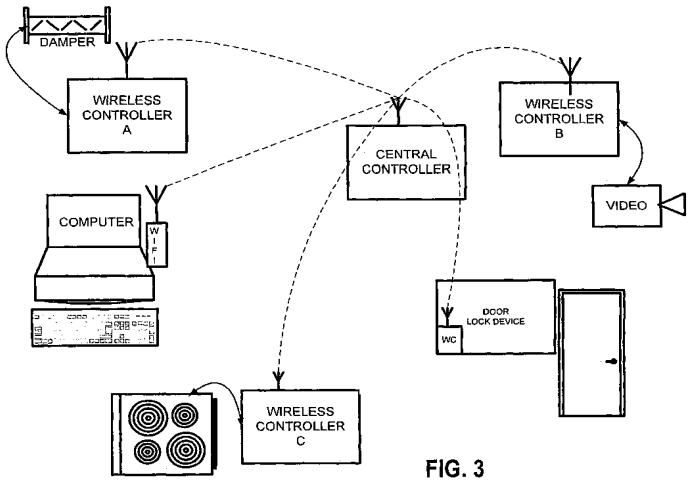

FIG. 3

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Description

Related Applications

[0001] This application claims priority based on U.S. Provisional Patent Application Serial No. 60/619,400, filed October 14, 2004; and based on U.S. Provisional Patent Application Serial No. 60/714,938, filed September 7, 2005. Both of said provisional applications are hereby incorporated herein by this reference.

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Technical Field

[0003] The invention pertains to control systems for controlling various electrical loads, apparatus and systems in the context of home and commercial automation, with particular focus on improvements in user convenience, energy efficiency and reliability.

Background of the Invention

[0004] Home automation heretofore is either very limited, to basic tasks such as remote control of light dimmers and switches, or it involves complicated, expensive, custom hardware and software The known home automation systems have very limited "intelligence" and awkward interfaces. Simple wireless modules for lights and household appliances are commercially available from Intermatic Incorporated of Spring Grove, IL. See www.intermatic.com. Other wireless light modules including dimmers are available from Lutron and Zwave. It is well known that harmonic interference on AC power lines causes heat loss inefficiencies, and undue wear on equipment such as transformers. Harmonics are caused by non-linear loads, such as typical light dimmers, because they actively switch the power on and off to adjust the light level, as distinguished from a passive regulator such as a potentiometer or rheostat which, although resistive and therefore linear, is highly energy inefficient.

[0005] Passive solutions, such as filters, are known for reducing harmonic distortion, but they have limitations and also dissipate energy. Active solutions have been developed for reducing harmonics in 4-wire, 3-phase systems, as taught in U.S. Pat. No. 5,568,371 to Pitel et al. That solution, however, is not applicable to the usual single-phase household circuit. Moreover, Pitel et al. describe an active filter that requires substantial hardware housed in a separate box.

[0006] The need remains for improvements in home and commercial automation to reduce costs, enable a wide variety of applications without custom hardware development, improve user convenience and comfort, as well as reliability.

Summary

[0007] The present invention is directed in various aspects to a variety of improvements in home or commercial automation and energy savings. Additional aspects and advantages will be apparent from the following detailed description of preferred embodiments, which proceeds with reference to the accompanying drawings.

Brief Description of the Drawings

[0008] Fig. 1A is a front plan view illustrating replacement of a conventional light switch with a central controller.

[0009] Fig. 1 B is an exploded view illustrating a central controller sized and arranged for installation in lieu of a conventional light switch or outlet in a standard home electrical box.

[0010] Figs. 2A-2C illustrate examples of front panel display content of a central controller.

[0011] Fig. 3 is one example of a home automation network illustrating application of various components including integrated as well as external wireless controllers.

[0012] Fig. 4 is a functional hardware block diagram of one example of a central controller consistent with the present invention.

[0013] Fig. 5 is a simplified residential floor plan illustrating an example of an HVAC application of the invention for improved convenience and energy efficiency.

[0014] Fig. 6 is a simplified schematic diagram illustrating an asymmetric biprocessor architecture of a central controller in accordance with one aspect of the invention.

[0015] Fig. 7A shows linear loads in a single-phase A.C. power circuit.

[0016] Fig. 7B shows the essentially sinusoidal electrical current waveform in the circuit of FIG. 7A.

[0017] FIG. 8A illustrates a plurality of non-linear loads, here conventional light dimmers each set to 33% brightness.

[0018] FIG. 8B shows the resulting non-linear electrical current waveform through the loads of FIG. 8A.

[0019] FIG. 9A illustrates a system in accordance with one embodiment of the present invention for normalizing non-linear loading in a single-phase power circuit to reduce harmonic distortions.

[0020] FIG. 9B shows the resulting load current using intelligent controllers for phase control to linearize the load.

[0021] FIG. 10 illustrates a system arranged for regu-

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lating a resistive load so as to compensate for one or more non-linear loads in the same circuit.

[0022] FIG. 11 shows illustrative waveforms and communication paths for the system of FIG. 10.

[0023] FIG. 12 shows a waveform generated by the central controller for normalizing the circuit of FIGS. 10 and 11 by regulating the resistive load.

Detailed Description of Preferred Embodiments

[0024] Nomenclature Note: In the provisional application, we used the term "Control Panel" to refer to "microprocessor based electronic device, capable of running operating systems which supports the wireless protocol, graphical user interface, touch screen functionality ...". (Provisional page 3.) In the present application, we will instead use the term "central controller" to refer to various devices and embodiments functionally similar to what was previously called the "Control Panel". This is to avoid confusion as the typical Central Controller, in accordance with some embodiments of the invention, will itself include a front panel or control panel that provides an interface to the controller.

[0025] Thus "control panel" will be used herein consistent with its ordinary meaning. For example, in one preferred embodiment, a central controller is disposed in a standard electrical box, and the front panel of the central controller is installed over it, similar to a conventional light switch cover plate. The term "central controller" is not intended to imply that only one central controller can be used in a given installation such as a home or office. To the contrary, in most cases, a plurality of central controllers will be deployed so as to form a distributed or mesh network, communicating with one another as further described later. That said, a single central controller can be used in smaller applications.

[0026] The provisional application also defined a "wireless controller" as, "any chip implementing one or more of several radio interfaces to allow communication over wireless links with various communication networks supporting the wireless protocol." This may be confusing, both internally and because the typical central controller described herein in some embodiments is correctly characterized as wireless. In this document, we will use "wireless transceiver" to refer to apparatus that implements communication over a wireless channel, which may comprise an access point, for example in the case of 802.11 implementations, or not, as in the case of Bluetooth or other ad hoc wireless protocols.

[0027] The central controller preferably includes one or more wireless transceivers for communication with other central controllers in the same network, and for communications with various other components, some of which are "controllers" (but not central controllers). The central controller(s) is where the user(s) mainly interface with the system. Other controllers, such as dimmers, respond to commands from a central controller to operate lights or other electrical loads. Controllers can be deployed for various electrical and mechanical tasks, as further described below.

[0028] In accordance with the present invention, various embodiments of a central controller are disclosed. The central controller preferably is wireless, but it can be hardwired for communications. Other particulars of preferred embodiments are as follows.

[0029] Basically, the central controller is a microprocessor-based electronic device to enable home or commercial automation functionality. It is the main hardware component of a home automation network, although as noted there can be more than one central controller. The central controller preferably executes at least one industry standard operating system, so that it provides an "open platform" for third party application software developers. Some of those applications will include lighting (both interior and exterior of a structure), HVAC (heating, ventilation and air conditioning), security (audio, motion detecting, video surveillance, etc.), entertainment, energy savings, etc. Implementation of any desired application can be accomplished with suitable programming and applying the invention as described herein.

[0030] In one preferred embodiment, the central controller is sized and arranged to fit inside of a standard household electrical box of the type that would commonly house a conventional light switch or outlet. A small central controller could be fit into a single switch box, while a two-gang, three-gang or larger box can accommodate a larger central controller and a correspondingly larger display panel -further described below. FIG. 1A illustrates the front appearance of a light switch replaced by a central controller in accordance with an embodiment of the invention. FIG. 1 B is an exploded view showing in more detail how a central controller can be deployed in a standard electrical box. The household wiring (available in the box) provides power for the central controller, although it can be battery powered or have battery backup.

[0031] The front panel of the central controller, which is removable for service and generally covers the central controller, preferably includes a display screen, which preferably comprises a touch-sensitive area, at least in part, for user input by touching an icon or other textual or graphic indicia to make a selection or adjustment.

[0032] The display / touch screen can be employed by suitable programming to provide an effective graphical user interface. In a simple example, one screen display (not shown) can be used to emulate a conventional light switch or dimmer control. This is a useful default value, say for a bedroom, where the user commonly enters the room and expects a light switch in the usual location inside the door. A central controller can replace the light switch in that box, and the default screen display can look like a light switch, and indeed function to turn the light off and on, responsive to a user press of the touch screen.

[0033] Referring again to FIG. 2A, it illustrates certain preferred features of the front panel. For example, the panel includes a few "hard" buttons -actual physical but-

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tons, that can be operated at any time without using the touch screen. These are labeled for illustration as "Application" and "Select". Continuing the bedroom example, after the default display is used to turn on the light, the user may press "Application" to see a list or set of icons representing applications currently available to her at that central controller. She may select "Audio" by pressing the corresponding icon, in which case the screen display changes again to present the audio player controls of FIG. 2A. By touching the screen where the pause, play, etc buttons are shown, the user can conveniently operate the audio system from the central controller. This is accomplished by a wireless controller that is inside or coupled to the audio equipment to receive corresponding commands from the central controller.

[0034] Note the top of the screen display preferably shows the location of the central controller, for example "Room Two" (FIG. 2A), "Living Room" (FIG. 2B), "Kitchen" (FIG. 2C) etc. The display preferably also includes a screen number where a given function requires more than one screen display. For example, in the living room, the lighting control screens span a total of six screens, with screen "2/6" shown in FIG. 2B. These principles of graphical user interface can be applied to other applications as well. In general, the central controller can interact with any electrical apparatus or system within the local network. The local network comprises one or more central controllers together with one or more, preferably many, controllers that communicate with the central controller and interact with various apparatus coupled to those controllers, such as audio, video, HVAC equipment, lighting, etc.

[0035] Some of these features are illustrated in FIG. 3 -a simplified network diagram. In this example, a central controller implements wireless communications, shown by dashed lines, with various components of the network. For example, a wireless controller "A" is connected to a motorized damper for HVAC control. It adjusts the damper in response to commands from the central controller. Another wireless controller "B" is connected to a video camera for security surveillance. The controller can adjust the camera in response to commands from the central controller, as well as communicate video data to the central controller. Surveillance software in the central controller may include, for example, image recognition software for detecting an intruder outside the premises by analyzing the captured video data. A wireless hub can be used to interface multiple appliances to a central controller where they are not coupled to it directly.

[0036] Wireless controllers may vary in their particular features and characteristics as necessary. A simple, low cost controller, for example, can be used merely to switch a light or outlet on and off responsive to remote commands. Simple wireless modules for lights and household appliances are commercially available from Intermatic Incorporated of Spring Grove, IL. See www.intermatic.com. Other wireless light modules including dimmers are available from Lutron and Zwave. In preferred embodiments, a central controller in accordance with the present invention executes application software and includes wireless transceivers that are compatible with these existing modules so as to include them in the new network. More sophisticated controllers, called "intelligent controllers," are discussed later with regard to managing harmonics caused by non-linear loads.

[0037] FIG. 3 also illustrates a wireless controller "C" coupled to an appliance such as a stove. The central controller can check to ensure that the stove is not left on when no one is at home. Motion or thermal detectors, as part of the network, can be used to determine whether people are at home. The same sensors are conveniently used for HVAC/ comfort control, automated lighting applications, security, etc. In that regard, a door lock device is shown in FIG. 3 as well. Here, the wireless transceiver capability is integrated into the door lock device itself; a separate wireless controller is not required. This device can be used to remotely lock or unlock the door, but also to report its status, open, closed, locked, to the security application software executing on the central controller in some embodiments of the invention. Various security algorithms can be used to secure the wireless communications in the network and prevent unauthorized intrusion.

[0038] FIG. 4 is a simplified hardware block diagram of one example of a central controller consistent with the present invention. Interconnections among the various components are omitted to avoid obscuring the drawing. Preferably, the CPU is an industry standard off-the-shelf microprocessor, along with internal and or external memory as appropriate, including both volatile and non-volatile memory such as flash memory. Preferably the CPU is provided with at least one standard embedded operating system such as Windows CE®, Linux Embedded, QnX or the like.

[0039] In the example illustrated, sensors are provided for sensing local ambient temperature, proximity (of a person), ambient light level, and so on. A microphone enables voice command inputs (in cooperation with voice recognition software stored in the memory and executable on the CPU). A speaker enables audible alarms, warnings or other announcements. A service connection, for example a standard connector such as an USB port can be provided for diagnostics, software loading, etc. Alternatively, the wireless transceiver can be used for communication with a computer or similar device for such functions. Other embodiments may have more of fewer sensors, inputs or outputs. Additional details of various specific embodiments of the invention will be within the design capabilities of persons skilled in electronics and microprocessor applications in view of the present disclosure. A alternative biprocessor architecture that incorporates the secondary processor is described later.

[0040] FIG. 5 is a simplified residential floor plan to illustrate selected aspects of HVAC control using the present invention. Here, each room illustrated includes a motion or proximity sensor "M" and a temperature sen-

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sor "T". These may be "standalone" remote sensor units, with the ability to communicate with a central controller. Or, one or more of them may itself be a local central controller in that room. Either way, comfort control software executing on the central controller can determine which rooms are occupied, as well as the current temperature of each room. Based on that information, it can adjust each local room HVAC damper(s) to optimize comfort while minimizing energy consumption. The system can also be used to control the HVAC system itself as part of this process.

[0041] To briefly summarize this section, the invention enables a user to conveniently: control any wireless light switch in any room; control any wireless power outlet; control any other electrical appliance which can be controlled via wireless protocol (coffee makers, rice makers, floor lamps, pool/tub electrical systems, smoke detectors, electrical locks, garage openers, etc), i.e. appliances that have integrated or "built-in" wireless control capability; and access media stored on the wireless server or on any other media storage device connected directly or indirectly by the wireless protocol to other system components. Of course, some embodiments of the invention will implement fewer than all of these features; they are not all required by the invention. The key point is that the central controller and distributed network described herein can be used in myriad ways, without significant hardware changes or added expense, because this system is fundamentally application software driven.

[0042] Additional functionality can include: monitor video from any video camera or other video signal source connected directly or indirectly by the wireless protocol to other system components; access settings and control the HVAC system in the household; have voice communication via the phone or inside the household between two or more central controller's; operate electrical devices which support infrared remote controls via the device which is equipped with the wireless controller and infrared emitter; access, control, query any other electronic devices via wireless protocol or infrared sequences.

[0043] All the foregoing functions of the central controller can be accessed with the touch screen or by voice command, or automatically (under software control) in response to sensor inputs, time or other trigger conditions or a combination of trigger conditions. In a preferred embodiment, any particular setting or parameter of the system can be used as a part of a saved profile. Any profile can be selected by user or automatically (according to schedule, day light, etc.).

[0044] The user interface of the central controller is designed to accommodate people's habit of entering a room and switching the light on. To do so, the user interface in one embodiment implements the "default switch" virtual button. This graphic button is displayed as the default screen display on the cc after a short timeout period following the last active user input. Any combination of the parameters or settings can be controlled by the "default button". Thus, for example, where each bedroom has a central controller installed, the occupant need merely touch the central controller panel once upon arrival to set lighting, audio, heat, etc. as determined by that user's personal profile. Profiles can be used in individual spaces and or network-wide. Some illustrative home-wide profiles are as follows:

Profile 1: No one home

[0045] Lighting: Lights off except, after dark, ON bathroom #1 and bedroom #3 and hall #2.
Security: Full ON after one minute for exit, check door locks, commence video surveillance.
Comfort: Lower all living spaces to 62-degrees F.
Entertainment: Off

Profile 2: Home: Commencing at 4:00 pm on weekdays

[0046] Lighting: Lights ON after dark, OFF bathroom #1 and all bedrooms; ON living room default settings
Security: door and window chimes only, discontinue video surveillance.
Comfort: Raise all living spaces to 72-degrees F.
Entertainment: Audio enabled, download daily news feed.

[0047] Profile 3: Sunday morning; etc....Profile 4: Sunday afternoons, etc.

[0048] Profile 5: short vacation, and so on. Profiles are created under software control and stored in non-volatile memory in the appropriate central controller.

Asymmetrical biprocessor architecture

[0049] An asymmetrical biprocessor architecture is optional but preferred to improve the reliability, availability and serviceability of home or commercial automation systems such as those described above.

[0050] Modem home automation system contain hundreds electronic components and hundred of thousands to millions lines of lines of software code. The failure of a single component (hardware and software) may render the system completely unusable which is unacceptable for home automation applications. There is a need for reliable, available and easily services and updated system.

[0051] There are two main contributing factors that can lead to failure in a home automation system:

1. Software errors. Bugs occurs because it's impracticable to provide 100% testing of large programs.
2. Main processor has a lot of dependencies on other electronic components. Failure of any of these components as failure of CPU itself makes the whole system unworkable. Also, the typical system contains fragile components like a touch screen, so there is always a risk that this screen can be broken, and even when formally the system is alive, it becomes very difficult to use it.

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