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(54) **APPARATUS AND METHODS FOR
COORDINATED STATIC SWITCH
OPERATIONS FOR LOAD TRANSFERS IN
UNINTERRUPTIBLE POWER SUPPLY
SYSTEMS**

(52) **U.S. CL. 307/64**(57) **ABSTRACT**

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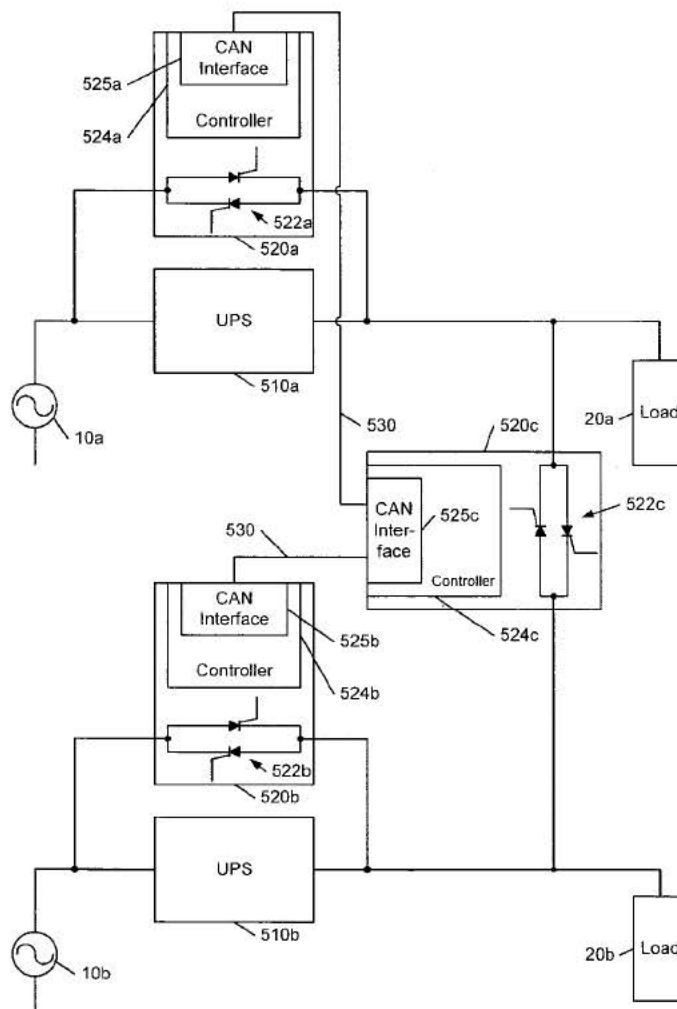
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A power supply apparatus includes an uninterruptible power supply (UPS) having an input configured to be coupled to a first power source and an output configured to be coupled to a load and a first static switch configured to provide a switchable bypass path from the first power source to the load. The apparatus further includes a second static switch controllable to provide a switchable path between the load and a second power source, and a controller circuit configured to cooperatively control the first and second static switches to transfer the load to the second power source. The controller circuit may be operative to transition the load from a first state wherein the load receives power from the first power source via the first static switch to a second state wherein the load receives power from the second power source while isolated from the first power source.



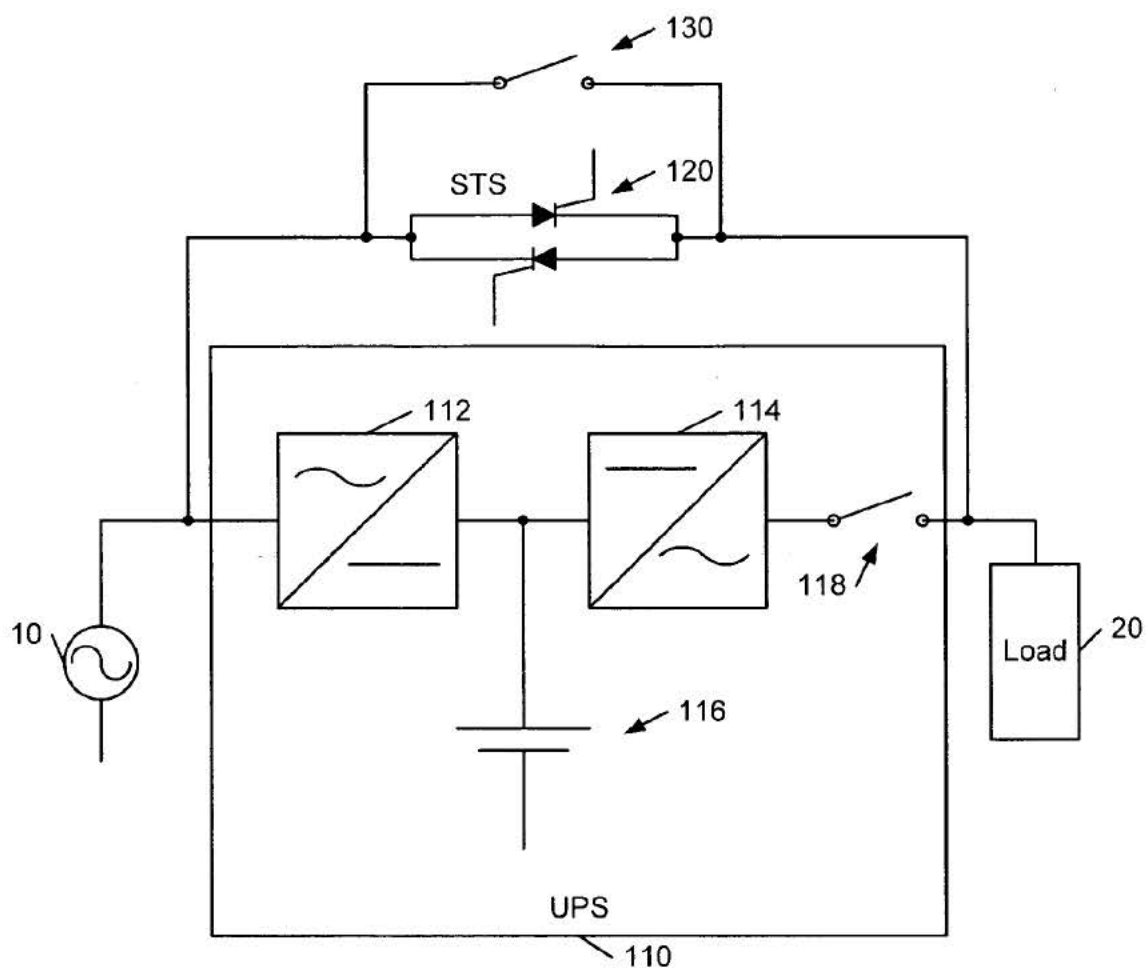
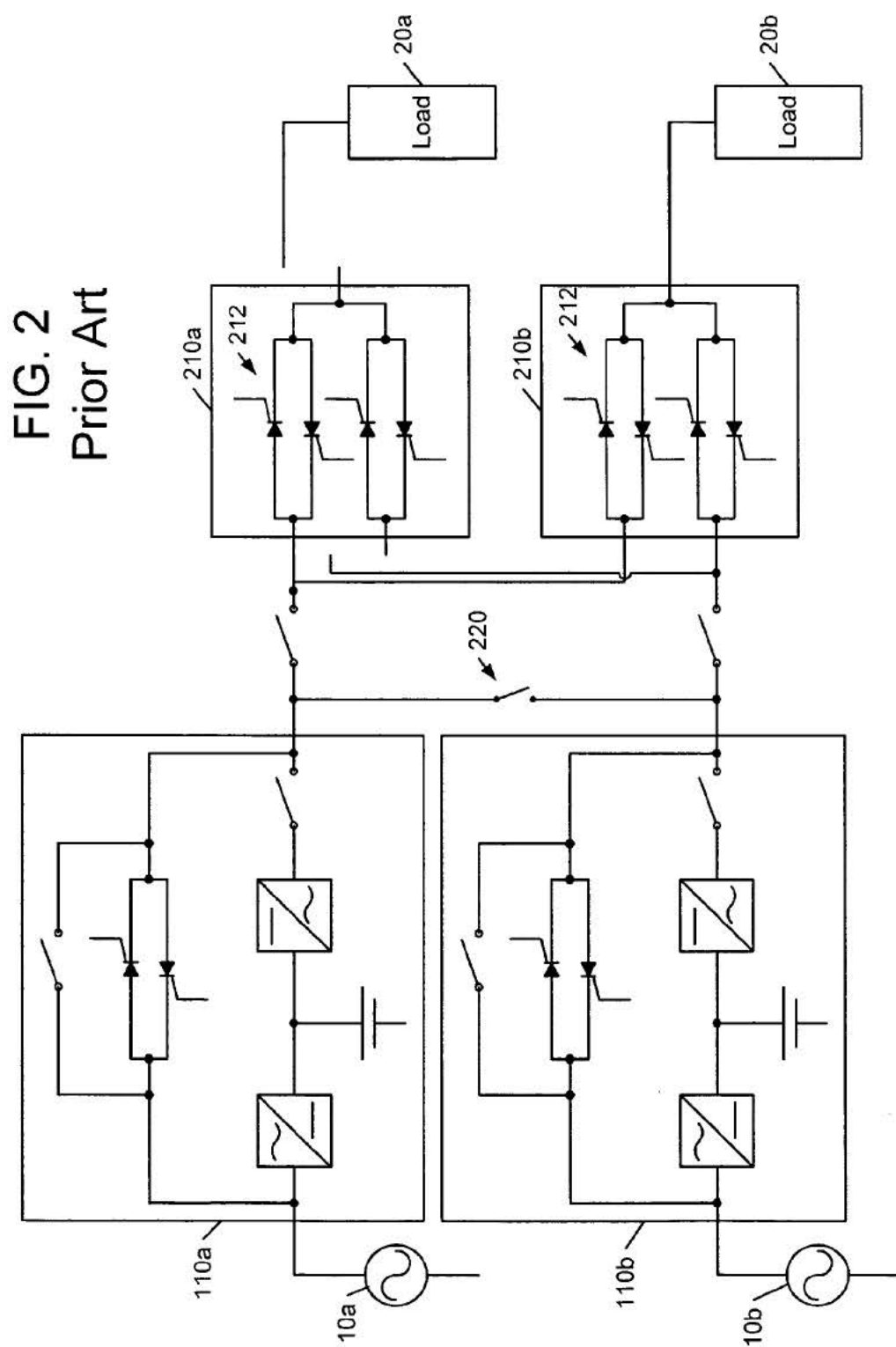


FIG. 1
Prior Art



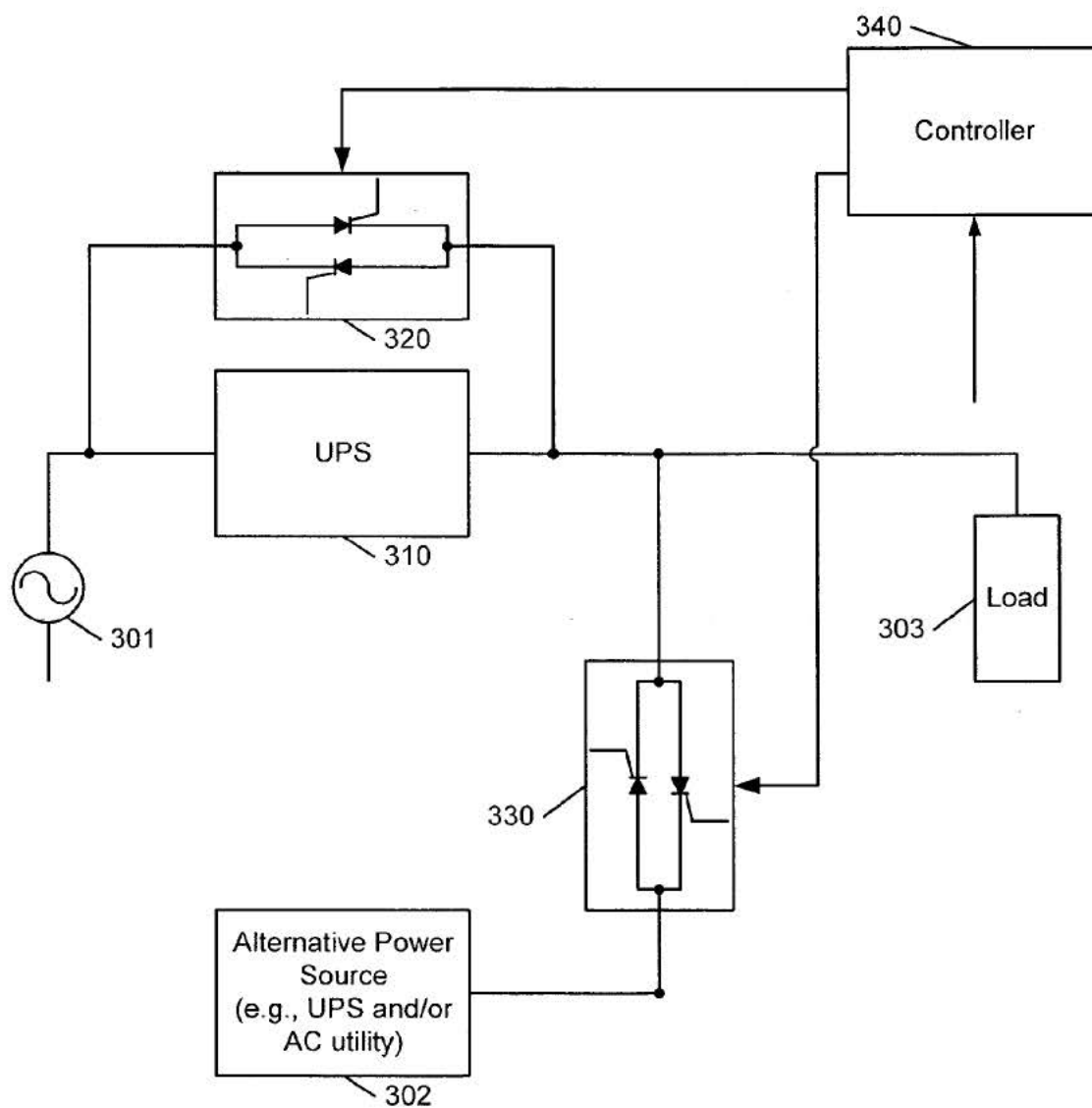
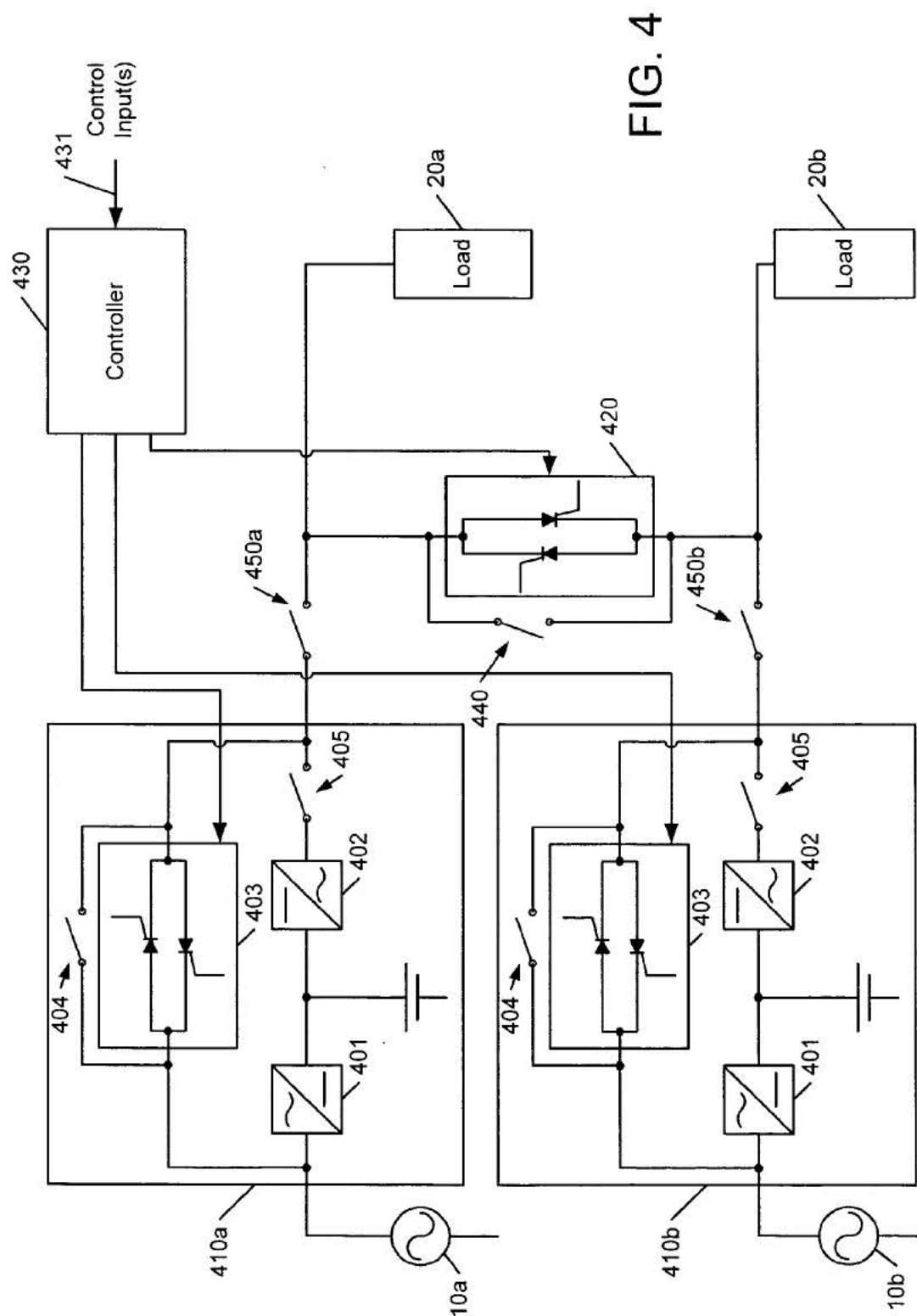
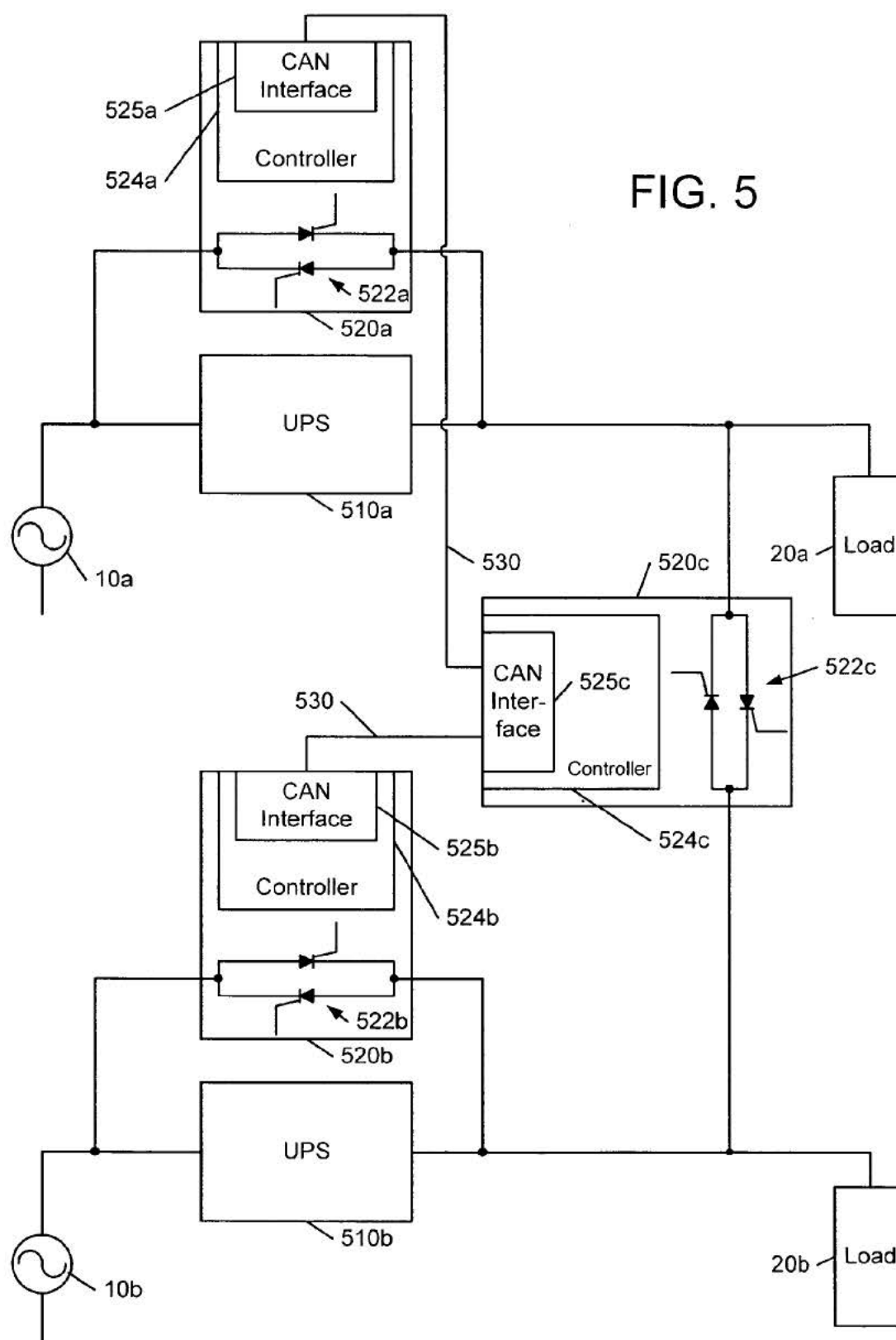


FIG. 3





APPARATUS AND METHODS FOR COORDINATED STATIC SWITCH OPERATIONS FOR LOAD TRANSFERS IN UNINTERRUPTIBLE POWER SUPPLY SYSTEMS

BACKGROUND OF THE INVENTION

[0001] The present invention relates to power supply apparatus and methods and, more particularly, to apparatus and methods for transferring loads among multiple power sources.

[0002] A "reverse transfer" or "on-line" uninterruptible power supply (UPS) may be used to provide protected power to a load. As shown in **FIG. 1**, a typical on-line UPS **110** includes a rectifier **112** that is configured to be coupled to an AC power source **10** and to produce a DC voltage therefrom. The DC voltage is applied to an inverter **114**, which generates an AC voltage for a load **20** coupled thereto. An alternative power source, e.g., a battery **116**, may be coupled to the intermediate DC link to provide power to the inverter **114** in the event of failure of the AC power source **10**. If the UPS **110** fails or is taken off line for maintenance, a high-speed solid-state static switch **120**, which, as shown, may include anti-parallel connected silicon controlled rectifiers (SCRs) or other solid-state circuits that provide similar switching capabilities, may be used to provide a bypass path between the power source **10** and power to the load **20**. The high-speed nature of the static switch **120** allows the load **20** to be transferred to the main source **10** with little or no interruption. In some applications, the static switch **120** may be integrated with the UPS **110** while, in other applications, the static switch **120** may be a separate device. As shown, a lower-speed switching device **130**, such as switch, relay or circuit breaker, may be provided to allow for bypassing of the static switch **120**. Other switches/breakers **118** may be provided for isolation and/or circuit protection.

[0003] Static switches may also be used to provide for transfer of loads among UPSs. Referring to **FIG. 2**, a first UPS **110a**, here shown as including bypass static switch and other isolation/circuit protection devices, may be coupled to a first power source **10a** and switchably coupled to a first load **20a** via a static switch **212** of a first static transfer switch (STS) **210a** and to a second load **20b** via a static switch **212** of a second STS **210b**. Similarly, a second UPS **110b** may be coupled to a second power source **10b** and switchably coupled to the first load **20a** via a static switch **212** of the first STS **210a** and to the second load **20b** via a static switch **212** of the second STS **210b**. A switch/breaker **220** may be provided between the outputs of the UPSs **110a**, **110b**.

[0004] The STSs **210a**, **210b** allow for transfer of the loads **20a**, **20b** between the first and second UPSs **110a**, **110b** by providing for selective coupling therebetween. In particular, at a given time, one static switch **212** in each STS **210a**, **210b** is activated to provide power to one of the loads **20a**, **20b**, while the other static switch **212** isolates the same load from the other power source. Each of the STSs **210a**, **210b** can transfer a load in an uninterrupted manner by substantially simultaneously turning off the active static switch and turning on the inactive static switch. The STSs **210a**, **210b** are typically built as integrated units that include electronic circuits to monitor voltages applied to the loads **20a**, **20b** and responsively control the static switches **212**. It will be

appreciated that, although **FIG. 2** illustrates dual STSs **210a**, **210b**, STSs with more than two static switches **212** may be used in applications in which more than two UPSs (or other power sources) are to be interconnected. A relatively less complex load transfer capability has also been provided in conventional systems by using a single static transfer switch that is coupled between two UPS outputs (or other power sources) and that operates responsive to a voltage at one or both of the outputs.

SUMMARY OF THE INVENTION

[0005] In some embodiments of the present invention, a power supply apparatus includes an uninterruptible power supply (UPS) having an input configured to be coupled to a first power source and an output configured to be coupled to a load. The apparatus also includes a first static switch configured to provide a switchable bypass path from the first power source to the load. The apparatus further includes a second static switch controllable to provide a switchable path between the load and a second power source, and a controller circuit configured to cooperatively control the first and second static switches to transfer the load to the second power source. The controller circuit may be operative to transition the load from a first state wherein the load receives power from the first power source via the first static switch to a second state wherein the load receives power from the second power source while isolated from the first power source. In particular, the controller circuit may be configured to cooperatively open the first static switch and close the second static switch to transition the load from the first state to the second state.

[0006] In further embodiments, the UPS is a first UPS having an output configured to be coupled to a first load, and the apparatus further includes a second UPS having an input configured to be coupled to the second power source and an output configured to be coupled to a second load and a third static switch controllable to provide a switchable bypass path between the second power source and the second load. The controller circuit is further configured to control the first and second static switches to transition the first load from the first state to the second state, wherein the first load in the second state receives power from the second power source via the second UPS and/or the third static switch while isolated from the first power source. The controller circuit may be further configured to cooperatively control the second and third static switches to transfer the second load to the first power source.

[0007] According to some embodiments, the controller circuit includes a first static switch controller circuit configured to operate the first static switch responsive to a first control signal and a second static switch controller circuit configured to operate the second static switch responsive to a second control signal. A third static switch controller circuit is configured to generate the first and second control signals. The first static switch controller circuit and/or the second static switch controller circuit may include a communications interface configured to receive messages from a digital communications bus, and the first control signal and/or the second control signal may include a message communicated over the digital communications bus. In some embodiments, the first static switch controller circuit and/or the second static switch controller circuit may be integrated with the load transfer controller circuit in a

common assembly. In further embodiments, the UPS, the first static switch and the first static switch controller circuit are integrated in a common assembly.

[0008] In additional embodiments of the present invention, an apparatus is provided for controlling load transfers in a power supply system including an uninterruptible power supply (UPS) having an input configured to be coupled to a first power supply and an output configured to be coupled to a load, a first static switch controllable to provide a switchable bypass path between the first power source and the load and a second static switch controllable to provide a switchable path between the load and a second power source. The apparatus includes a static switch controller circuit configured to cooperatively control the first and second static switches to transfer a load coupled to the output of the UPS to the second power source.

[0009] In some embodiments of the present invention, methods are provided for operating a power supply apparatus that includes an uninterruptible power supply (UPS) having an input configured to be coupled to a first power source and an output configured to be coupled to a load, a first static switch controllable to provide a switchable bypass path between the first power source and the load, and a second static switch controllable to provide a switchable path between the load and a second power source. The methods include cooperatively controlling the first and second static switches to transfer the load to the second power source. Cooperatively controlling the first and second static switches to transfer the load to the second power source may include controlling the first and second static switches to transition the load from a first state wherein the load receives power from the first power source via the first static switch to a second state wherein the load receives power from the second power source while isolated from the first power source. Controlling the first and second static switches to transition the load from a first state wherein the load receives power from the first power source via the first static switch to a second state wherein the load receives power from the second power source while isolated from the first power source may include cooperatively opening the first static switch and closing the second static switch to transition the load from the first state to the second state.

[0010] In further embodiments, the UPS includes a first UPS having an output configured to be coupled to a first load, and the power supply system further includes a second UPS having an input configured to be coupled to the second power source and an output configured to be coupled to a second load and a third static switch controllable to provide a switchable bypass path between the second power source and the second load. Controlling the first and second static switches to transition the load from a first state wherein the load receives power from the first power source via the first static switch to a second state wherein the load receives power from the second power source while isolated from the first power source includes controlling the first and second static switches to transition the load from the first state to the second state, wherein the load in the second state receives power from the second power source via the second UPS and/or the third static switch while isolated from the first power source. The methods may further include cooperatively controlling the second and third static switches to transfer the second load to the first power source.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 illustrates a conventional UPS with bypass capability.

[0012] FIG. 2 illustrates conventional use of static transfer switches (STSs) to provide load transfer capability for interconnected UPSs.

[0013] FIG. 3 is a schematic diagram illustrating apparatus and operations for load transfer for a UPS according to some embodiments of the present invention.

[0014] FIG. 4 is a schematic diagram illustrating apparatus and operations for load transfer among UPSs according to further embodiments of the present invention.

[0015] FIG. 5 is a schematic diagram illustrating apparatus and operations for load transfer among UPSs using static switches interconnected by a communications bus according to further embodiments of the present invention.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0016] Specific exemplary embodiments of the invention now will be described with reference to the accompanying drawings. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. The terminology used in the detailed description of the particular exemplary embodiments illustrated in the accompanying drawings is not intended to be limiting of the invention. In the drawings, like numbers refer to like elements.

[0017] As used herein, the singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless expressly stated otherwise. It will be further understood that the terms “includes,” “comprises,” “including” and/or “comprising,” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. It will be understood that when an element is referred to as being “connected” or “coupled” to another element, it can be directly connected or coupled to the other element or intervening elements may be present. Furthermore, “connected” or “coupled” as used herein may include wirelessly connected or coupled. As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

[0018] Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

[0019] As referred to herein, a “static switch” refers to a switching device with a solid-state (i.e., mechanically “static”) switching element that may be used for power

distribution applications. Such devices are typically capable of transitioning between open and closed states in an amount of time that supports substantially uninterrupted provision of power to a connected load. It will be appreciated that static switches may include, but are not limited to, devices including anti-parallel connected silicon-controlled rectifiers (SCRs) or other thyristor devices, as well as other types of semiconductor switching devices that provide substantially similar switching capability. It will be further appreciated that, in various embodiments, a “static switch” may also include electronic circuits, such as control circuits for firing SCRs or other semiconductor devices, that support static switch operations, as well as mechanical switches or breakers that may be used for isolation or bypass functions.

[0020] Some embodiments of the present invention arise from a realization that reduced cost and/or improved reliability in redundant power distribution systems may be provided by coordinating operations of a static switch that serves as a UPS bypass with operations of a static switch that serves as an inter-bus tie to allow for load transfers between power sources. Thus, for example, in parallel UPS installations, STSs coupled to the UPS outputs can be eliminated while still providing redundancy. The elimination of these STSs can significantly reduce system cost and improve system reliability by eliminating a potential serial point of failure.

[0021] FIG. 3 illustrates power supply apparatus and operations according to some embodiments of the present invention. A UPS 310 has an input configured to be coupled to a first power source 301 (e.g., an AC utility) and an output configured to be coupled to a load 303. It will be appreciated that other devices, such as mechanical switches, relays, or the like, may or may not be present between the first power source 301 and the UPS 310 and/or between the UPS 310 and the load 303. A first static switch 320 is controllable to provide a switchable bypass path from the first power source 301 to the output of the UPS 310. A second static switch 330 is controllable to provide a switchable path between the load 303 and a second, alternative power source 302. A controller 340 is configured to cooperatively control the first and second static switches 320, 330 to uninterruptedly transfer the load 303 to the second power source 302.

[0022] The controller 340 may control the static switches 320, 330 responsive to various system states, such as voltage at the first power source 301, the second power source 302 and/or the load 303. The cooperative operation of the static switches 320, 330 may occur in any of a number of different ways. For example, the switches 320, 330 may be operated substantially simultaneously, in a “make before break” fashion and/or in a “break before make” fashion. The switches 320, 330 may be driven independently and/or may operate in an interdependent fashion, for example, the controller 340 may include circuitry that operates a first one of the switches 320, 330 responsive to operation of a second one of the switches 320, 330, such as by sensing a state of the second one of the switches 320, 330. It will be appreciated that the UPS 310 may be a single unit or may include a plurality of paralleled UPS units. The second power source 302 may include, for example, another UPS and/or an AC utility source switchably coupled to the second static switch 330 by another switching device.

[0023] FIG. 4 illustrates an exemplary implementation according to further embodiments of the present invention.

First and second UPS systems 410a, 410b include rectifiers 401, inverters 402 and integrated bypass static switches 403, along with other switches/breakers 404, 405. The first UPS system 410a has its input coupled to a first AC power source 10a, and normally serves a first load 20a via a switch/breaker 450a. Similarly, the second UPS system 410b has its input coupled to a second AC power source 10b, and normally serves a second load 20b via a switch/breaker 450b. A static switch 420 is coupled between the first and second loads 20a, 20b and is controllable to provide a switchable path between the first load 20a and the second power source 10b via the static switch 404 and/or the rectifier 401 and inverter 402 of the second UPS system 410b. Similarly, the static switch 420 provides a switchable path between the second load 20b and the first power source 10a via the static switch 404 and/or the rectifier 401 and inverter 402 of the first UPS system 410a. A controller 430 cooperatively controls the static switches 404 of the first and second UPS systems 410a, 410b and the static switch 420 responsive to one or more control inputs 431, such that the first load 20a and/or the second load 20b may be transferred between the first and second UPS systems 410a, 410b.

[0024] For example, if the first UPS system 410a is powering the first load 20a in a bypassed mode, e.g., the static switch 404 of the first UPS system 410a is closed, and failure of the first power source 10a is detected, the controller 430 may substantially simultaneously open the static switch 404 of the first UPS system 410a and close the static switch 420 to provide uninterrupted transfer of the first load 20a to the second UPS system 410b. Similarly, if the second UPS system 410b is powering the second load 20b in a bypassed mode and failure of the second power source 10b is detected, the controller 430 may substantially simultaneously open the static switch 404 of the second UPS system 410b and close the static switch 420 to provide uninterrupted transfer of the second load 20b to the first UPS system 410a. It will be appreciated that the control inputs 431 may include any of a variety of system states, such as voltages at the first and second loads 10a, 10b and/or voltages of the first and second power sources 10a, 10b, and that the transfer operations of the controller 430 may be conditioned upon any of a variety of criteria, such as voltage magnitude, voltage frequency, waveform quality and the like.

[0025] FIG. 5 illustrates other exemplary embodiments of the present invention, in which static switches are controlled via digital communications links. First and second UPSs 510a, 510b have inputs coupled to respective first and second AC power sources 10a, 10b and outputs coupled to respective first and second loads 20a, 20b (further elements, such as isolation switches/breakers, may be present). Respective first and second static switches 520a, 520b are controllable to provide respective switchable bypass paths for the first and second UPSs 510a, 510b, while a third static switch 520c is controllable to provide a switchable path between the first UPS 510a/first static switch 520a and the second load 20b and between the second UPS 510b/second static switch 520b and the first load 20a. The first, second and third static switches 520a, 520b, 520c include respective static switch elements 522a, 522b, 522c and respective first, second and third static switch controllers 524a, 524b, 524c, each of which includes a communications interface, here shown as Controller Area Network (CAN) interfaces 525a,

525b, 525c. CAN is a serial bus system developed by Robert Bosch GmbH and is the subject of the ISO 11898 international standard.

[0026] The first, second and third static switch controllers **524a, 524b, 524c** may include, for example, drive circuitry and other electronics that control the first, second and third static switch elements **522a, 522b, 522c** responsive to messages received via the CAN interfaces **525a, 525b, 525c** and/or other signal inputs, such as sensor signal inputs. As shown, the first and second static switch controllers **524a, 524b** may be controlled by the third static switch controller **524c**. For example, the third static switch controller **524c** may sense voltages or other conditions that warrant load transfer, and may responsively issue command messages to the first static switch controller **524a** and/or the second static switch controller **524c** via communications busses **530** to control the first static switch **520a** and/or the second static switch **520b** in cooperation with the third static switch **520c** to achieve uninterrupted transfer of the first load **20a** and/or the second load **20b** between the first and second power sources **10a, 10b**.

[0027] It will be understood that static switch control circuitry in various embodiments of the present invention may be configured in various different ways. In some embodiments, for example, the first and second static switches **520a, 520b** may be integrated with the respective first and second UPSs **510a, 510b**, and the third static switch **520c** may be a separate assembly which is configured to be connected (e.g., by serial busses) to communications interfaces of the integrated UPS/static switch units. In such embodiments, the third static switch controller **524c** may, for example, include voltage or other sensors and associated electronics that monitor voltage or other conditions and electronic control circuits that responsively control power switching operations of the first, second and third static switches **520a, 520b, 520c**. It will be appreciated, however, that other control configurations fall within the scope of the present invention. For example, instead of having a static switch controller **524c** associated with the inter-bus static switch **520c** act as a monitor/master device as discussed above, one of the first static switch controller **524a** or the second static switch controller **524b** could serve in the monitor/master role. In further embodiments, the first and second static switches **520a, 520b** and associated controllers **524a, 524b** could be separate assemblies configured to be connected in parallel with the UPSs **510a, 510b**.

[0028] In the drawings and specification, there have been disclosed exemplary embodiments of the invention. Although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention being defined by the following claims.

That which is claimed is:

1. A power supply apparatus, comprising:

an uninterruptible power supply (UPS) having an input configured to be coupled to a first power source and an output configured to be coupled to a load;

a first static switch configured to provide a switchable bypass path from the first power source to the load;

a second static switch controllable to provide a switchable path between the load and a second power source; and

a controller circuit configured to cooperatively control the first and second static switches to transfer the load to the second power source.

2. An apparatus according to claim 1, wherein the controller circuit is operative to transition the load from a first state wherein the load receives power from the first power source via the first static switch to a second state wherein the load receives power from the second power source while isolated from the first power source.

3. An apparatus according to claim 2, wherein the controller circuit is configured to cooperatively open the first static switch and close the second static switch to transition the load from the first state to the second state.

4. An apparatus according to claim 2, wherein the UPS comprises a first UPS having an output configured to be coupled to a first load, and wherein the apparatus further comprises a second UPS having an input configured to be coupled to the second power source and an output configured to be coupled to a second load and a third static switch controllable to provide a switchable bypass path between the second power source and the second load, wherein the controller circuit is further configured to control the first and second static switches to transition the first load from the first state to the second state, and wherein the first load in the second state receives power from the second power source via the second UPS and/or the third static switch while isolated from the first power source.

5. An apparatus according to claim 4, wherein the controller circuit is further configured to cooperatively control the second and third static switches to transfer the second load to the first power source.

6. An apparatus according to claim 1, wherein the controller circuit cooperatively controls the first and second static switches responsive to a voltage.

7. An apparatus according to claim 1, wherein the controller circuit comprises:

a first static switch controller circuit configured to operate the first static switch responsive to a first control signal;

a second static switch controller circuit configured to operate the second static switch responsive to a second control signal; and

a load transfer controller circuit configured to generate the first and second control signals.

8. An apparatus according to claim 7, wherein the first static switch controller circuit and/or the second static switch controller circuit comprises a communications interface configured to receive messages from a digital communications bus, and wherein the first control signal and/or the second control signal comprises a message communicated over the digital communications bus.

9. An apparatus according to claim 8, wherein the communications bus comprises a controller area network (CAN) bus.

10. An apparatus according to claim 7, wherein the first static switch controller circuit and/or the second static switch controller circuit is integrated with the load transfer controller circuit in a common assembly.

11. An apparatus according to claim 7, wherein the UPS, the first static switch and the first static switch controller circuit are integrated in a common assembly.

12. An apparatus according to claim 1, wherein the UPS comprises a plurality of parallel-connected UPSs.

13. An apparatus for controlling load transfers in a power supply system including an uninterruptible power supply (UPS) having an input configured to be coupled to a first power supply and an output configured to be coupled to a load, a first static switch controllable to provide a switchable bypass path between the first power source and the load and a second static switch controllable to provide a switchable path between the load and a second power source, the apparatus comprising:

a controller circuit configured to cooperatively control the first and second static switches to transfer a load coupled to the output of the UPS to the second power source.

14. An apparatus according to claim 13, wherein the controller circuit is operative to transition the load from a first state wherein the load receives power from the first power source via the first static switch to a second state wherein the load receives power from the second power source while isolated from the first power source.

15. An apparatus according to claim 14, wherein the controller circuit is configured to cooperatively open the first static switch and close the second static switch to transition the load from the first state to the second state.

16. An apparatus according to claim 14, wherein the UPS comprises a first UPS having an output configured to be coupled to a first load, wherein the power supply system further includes a second UPS having an input configured to be coupled to the second power source and an input configured to be coupled to a second load and a third static switch controllable to provide a switchable bypass path between the second power source and the second load, wherein the controller circuit is further configured to control the first and second static switches to transition the load from the first state to the second state, wherein the load in the second state receives power from the second power source via the UPS and/or the third static switch while isolated from the first power source.

17. An apparatus according to claim 16, wherein the controller circuit is further configured to cooperatively control the second and third static switches to transfer the second load to the first power source.

18. An apparatus according to claim 13, wherein the controller circuit cooperatively controls the first and second static switches responsive to a voltage.

19. A method of operating a power supply apparatus that includes an uninterruptible power supply (UPS) having an input configured to be coupled to a first power source and an output configured to be coupled to a load, a static switch controllable to provide a switchable bypass path between the

first power source and the load, and a second static switch controllable to provide a switchable path between the load and a second power source, the method comprising:

cooperatively controlling the first and second static switches to transfer the load to the second power source.

20. A method according to claim 19, wherein cooperatively controlling the first and second static switches to transfer the load to the second power source comprises controlling the first and second static switches to transition the load from a first state wherein the load receives power from the first power source via the first static switch to a second state wherein the load receives power from the second power source while isolated from the first power source.

21. A method according to claim 20, wherein controlling the first and second static switches to transition the load from a first state wherein the load receives power from the first power source via the first static switch to a second state wherein the load receives power from the second power source while isolated from the first power source comprises cooperatively opening the first static switch and closing the second static switch to transition the load from the first state to the second state.

22. A method according to claim 20, wherein the UPS comprises a first UPS having an output configured to be coupled to a first load, wherein the power supply system further includes a second UPS having an input configured to be coupled to the second power source and an output configured to be coupled to a second load and a third static switch controllable to provide a switchable bypass path between the second power source and the second load, and wherein controlling the first and second static switches to transition the load from a first state wherein the load receives power from the first power source via the first static switch to a second state wherein the load receives power from the second power source while isolated from the first power source comprises controlling the first and second static switches to transition the load from the first state to the second state, wherein the load in the second state receives power from the second power source via the second UPS and/or the third static switch while isolated from the first power source.

23. A method according to claim 22, further comprising cooperatively controlling the second and third static switches to transfer the second load to the first power source.

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