

CLAIMS:

1. An electrical power supply system, including:

at least one virtual air gap transformer, including at least one primary winding, at least one secondary winding, and one or more control windings to control the electromagnetic coupling between the primary and secondary windings;
an input port configured to receive a first input signal having a first input fundamental frequency and a first input voltage; and

a control component configured:

to receive a signal representing the first input voltage and the first input fundamental frequency of the first input signal, and to generate a corresponding virtual air gap control signal to determine the electrical current in the control windings of the at least one virtual air gap transformer, such that a target output voltage of a target output frequency is generated at the secondary windings;

wherein the electrical power supply system receives input electrical energy in the form of the first input signal having the first input fundamental frequency and the first input voltage, and generates corresponding output electrical energy in the form of a corresponding first output signal of the target frequency and the target output voltage.

2. The electrical power supply system of claim 1, wherein the system is configured for bi-directional use such that the system receives second input electrical energy in the form of a second input signal having a second input fundamental frequency and a second input voltage, and generates corresponding output electrical energy in the form of a corresponding second output signal of a second target frequency and a second target output voltage, wherein the second input signal or a corresponding signal derived from the second input signal is applied to the secondary winding of the at least one virtual air gap transformer to generate a corresponding signal having the second target output voltage at the primary winding of the virtual air gap transformer.

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3. The electrical power supply system of any one of claims 1 and 2, wherein the at least one virtual air gap transformer includes two or more virtual air gap transformers connected in series by one or more corresponding loops configured to store energy.
4. The electrical power supply system of any one of claims 1 to 3, including one or more inductors and/or one or more capacitors configured to store and release energy.
5. The electrical power supply system of any one of claims 1 to 4, wherein the at least one virtual air gap transformer includes at least one single-phase virtual air gap transformer.
6. The electrical power supply system of any one of claims 1 to 5, wherein the at least one virtual air gap transformer includes at least one three-phase virtual air gap transformer.
7. The electrical power supply system of any one of claims 1 to 6, wherein the at least one virtual air gap transformer includes at least one shell-type virtual air gap transformer.
8. The electrical power supply system of any one of claims 1 to 7, wherein the at least one virtual air gap transformer includes at least one virtual air gap transformer having a magnetic core composed of different materials having respective different magnetic properties such that a region of the magnetic core in which a virtual air gap is formed in the magnetic circuit is composed of a first material and another region of the magnetic core is composed of a second material, wherein at least one magnetic property of the first material has a different value to a value of that at least one magnetic property of the second material.
9. The electrical power supply system of any one of claims 1 to 8, wherein the at least one virtual air gap transformer includes a virtual air gap transformer having one or more control windings disposed between opposing faces of respective pole pieces of the virtual air gap transformer.

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10. The electrical power supply system of any one of claims 1 to 9, wherein the at least one virtual air gap transformer includes a virtual air gap transformer having a magnetic core with mutually spaced openings formed therein, one or more control windings being wound through the openings and around portions of the magnetic core disposed between the openings.
11. The electrical power supply system of claim 10, wherein the magnetic core is formed by stacked laminations, and the openings are defined by gaps in the stacked laminations.
12. The electrical power supply system of any one of claims 1 to 11, including flux sensors configured to generate flux signals representing magnetic flux, wherein the control component is configured to generate the virtual air gap control signal on the basis of the flux signals.
13. The electrical power supply system of any one of claims 1 to 12, wherein the control component is configured to operate at a frequency that is sufficiently high to allow removal of harmonics present in the first input signal.
14. The electrical power supply system of any one of claims 1 to 13, wherein the virtual air gap control signal is generated as a pulse width modulation (PWM) digital signal to determine the electrical current in the control windings.
15. The electrical power supply system of claim 14, wherein the control component is configured to generate the PWM digital signal at a frequency that is sufficiently high to allow removal of harmonics present in the first input signal.
16. The electrical power supply system of claim 15, wherein the PWM frequency is at least 10 kHz.
17. The electrical power supply system of any one of claims 1 to 16, wherein the control component is configured to generate the virtual air gap control signal as a DC signal.
18. The electrical power supply system of any one of claims 1 to 16, wherein the control component is configured to generate the virtual air gap control signal as a

DC signal modulated with harmonics to reduce harmonics in the first output signal.

19. The electrical power supply system of any one of claims 1 to 16, wherein the control component is configured to generate the virtual air gap control signal as an AC signal.
20. The electrical power supply system of any one of claims 1 to 19, wherein the at least one virtual air gap transformer includes multiple virtual air gaps arranged to selectably define opposing flux paths through the at least one secondary winding.
21. The electrical power supply system of any one of claims 1 to 20, wherein the at least one virtual air gap transformer includes multiple virtual air gaps arranged to define multiple flux paths to allow control of the amount of flux flowing through the at least one secondary winding.
22. An electrical power supply process, including:
 - receiving, at a control component of an electrical power supply system, at least one signal representing at least a time-varying first fundamental frequency of a first input signal and a time-varying first voltage of the first input signal;
 - processing the received signal to generate:
 - a corresponding control signal to cause a virtual air-gap transformer of the electrical power supply system to generate a corresponding signal having a target output voltage and a target output frequency;
 - whereby the received input electrical energy in the form of the first input signal having the first input fundamental frequency and the first voltage is processed to generate corresponding output electrical energy in the form of a corresponding first output signal of the target frequency and the target output voltage.
23. An electrical power supply system, including:
 - at least one virtual air gap transformer, including at least one primary winding, at least one secondary winding, and one or more control windings to control the electromagnetic coupling between the primary and secondary windings;
 - a heterodyning component configured to receive a signal having a first

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fundamental frequency and to generate a corresponding heterodyned signal having frequency components corresponding to a sum and a difference of the first fundamental frequency and a reference frequency;

a filtering component configured to filter a heterodyned signal to remove one of the sum and the difference frequency components therefrom and provide a corresponding filtered signal;

an input port configured to receive a first input signal having a first input fundamental frequency and a first input voltage; and

a control component configured:

- (i) to receive a signal representing at least the first input fundamental frequency of the first input signal and to generate a corresponding frequency control signal to determine a reference frequency of the heterodyning component such that the filtered signal has a target output frequency; and
- (ii) to receive a signal representing the first input voltage, and to generate a corresponding virtual air gap control signal to determine the electrical current in the control windings of the at least one virtual air gap transformer, such that a target output voltage is generated at the secondary windings;

wherein the electrical power supply system receives input electrical energy in the form of the first input signal having the first input fundamental frequency and the first input voltage, and generates corresponding output electrical energy in the form of a corresponding first output signal of the target frequency and the target output voltage.

24. The electrical power supply system of claim 23, wherein the system is configured for bi-directional use such that the system receives second input electrical energy in the form of a second input signal having a second input fundamental frequency and a second input voltage, and generates corresponding output electrical energy in the form of a corresponding second output signal of a second target frequency and a second target output voltage, wherein the second input signal or a corresponding signal derived from the second input signal is applied to the secondary winding of the at least one virtual air gap transformer to generate a corresponding signal having the second target output voltage at the primary winding of the virtual air gap transformer.

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25. The electrical power supply system of claim 24, wherein the second input signal or a corresponding signal derived from the second input signal is received by the heterodyning component to generate a corresponding second heterodyned signal having second frequency components corresponding to a sum and a difference of the second fundamental frequency and a reference frequency, and the filtering component is configured to filter the second heterodyned signal to remove one of the sum and the difference frequency components therefrom and provide a corresponding second filtered signal.
26. The electrical power supply system of claim 24, wherein the heterodyning component is a first heterodyning component, the filtering component is a first filtering component, and the system includes a second heterodyning component and a second filtering component, wherein the first heterodyning component and the first filtering component are configured to process signals flowing through the system along a first pathway, and the second heterodyning component and the second filtering component are configured to process signals flowing through the system along a second pathway generally opposite in sense to the first pathway.
27. The electrical power supply system of claim 23 or 24, wherein the heterodyning component is a first heterodyning component, the filtering component is a first filtering component, and the system includes a second heterodyning component and a second filtering component, wherein the heterodyning components and the filtering components are configured such that the first signal received by the system is upconverted to a higher frequency by the first heterodyning component and the first filtering component before being provided as an input to the at least one virtual air gap transformer, and the corresponding output of the at least one virtual air gap transformer is downconverted to the target frequency by the second heterodyning component and the second filtering component, the use of the higher frequency improving the efficiency of the at least one virtual air gap transformer.
28. The electrical power supply system of any one of claims 23 to 27, wherein the at least one virtual air gap transformer includes two or more virtual air gap transformers connected in series by one or more corresponding loops configured to store energy.

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29. The electrical power supply system of any one of claims 23 to 28, including one or more inductors and/or one or more capacitors configured to store and release energy.
30. The electrical power supply system of any one of claims 23 to 29, wherein the at least one virtual air gap transformer includes at least one single-phase virtual air gap transformer.
31. The electrical power supply system of any one of claims 23 to 30, wherein the at least one virtual air gap transformer includes at least one three-phase virtual air gap transformer.
32. The electrical power supply system of any one of claims 23 to 31, wherein the at least one virtual air gap transformer includes at least one shell-type virtual air gap transformer.
33. The electrical power supply system of any one of claims 23 to 32, wherein the at least one virtual air gap transformer includes at least one virtual air gap transformer having a magnetic core composed of different materials having respective different magnetic properties such that a region of the magnetic core in which a virtual air gap is formed in the magnetic circuit is composed of a first material and another region of the magnetic core is composed of a second material, wherein at least one magnetic property of the first material has a different value to a value of that at least one magnetic property of the second material.
34. The electrical power supply system of any one of claims 23 to 33, wherein the at least one virtual air gap transformer includes a virtual air gap transformer having one or more control windings disposed between opposing faces of respective pole pieces of the virtual air gap transformer.
35. The electrical power supply system of claim 34, wherein each control winding is in the form of a serpentine planar loop.
36. The electrical power supply system of claim 34, wherein each control winding is in the form of a spiralling circular planar loop.

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37. The electrical power supply system of claim 34, wherein the control windings include one or more serpentine planar loops and one or more spiralling circular planar loops.
38. The electrical power supply system of claim 34, wherein control windings of any one of claims 13 to 15 are wound around a core section.
39. The electrical power supply system of any one of claims 23 to 38, wherein the at least one virtual air gap transformer includes a virtual air gap transformer having a magnetic core with mutually spaced openings formed therein, one or more control windings being wound through the openings and around portions of the magnetic core disposed between the openings.
40. The electrical power supply system of claim 39, wherein the magnetic core is formed by stacked laminations, and the openings are defined by gaps in the stacked laminations.
41. The electrical power supply system of claim 39, wherein the magnetic core is in the form of a solid body, with openings formed by drilling after manufacture.
42. The electrical power supply system of any one of claims 23 to 41, wherein the at least one virtual air gap transformer includes multiple virtual air gaps arranged to selectably define opposing flux paths through the at least one secondary winding.
43. The electrical power supply system of any one of claims 23 to 42, wherein the at least one virtual air gap transformer includes multiple virtual air gaps arranged to define multiple flux paths to allow control of the amount of flux flowing through the at least one secondary winding.
44. An electrical power supply process, including:
 receiving, at a control component of an electrical power supply system, at least one signal representing at least a time-varying first fundamental frequency of a first input signal and a time-varying first voltage of the first input signal;
 processing the received signal to generate:
 (i) a corresponding frequency control signal to cause a

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heterodyning component of the electrical power supply system to generate a corresponding heterodyned signal having frequency components corresponding to a sum and a difference of the first fundamental frequency and a reference frequency; and

- (ii) a corresponding voltage control signal to cause a virtual air-gap transformer of the electrical power supply system to generate a corresponding signal having a target output voltage;

whereby the received input electrical energy in the form of the first input signal having the first input fundamental frequency and the first voltage is processed to generate corresponding output electrical energy in the form of a corresponding first output signal of the target frequency and the target output voltage.

45. The electrical power supply process of claim 44, wherein the heterodyning component is a first heterodyning component, the filtering component is a first filtering component, and the system includes a second heterodyning component and a second filtering component, wherein the process includes controlling the heterodyning components and the filtering components such that the first signal received by the system is upconverted to a higher frequency by the first heterodyning component and the first filtering component before being provided as an input to the at least one virtual air gap transformer, and the corresponding output of the at least one virtual air gap transformer is downconverted to the target frequency by the second heterodyning component and the second filtering component, the use of the higher frequency improving the efficiency of the at least one virtual air gap transformer.