

A REGENERATIVE POWER SUPPLY SYSTEM FOR SHORT-TERM POWER INTERRUPTION

Field Of Invention

The present invention relates generally to a power supply system. In particular, the invention relates to a power supply system utilising regenerative power for supplying short-term uninterruptible power to a load.

Background

Industries suffer substantial losses when power supply from a power grid experiences interruptions in power supply. Power dependent systems, for example automated production and manufacturing systems, suffer from data loss or process disruptions as a result of the interruption in the power supply.

Conventional uninterruptible power supply systems, hereinafter known as UPSs, are used to maintain the power supply to such power dependent systems in the event of an interruption in the power supply.

These conventional UPSs use batteries for energy storage. These batteries require high maintenance costs. The initial investment required to purchase such a battery-based UPS is also high. The batteries used in these conventional UPSs have short life spans. The number of batteries required to provide for adequate energy storage is also high. The inefficiency of conventional UPSs also leads to high operating costs. These conventional battery-based UPSs also produces toxic gases.

Hence, this clearly affirms a need for a power supply system that addresses the foregoing problems.

Summary

Embodiments of the invention are based on the principle that an AC induction motor operates either in a MOTORING mode or a REGENERATING mode. AC power is supplied to the AC motor during the MOTORING mode, and the AC motor generates regenerative AC power in the REGENERATING mode. The regenerative AC power is conventionally channelled to an array of resistors which acts to dissipate the regenerative power. The channelling of the regenerative AC power to the array of resistors does not fully harness the use of the regenerative AC power.

Embodiments of the invention, however, utilise an optimized power supply system configuration to fully leverage on the regenerative AC power so as to provide efficient short-term power supply.

Coupling a load and a motor to a primary inverter and a secondary inverter respectively allows power to be drawn by the primary and secondary inverters from a common energy store. The load uses power converted from the common energy store. As the power at the energy store is DC and the power required to drive the motors is AC, both the primary and the secondary inverters function to transform DC power to AC power and vice versa.

The motor also draws power from the common energy store during normal operating conditions. During a power supply interruption at the power grid, regenerative power from the motor is supplied to the common energy store to maintain a NORMAL power voltage level at the common energy store. The regenerative power supplied from the motor is short-term. This allows power at a NORMAL voltage level to be supplied to the load even during the power supply interruption at the utility grid.

As a majority of power supply interruptions are short-term, the power supply system is only required to provide short-term power supply.

In accordance with an aspect of the invention, there is disclosed a power supply system comprising:

- an energy store, the energy store receiving and supplying DC power;
- a compensator unit, the compensator unit receiving AC power converted from DC power supplied by the energy store;

- a first inverter module comprising:

- a first input, the first input receiving AC power from a power source, the received AC power being converted into DC power supplied to the energy store;
- and

- a first output, the first output providing a continuous supply of AC power to a load, the AC power being converted from DC power received from the energy store; and

- a second inverter module comprising:

- a second input, the second input receiving AC power from the power source, the received AC power being converted into DC power supplied to the energy store; and

- a second output, the second output providing a supply of AC power to the compensator unit, the AC power being converted from DC power received from the energy store,

wherein short-term AC power is supplied from the first output to the load, the short-term AC power being converted from DC power supplied by the energy store.

Brief Description Of The Drawings

Embodiments of the invention are described hereinafter with reference to the following drawings, in which:

FIG. 1 shows a system flow diagram of a power supply system;

FIG. 2 shows a modularised circuit diagram of the power supply system in FIG. 1;

FIG. 3 shows a system flow diagram of the power supply system in FIG. 1 with a power transformer and a signal filter; and

FIG. 4 shows a system flow diagram of the power supply system in FIG. 1 with a controller.

Detailed Description

A power supply system for addressing the foregoing problems is described hereinafter. For convenience, the embodiments of the invention, a power supply system, described hereinafter refers to three-phase AC supply systems. However, the application of this invention is not restricted to only three-phase AC supply systems but can also be applied to single-phase AC systems.

For illustrative purposes, an embodiment of the power supply system is applied to a power dependent system having a primary motor and a secondary motor in which both the primary and the secondary motors decelerate when power supply thereto is cut. A primary inverter drives the primary motor, while a secondary inverter drives the secondary motor. The use of a DC bus to couple the DC point of the primary inverter to the DC point of the secondary inverter allows power to be channeled from the primary motor to the secondary motor, or from the secondary motor to the primary motor. By attaching a flywheel to the rotor of the secondary motor, excess power from either the power store or the primary motor can be used to accelerate the secondary motor and rotational speed of the flywheel. Accelerating the rotational speed of the flywheel increases the amount kinetic energy stored by the flywheel. The stored kinetic energy is extracted by decelerating the rotational speed of the flywheel and channeling regenerative power generated by the decelerating secondary motor to the DC bus.

A first embodiment of the invention, a power supply system 20 as seen in FIG. 1 and FIG. 2, includes a first inverter module 22, a compensator unit 24, and a second inverter module 26. Both the first inverter module 24 and the second inverter module 26, receives

AC power from a power source 28, the power source 28 being part of a power utility grid.

The first inverter module 22 has a first input 30 receiving AC power from the power source 28, a first capacitor bank 32 containing at least one capacitor, and a first output 34 providing a continuous supply of AC power to a load 36. The second inverter module 26 is similar to the first inverter module 22 and contains a second input 38 receiving AC power from the power source 28, a second capacitor bank 40 comprising of at least one capacitor, and a second output 42 supplying AC power to the compensator unit 24. The power supply system 20 further contains a DC bus 44 extending from the first capacitor bank 32 to the second capacitor bank 40. The DC bus 44 couples both the first capacitor bank 32 and the second capacitor bank 40 in parallel. The first capacitor bank 32, the second capacitor bank 40 and the DC bus 44 form an energy store 45 (not shown).

The first inverter module 22 further contains a first rectifier 46 coupled to both the first input 30 and the first capacitor bank 32. The first rectifier 46 functions to transform AC power received from the first input 30 into DC power provided to the first capacitor bank 32. Similar to the first inverter module 22, the second inverter module 26 further contains a second rectifier 48 coupled to both the second input 38 and the second capacitor bank 40. The second rectifier 48 functions to transform AC power received from the second input 38 into DC power provided to the second capacitor bank 40.

The compensator unit 24 includes a first AC motor 50 having a stator 52 and a rotor 54. The first AC motor 50 is a three-phase induction motor wherein the rotor 54 is coupled to the stator 52. A flywheel 56 is mounted to the rotor 54 of the first AC motor 50. The flywheel 56 is a weight that has preferably been dynamically balanced. Power supplied from the second output 42 to the first AC motor 50 rotationally displaces the rotor 54 and the flywheel 56. The inertia of the flywheel 56 enables the storing or expending of kinetic energy when the flywheel is respectively accelerating or decelerating.

The first inverter module 22 further includes a first power inverter 58. The first power inverter 58 converts DC power received from the energy store 45 into AC power. The first power inverter 58 controls the frequency of AC power supplied to the load 36. During a HIGH or a NORMAL power supply voltage level condition from the power source 28, the first power inverter 58 continues to supply power to the load 36 at a NORMAL voltage level.

The second inverter module 26 further includes a second power inverter 60. The second power inverter 60 converts DC power received from the energy store 45 into AC power. The second power inverter 60 controls the frequency of power supplied to the first AC motor 50, and therefore consequently regulating the rotational speed of the flywheel 56. In the event of a HIGH power supply voltage level condition at the power source 28, the second power inverter 60 accelerates the rotational speed of the flywheel 56.

An AC motor operates in either a MOTORING mode or a REGENERATING mode. For illustrative purposes, the AC motor is used in, for example, an elevator shaft for the hoisting of an elevator cage. In the example, hereinafter known as the elevator example, a cable is coupled at one end to the elevator cage and at the other end to the rotor of the AC motor. The rotation of the rotor in the forward or reverse direction respectively results in the coiling or uncoiling of the cable around the rotor of the AC motor. As the AC motor continuously bears the load of the elevator cage, forward torque is experienced at the stator of the AC motor. The AC motor operates in the MOTORING mode when it rotates in the forward direction to elevate the elevator cage. Conversely, the AC motor operates in the REGENERATING mode when it rotates in the reverse direction to lower the elevator cage. AC power is supplied to the AC motor during the MOTORING mode, whereas, regenerative AC power is generated by the AC motor during the REGENERATING mode.

Similar to the AC motor in the elevator example, the first AC motor 50 operates in the MOTORING mode when forward torque is produced at the stator 52 of the first AC

motor 50 during the rotation of the flywheel 56 in the forward direction. The first AC motor 50 receives AC power from the second output 42 in the MOTORING mode.

Similarly in the REGENERATING mode, reverse torque is produced at the stator 52 of the first AC motor 50 during the rotation of the flywheel 56 in the forward direction. The first AC motor 50 supplies regenerative AC power to the second output 42 in the REGENERATING mode.

A HIGH AC power supply voltage level condition at the power source 28 results in a HIGH DC power voltage condition at the energy store 45 and a LOW AC power supply voltage condition at the power source 28 results in a LOW DC power voltage level condition at the energy store 45.

During the HIGH or NORMAL DC power voltage condition at the energy store 45, the second power inverter 60 supplies AC power to the first AC motor 50 to accelerate it. The accelerated first AC motor 50 operates in the MOTORING mode.

However, the second power inverter 60 reduces the supply of AC power to the first AC motor 50 during the LOW DC power voltage condition at the energy store 45. The reduction of AC power decelerates the first AC motor 50, causing the first AC motor 50 to operate in the REGENERATING mode.

In the REGENERATING mode, the first AC motor 50 generates regenerative AC power. The second power inverter 60 converts the regenerative AC power received from the first AC motor 50 into DC power supplied to the energy store 45.

A NORMAL power supply voltage level condition at the power source 28 produces a NORMAL DC power voltage level condition at the energy store 45. Both the first power inverter 58 and the second power inverter 60 receive DC power supplied at a

NORMAL voltage level from the energy store 45 during the NORMAL DC power voltage level condition.

The second power inverter 60 is able to further control the deceleration of the flywheel 56 during the LOW DC power voltage level condition. The compensator unit 24 provides a controlled supply of regenerative AC power in the REGENERATING mode during the controlled deceleration. The controlled supply of regenerative AC power further allows the second power inverter 60 to convert regenerative AC power into DC power in a controlled manner. The controlled deceleration characteristic is pre-calculated by the user of the power supply system 20 so as to achieve a CONSTANT DC power voltage level condition at the energy store 45. This facilitates the supply of DC power at a CONSTANT voltage level to the first power inverter 58 and consequently the load 36.

A second embodiment of the invention, a power supply system 20 as seen in FIG. 3, comprises of five main elements: a first inverter module 22, a second inverter module 26, a compensator unit 24 and a DC bus 44. The descriptions in relation to the circuitry functions and circuitry relationships among the components described in the first embodiment of the invention with reference to FIG. 1 and FIG. 2 are incorporated herein.

The first output 34 is coupled to a three-phase power transformer 62 that allows the voltage of the AC power supplied from the first output 34 to be changed. The three-phase transformer 62 is further coupled to a signal filter 64. The signal filter 64 functions as a frequency interference filter to pass desired power and to reject spurious power signal. This allows the frequency of power supplied from the three-phase power transformer 62 to be processed so that the power possesses pure sinusoidal characteristic. The frequency interference filter is also commonly known as an electro-magnetic compliance filter.

A third embodiment of the invention, a power supply system 20 as seen in FIG. 4, comprises of five main elements: a first inverter module 22, a second inverter module 26,

a compensator unit 24 and a DC bus 44. The descriptions in relation to the circuitry functions and circuitry relationships among the components described in the first embodiment of the invention with reference to FIG. 1 and FIG. 2 are incorporated herein.

The power supply system 20 further includes a second AC motor 68 having a stator and a rotor. The second AC motor 68 is a three-phase induction motor and is coupled to the first output 34.

Similar to the AC motor described in the elevator example, the second AC motor 68 operates in a MOTORING mode when forward torque is produced at the stator of the second AC motor 68 during the rotation of the rotor in a forward direction. The second AC motor 68 receives AC power from the first output 34 in the MOTORING mode.

The second AC motor 68 further operates in a REGENERATING mode when reverse torque is produced at the stator of the second AC motor 68 during the rotation of the rotor in the forward direction. The second AC motor 68 supplies regenerative AC power to the first output 34 in the REGENERATING mode.

The first power inverter 58 converts regenerative AC power received from the second AC motor 68 into DC power supplied to the energy store 45.

The power supply system 20 further includes a controller 66 that is programmable. The controller is coupled to the first power inverter 58, the second power inverter 60 and the power source 28.

The controller 66 continuously registers both the AC power supply voltage level at the power source 28 and the DC power voltage level at the energy store 45. From the registered AC power supply voltage level, the controller generates a reference DC power voltage level.

In a situation where the second AC motor 68 is operating in the MOTORING mode, the DC power voltage level at the energy store 45 becomes lower than the reference DC power voltage level. The controller 66 transmits a REGENERATING signal to the second power inverter 60 when the second AC motor 68 is operating in the MOTORING mode. The second power inverter 60 decelerates the first AC motor 52 when the REGENERATING signal is received from the controller 66, causing the first AC motor 52 to operate in the REGENERATING mode.

In another situation where the second AC motor 68 is operating in the REGENERATING mode, the DC power voltage level at the energy store 45 becomes higher than the reference DC power voltage level. The controller 66 transmits a MOTORING signal to the second power inverter 60 when the second AC motor 68 is operating in the REGENERATING mode. The second power inverter 60 accelerates the first AC motor 52 when the MOTORING signal is received from the controller 66, causing the first AC motor 52 to operate in the MOTORING mode.

In the foregoing manner, a power supply system is described according to an embodiment of the invention for addressing the foregoing disadvantages of conventional uninterruptible power supply system. Although only three embodiments of the invention are disclosed, it is apparent to one skilled in the art in view of this disclosure that numerous changes and/or modification can be made without departing from the scope and spirit of the invention.



Claims

1. A power supply system comprising:
 - an energy store, the energy store receiving and supplying DC power;
 - a compensator unit, the compensator unit receiving AC power converted from DC power supplied by the energy store;
 - a first inverter module comprising:
 - a first input, the first input receiving AC power from a power source, the received AC power being converted into DC power supplied to the energy store; and
 - a first output, the first output providing a continuous supply of AC power to a load, the AC power being converted from DC power received from the energy store; and
 - a second inverter module comprising:
 - a second input, the second input receiving AC power from the power source, the received AC power being converted into DC power supplied to the energy store; and
 - a second output, the second output providing a supply of AC power to the compensator unit, the AC power being converted from DC power received from the energy store,wherein short-term AC power is supplied from the first output to the load, the short-term AC power being converted from DC power supplied by the energy store.
2. The power supply system claimed in claim 1, the first inverter module further comprising a first rectifier, the first rectifier converting AC power received from the first input into DC power supplied to the energy store.



3. The power supply system claimed in claim 1, the second inverter module further comprising a second rectifier, the second rectifier converting AC power received from the second input into DC power supplied to the energy store.
4. The power supply system claimed in claim 1, wherein the first inverter module further comprising a first power inverter converting DC power received from the energy store into AC power supplied to the first output, the first power inverter controlling the frequency of AC power supplied to the first output.
5. The power supply system claimed in claim 4, wherein the second inverter module further comprising a second power inverter converting DC power received from the energy store into AC power supplied to the second output, the second power inverter controlling the frequency of AC power supplied to the second output.
6. The power supply system claimed in claim 5, wherein the compensator unit comprising:
 - a first AC motor having a stator and a rotor, the first AC motor being a three-phase induction motor, and the rotor being coupled to the stator; and
 - a flywheel mounted to the rotor of the first AC motor, the flywheel being a dynamically balanced weight,wherein AC power supplied from the second output to the first AC motor produces forward torque at the stator which rotationally displaces both the rotor and the flywheel in a forward direction, the rotating flywheel having inertial energy.
7. The power supply system claimed in claim 6, wherein the first AC motor operates in a MOTORING mode when forward torque is produced at the stator of the first AC motor during the rotation of the flywheel in the forward direction, the first AC motor receiving AC power from the second output in the MOTORING mode.



8. The power supply system claimed in claim 7, wherein the first AC motor operates in a REGENERATING mode when reverse torque is produced at the stator of the first AC motor during the rotation of the flywheel in the forward direction, the first AC motor supplying regenerative AC power to the second output in the REGENERATING mode.
9. The power supply system claimed in claim 8, wherein a HIGH AC power supply voltage level condition at the power source results in a HIGH DC power voltage level condition at the energy store and a LOW AC power supply condition at the power source results in a LOW DC power voltage level condition at the energy store.
10. The power supply system claimed in claim 9, wherein the second power inverter supplies AC power to the first AC motor during the HIGH or a NORMAL DC power voltage level condition at the energy store, the supplied AC power accelerating the first AC motor and the accelerating first AC motor operating in the MOTORING mode.
11. The power supply system claimed in claim 10, wherein the second power inverter reduces the supply of AC power to the first AC motor during the LOW DC power voltage level condition at the energy store, the reduction of AC power decelerating the first AC motor and the decelerating first AC motor operating in the REGENERATING mode.
12. The power supply system claimed in claim 11, wherein the second power inverter converts regenerative AC power received from the first AC motor into DC power supplied to the power store, the first AC motor generating the regenerative AC power in the REGENERATING mode.



13. The power supply system claimed in claim 12, wherein a NORMAL power supply voltage level condition at the power source produces a NORMAL DC power voltage level condition at the energy store, the first power inverter and the second power inverter receiving DC power supplied at a NORMAL voltage level by the energy store during the NORMAL DC power voltage level condition.
14. The power supply system claimed in claim 13, wherein the second power inverter further controls the deceleration of the flywheel during the LOW DC power voltage level condition, the compensator unit providing a controlled supply of regenerative AC power in the REGENERATING mode during the controlled deceleration, and the controlled supply of regenerative AC power being converted by the second power inverter into DC power to achieve a CONSTANT DC power voltage level condition at the energy store.
15. The power supply system claimed in claim 13, wherein the first output is coupled to a power transformer, the power transformer changing the voltage of the AC power received from the first output.
16. The power supply system claimed in claim 15, wherein the power transformer is further coupled to a signal filter, the signal filter being a frequency interference filter to pass desired power and to reject spurious power signal so that the frequency of power supplied by the signal filter possesses pure sinusoidal characteristic.
17. The power supply system claimed in claim 13, further comprising a second AC motor having a stator and a rotor, the second AC motor being coupled to the first output and receiving AC power from the first output.
18. The power supply system claimed in claim 17, wherein the second AC motor operates in a MOTORING mode when forward torque is produced at the stator of



the second AC motor during the rotation of the rotor in a forward direction, the second AC motor receiving AC power from the first output in the MOTORING mode.

19. The power supply system claimed in claim 18, wherein the second AC motor operates in a REGENERATING mode when reverse torque is produced at the stator of the second AC motor during the rotation of the rotor in the forward direction, the second AC motor supplying regenerative AC power to the first output in the REGENERATING mode.
20. The power supply system claimed in claim 19, wherein the first power inverter converts regenerative AC power received from the second AC motor into DC power supplied to the energy store, the second AC motor generating the regenerative AC power in the REGENERATING mode.
21. The power supply system claimed in claim 20, further comprising a controller, the controller being programmable and being coupled to the first power inverter, the second power inverter and the power source.
22. The power supply system claimed in claim 21, wherein the controller continuously registers both the AC power supply voltage level at the power source and the DC power voltage level at the energy store, the controller generating a reference DC power voltage level from the registered AC power supply voltage level.
23. The power supply system claimed in claim 22, wherein the DC power voltage level at the energy store is lower than the reference DC power voltage level when the second AC motor is operating in the MOTORING mode, the controller



transmitting a REGENERATING signal to the second power inverter when the second AC motor is operating in the MOTORING mode.

24. The power supply system claimed in claim 23, wherein the second power inverter decelerates the first AC motor when the REGENERATING signal is received from the controller, the first AC motor operating in the REGENERATING mode when decelerated.
25. The power supply system claimed in claim 22, wherein the DC power voltage level at the energy store is higher than the reference DC power voltage level when the second AC motor is operating in the REGENERATING mode, the controller transmitting a MOTORING signal to the second power inverter when the second AC motor is operating in the REGENERATING mode.
26. The power supply system claimed in claim 25, wherein the second power inverter accelerates the first AC motor when the MOTORING signal is received from the controller, the first AC motor operating in the MOTORING mode when accelerating.