Multimode Power Processor

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	Publication Number	Kind	Date	Application Number	Filing Date
Main Patent	US 5929538	A	19990727	US 97884306	19970627
Priority				US 97884306	19970627

Current US Classification (Main): 307066000 (X-ref): 307044000; 307064000
US Classification on document (Main): 307066 (X-ref): 307064; 307044; 36452821
International Classification (Edition 1): H02J-007/00
Examiner Field of Search (US): 307043; 307044; 307045; 307046; 307047; 307048; 307049; 307050; 307051; 307064; 307065; 307066; 307085; 307086; 307087; 364480; 364492; 364493; 36452821; 36452822; 36452823; 3645283; 36452832

Cited US Patents:

Patent Number	Date YYYYMM	Main US Class	Inventor
US 4277692	198107	3067066	Small
US 4287465	198109		Godard
US 4528457	198507		Keefe
US 4652770	198703		Kumano
US 4731547	198803	307085	Alenduff
US 4761563	198808		Ross
US 4775800	198810		Wood
US 5010469	199104		Bobry
US 5057697	199110		Hammond
US 5070251	199112		Rodes
US 5126585	199206		Boys
US 5168436	199212		Barlage
US 5184025	199302		McCurry
US 5198698	199303		Paul
US 5198970	199303		Kawabata
US 5229651	199307		Baxter, Jr.
US 5241217	199308		Severinsky
US 5264732	199311		Fiorina
US 5285365	199402		Yamato
US 5289045	199402		Lavin
US 5289046	199402		Gregorich
US 5295078	199403		Stich
US 5302858	199404		Folts
US 5332927	199407		Paul
US 5384792	199501		Hirachi
US 5483463	199601	364492	Qin
US 5500561	199603	307064	Wilhelm
US 5532525	199607		Kaiser

Cited non-Patent References:
Bower et al. (1990) IEEE AES Magazine, Aug., pp. 16-21.
O'Sullivan, G. (1988), PCIM Magazine, Dec. :42-6.
O'Sullivan, G. (1989), "Bimode UPS reduces systen complexity," European Power News, Nov./Dec., Hastings Printing Co. Ltd, East Sussex, England.
O'Sullivan, G. (1990), "The myth of On-Line UPS", Atlantic Tech., vol: 5, No: 10.
O'Sullivan, G. (1993), "Fault Tolerant Battery Power Recycling", Fourth Int. Conference, Sep. 7-Oct.1, Berlin, Germany, pp. 18-31.

Fulltext Word Count: 15926
Number of Claims: 35
Exemplary Claim Number: 1
Number of Drawing Sheets: 25
Number of Figures: 31
Number of US cited patent references: 28
Number of non-patent cited references: 5
Calculated Expiration Date: 20170627

Abstract:
In one embodiment, a power processor which operates in three modes: an inverter mode wherein power is delivered from a battery to an AC power grid or load; a battery charger mode wherein the battery is charged by a generator; and a parallel mode wherein the generator supplies power to the AC power grid or load in parallel with the battery. In the parallel mode, the system adapts to arbitrary non-linear loads. The power processor may operate on a per-phase basis wherein the load may be synthetically transferred from one phase to another by way of a bumpless transfer which causes no interruption of power to the load when transferring energy sources. Voltage transients and frequency transients delivered to the load when switching between the generator and battery sources are minimized, thereby providing an uninterruptible power supply. The power processor may be used as part of a hybrid electrical power source system which may contain, in one embodiment, a photovoltaic array, diesel engine, and battery power sources.

We claim:

1. An AC power processor for delivering power to a load in coordination with an energy storage device and an AC power source comprising:
an electronic power control means, connecting said energy storage device and said alternating current power source, for selectively directing power from the AC power source to the energy storage device and from the energy storage device to the load, on a subcyclic basis with respect to the AC power source;
a single bridge including a plurality of switching elements capable of AC-DC and DC-AC conversions, wherein each switching element is capable of being positioned in an on state or off state;
wherein said processor is capable of operating in at least three modes including:
a first mode wherein power is supplied to the load only by said power processor;
a second mode wherein the AC power source supplies power to both the load and said power processor; and
a third mode wherein both the AC power source and said power processor supply power to the load in parallel;
whereby said processor is capable of adjusting the energy stored in

the energy storage device. (Main Claim)

2. The processor according claim 1 wherein said processor is adapted to control the power on a per-phase basis.
3. An AC power processor, for use with a DC voltage source, for delivering power to a load, in parallel and in coordination with an AC voltage source, the processor comprising means for controlling the flow of electrical energy into and out of said DC voltage source, including:
   a plurality of switching elements connected to the DC voltage source, wherein the switching elements are capable of converting an AC current from the AC voltage source to DC current and directing the DC current to the DC voltage source, and wherein the switching elements are capable of converting a DC current from the DC voltage source into an AC current and directing the AC current to the load;
   at least one inductive element interposed between said switching elements and said AC voltage source;
   means for determining a plurality of switch configurations on a subcyclic basis with respect to the AC power source and based on a desired optimization strategy; and
   means for switching the switching elements;
   wherein the processor is capable of operating in at least three modes including:
   an inverter mode wherein AC current is supplied to the load only by said power processor;
   a charge-supply mode wherein the AC power source supplies current to the load and said power processor; and
   a parallel supply mode wherein both the AC power source and the power processor supply current to the load in parallel.
4. A multi-modal power supply system for delivering power to a load in coordination with an AC power source and a DC voltage source, the system comprising:
   at least one bridge including a plurality of switching elements capable of AC-DC and DC-AC conversions, wherein each switching element is capable of being positioned in an on state or an off state;
   at least one means for connecting said bridge to the DC voltage source;
   at least one means for interconnecting said bridge, the AC power source and the load, including:
   a bridge-AC connection means for connecting said bridge to the AC voltage source;
   a parallel connection means for connecting the load to said bridge-AC connection means at parallel points; and
   an inductive means disposed between said bridge and the parallel points;
   at least one means for sensing the voltage and current of the DC voltage source;
   at least one means for sensing the voltage and current of the AC power source;
   at least one means for sensing the voltage and current between said bridge and said inductive means; and
   at least one control means for changing the positions of said plurality of switching elements on a subcyclic basis based on the sensed voltages and currents;
   wherein said plurality of switching elements is capable of converting the AC current from the AC voltage source to DC current, and directing the DC current to the DC voltage source;

wherein said plurality of switching elements is capable of converting the DC current from the DC voltage source into AC current and directing the AC current to the load;
wherein said plurality of switching elements are capable of being positioned into at least four configurations for each phase, including:
a first configuration wherein the DC voltage source supplies a positive polarity voltage to the load across said inductive means,
a second configuration wherein the DC voltage source supplies a negative polarity voltage to the load across said inductive means,
a third configuration wherein said inductive means supplies a positive polarity voltage to the load, and
a fourth configuration wherein said inductive means supplies a negative polarity voltage to the load; and
wherein said system is capable of operating in at least three modes including:
an inverter mode wherein AC current is supplied to the load by either the DC voltage source or said inductive means, or both;
a charge-supply mode wherein the AC power source supplies power to the load, said inductive means, or said DC voltage source, or a combination thereof; and
a parallel supply mode wherein the AC power source and at least one of said inductive means or the DC voltage source, or both, supply power to the load in parallel.

5. The system according claim 4 wherein said system is adapted for multiphase operation and includes, for each phase, a respective said bridge, said bridge-to-DC voltage source connecting means, said bridge-AC power source-load interconnecting means, said DC voltage source sensing means, said AC power source sensing means, and said means for sensing voltage and current between said bridge and said inductive means.
6. The system according to claim 4 further comprising a switching means disposed between the AC voltage source and the bridge for selectively disconnecting the AC voltage source.
7. The system according to claim 4 wherein said control means changes the positions of said plurality of switching elements on a subcyclic basis based on the sensed voltages and currents according to an optimization strategy.
8. The system according to claim 7 wherein said optimization strategy further comprises maintaining in phase the current and voltage of the AC power source during the charge-supply mode or the parallel supply mode.
9. The system according to claim 7 wherein said system further comprises a means for generating a reference waveform in phase with the voltage of the AC voltage source.
10. The system according to claim 9 wherein said optimization strategy further comprises means for minimizing the error between the AC voltage source current and the in-phase reference waveform.
11. The system according to claim 10 wherein said reference waveform is sinusoidal.
12. The system according to claim 10 wherein said reference waveform is triangular.
13. The system according to claim 10 wherein said reference waveform is trapezoidal.
14. The system according to claim 10 wherein the amplitude of said reference waveform corresponds to the maximum deliverable power of the AC voltage source.

15. The system according to claim 7 wherein said system is capable of optimizing the current waveform of the AC voltage source during the parallel supply mode by supplying power or withdrawing power from said parallel connection means on a subcyclic basis.
16. The system according to claim 15 wherein said system is capable of optimizing the current waveform of the AC power source during the charge-supply mode or the parallel supply mode by supplying power or withdrawing power from said parallel connection means on a subcyclic basis.
17. The system according to claim 16 wherein said system further comprises a means for generating a reference waveform in phase with the voltage of the AC power source.
18. The system according to claim 17 wherein said optimization strategy further comprises minimizing the mean integrated square-error between the AC power source current and the in-phase reference waveform.
19. The system according to claim 18 wherein said reference waveform is sinusoidal.
20. The system according to claim 18 wherein said reference waveform is triangular.
21. The system according to claim 18 wherein said reference waveform is trapezoidal.
22. The system according to claim 18 wherein the amplitude of said reference waveform corresponds to the maximum deliverable power of the AC power source.
23. The system according to claim 4 wherein said system further comprises means for determining the period of the AC power source; and wherein said control means further comprises:
    means for dividing the period into equal time intervals; and
    means for determining the durations of the on and off states of each switching element for each equal time interval.
24. An uninterruptible power supply system for delivering power to a load comprising:
    input lines for receiving an AC power input having a waveform with positive and negative half cycles;
    output lines for providing an AC power output to the load;
    a battery capable of providing a DC output voltage;
    a power transformer having a primary coupled to a secondary, the secondary being connected across the output lines;
    an inverter connected to the primary of the power transformer and to the battery, including switching devices connected in a bridge configuration which are controllable to convert DC voltage power from the battery to AC voltage power at the primary of the power transformer and to supply the battery with power from the primary, the switching devices being responsive to control signals to switch between on and off states; and
    control means, connected to the switching devices in the inverter, for controlling the power into and out of the inverter on a subcyclic basis relative to the AC power input, including:
    means for sensing the battery voltage;
    means for determining the polarity of the AC input;
    means for determining a desired AC power output current;
    means for generating a sinusoidal reference signal having an amplitude substantially equal to the desired output current;
    means for comparing the sinusoidal reference signal with the output current to yield a current error signal; and
    means for generating a pulse width proportional to the amplitude of the current error signal for modulating the inverter switching

devices;
wherein the switching devices are capable of assuming at least four pairs of configurations based upon the polarity of the error signal and the polarity of the AC input voltage, wherein the switches are pulsed on into a first configuration of each pair for the duration of each pulse width and pulsed off into a second configuration of each pair;
wherein said system is capable of operating in one of a plurality of states, including:
a first power supply state in which the battery is capable of supplying power to the load through the inverter, said state corresponding to the first configuration when the polarities of the error signal and the AC input voltage coincide;
a second power supply state in which an effective inductance, which includes the effective leakage inductances of the primary and secondary of the transformer, is capable of supplying power to the load, said state corresponding to the second configuration when the polarities of the error signal and the AC input voltage coincide;
a first power consumption state in which the AC power input is capable of charging the battery through the inverter, said state corresponding to the first configuration when the polarities of the error signal and the AC input voltage differ; and
a second power consumption state in which the AC power input is capable of supplying power to the effective inductance, said state corresponding to the second configuration when the polarities of the error signal and the AC input voltage differ;
wherein the system is capable of supplying power to the load from the battery and the AC power input simultaneously.

25. The system according to claim 24 wherein said system further comprises means for maintaining the AC input current in phase with the AC input voltage.
26. The system according to claim 25 wherein said system further comprises at least one switch means for detaching the AC power input from said system.
27. The system according to claim 26 wherein said control means further comprises a means for opening and closing said at least one switch means at least as fast as a half cycle of the AC input waveform.
28. The system according to claim 24 wherein said control means further comprises a means for selecting between a manual mode of operation and an automatic mode of operation.
29. The system according to claim 24 wherein said pulse width generation means further comprises:
means for determining the period of the AC power input;
means for dividing the period into equal time intervals;
means for generating a sampling reference signal; and
means for comparing the sampling reference signal and the current error signal to determine pulse endpoints from intersection points of said signals.
30. The system according to claim 29 wherein said sampling reference signal has a triangle waveform.
31. The system according to claim 24 wherein said system further comprises means for phase-locking the inverter to the AC power input.
32. The system according to claim 24 wherein said means for determining a desired AC power output current further comprises a means for sensing the load current.
33. The system according to claim 24 wherein said means for determining a desired AC power output current further comprises a means for

inputting a load current schedule.

34. An uninterruptible power supply system for delivering power to a load comprising:
input lines for receiving an AC power input having a waveform with positive and negative half cycles;
output lines for providing an AC power output to the load;
a battery capable of providing a DC output voltage;
a power transformer having a primary coupled to a secondary, the secondary being connected across the output lines;
an inverter connected to the primary of the power transformer and to the battery, including switching devices connected in a bridge configuration which are controllable to convert DC voltage power from the battery to AC voltage power at the primary of the power transformer and to supply the battery with power from the primary, the switching devices being responsive to control signals to switch between on and off states on a subcyclic basis; and
control means, connected to the switching devices in the inverter, for controlling the power into and out of the inverter on a subcyclic basis relative to the AC power input, including:
means for sensing the battery voltage;
means for determining the polarity of the AC input;
means for determining a desired AC power output current;
means for generating a sinusoidal reference signal having an amplitude substantially equal to the desired output current;
means for comparing the sinusoidal reference signal with the output current to yield a current error signal; and
means for generating a pulse having a width proportional to the amplitude of the current error signal for modulating the inverter switching devices;
wherein the switching devices are capable of assuming at least three configurations, including:
a first battery-connect configuration which enables current to flow between the battery and the primary when the AC input voltage is positive;
a second battery-connect configuration which enables current to flow between the battery and the primary when the AC input voltage is negative; and
a battery-isolation configuration which enables current to flow between the switching devices and an effective inductance which includes the effective leakage inductance of the primary and the secondary of the transformer, while substantially preventing current flow between the battery and the switching devices;
wherein said control means is capable of configuring said switching devices between said first battery-connect configuration, said second battery-connect configuration and said battery-isolation configuration based upon the polarity of the AC input voltage and the error signal;
wherein said switches are modulated into one of said battery-connect configurations for a duration based on the pulse width, and otherwise configured into the battery-isolation configuration;
wherein the battery is capable of supplying power to the load through said inverter when the polarities of the AC input voltage and the error signal coincide;
wherein the effective inductance is capable of supplying power to the load through said inverter when the polarities of the AC input voltage and the error signal coincide;
wherein the AC power input is capable of charging the battery through

the inverter means when the polarities of the AC input voltage and the error signal differ;

wherein the AC power input is capable of supplying power to the effective inductance by building up a current therein when the polarities of the AC input voltage and the error signal differ;

wherein said system is capable of supplying power to the load from the battery and the AC power input simultaneously; and

wherein said system is capable of supplying power to the load in the absence of AC input power;

whereby the inverter is capable of operating in at least three modes, including:

a battery charging mode in which the AC input power is rectified and supplied to the battery;

an inverter mode in which the battery supplies AC power to the load; and

a parallel mode in which the AC input power and the battery simultaneously supply AC power to the load.

35. The uninterruptible power supply system according to claim 34 wherein said control means is capable of configuring said switching devices according to an optimization strategy.