CLAIMS

1. A module-based energy system, comprising:

a first array of cascaded modules, wherein each module in the first array is switchably connected to at least one other module of the first array to generate a first multilevel voltage waveform for a load;

a second array of cascaded modules, wherein each module in the second array is switchably connected to at least one other module of the second array to generate a second multilevel voltage waveform for a load, wherein the first and second multilevel voltage waveforms each have a different phase angle;

an interconnection module coupled to both the first array and the second array, wherein the interconnection module comprises an energy source and switch circuitry, and wherein the interconnection module is configured to adjust the amount of energy supplied by the energy source to the first and/or second arrays; and

control circuitry configured to control the switch circuitry to selectively couple the energy source to the first and/or second arrays,

wherein the control circuitry comprises a master control device and a plurality of local control devices communicatively coupled with the master control device, and wherein each module of the system is associated with at least one of the plurality of local control devices.

2. The system of claim 1, wherein all cascaded modules of the first array and second array are positioned between the load and the interconnection module such that current from the interconnection module to the load will pass through all cascaded modules of the first array at a first time and all cascaded modules of the second array at a second time.

3. The system of claim 1, wherein the master control device is configured to determine whether the first array and second array are in an unbalanced condition.

4. The system of claim 3, wherein the master control device is configured to cause the local control device to generate one or more control signals for the switch circuitry that cause adjustment of energy supplied by the energy source to one of the first and second arrays.

5. The system of claim 1, wherein the load is a primary load, and wherein the interconnection module is configured to electrically couple to an auxiliary load.

6. The system of claim 5, wherein the switch circuitry is first switch circuitry, and wherein the interconnection module comprises second switch circuitry coupled with an inductor to regulate a voltage supply to the auxiliary load.

7. The system of claim 1, wherein the load is a primary load and the interconnection module is configured to electrically couple to an auxiliary load, and wherein the local control device is configured to assess a measured voltage and/or a measured current for the auxiliary load and, in response, control switch circuitry of the interconnection module to regulate a voltage or current supply to the auxiliary load.

8. The system of claim 1, wherein the control circuitry is configured to:

determine an amount of interphase imbalance between the first and second arrays;

cause the interconnection module to adjust net energy output to decrease the amount of interphase imbalance if below a threshold; and

cause a shift to a neutral point of the system to adjust net energy output to decrease the amount of interphase imbalance if above the threshold.

9. The system of claim 8, wherein the control circuitry is configured to also cause the interconnection module to adjust net energy output to assist in decrease of the amount of interphase imbalance if the amount of interphase imbalance is above the threshold.

10. The system of claim 1, wherein:

a first connection node electrically connects a first switch circuitry output of the interconnection module to a first switch circuitry output of a first module of the first array;

the first switch circuitry output of the interconnection module and the first switch circuitry output of the first module are the only switch circuitry outputs of the energy system electrically connected to the first connection node without traversing another module;

the first array and second array each have the same quantity of cascaded modules;

all cascaded modules of the first array are in series from the interconnection module to the load; and

all cascaded modules of the second array are in series from the interconnection module to the load.

11. The system of claim 10, wherein the control circuitry is configured to detect an unbalanced condition between the first and second arrays and control the switch circuitry such that the energy source discharges relatively more energy to the first array than to the second array in response to the unbalanced condition.

12. The system of claim 11, wherein the unbalanced condition relates to state of charge, temperature, capacity, state of health, voltage, and/or current.

13. The system of claim 11, wherein the unbalanced condition is that the first array has a relatively lower overall energy level than the second array.

14. The system of claim 11, wherein the master control device is configured to receive state of charge information from each cascaded module of the first and second arrays, determine if the first array or the second array has a relatively lower overall state of charge condition, and, if present, cause the energy source of the interconnection module to discharge more energy to the one of the first and second arrays having the relatively lower overall state of charge condition.

15. The system of claim 11, wherein the unbalanced condition is that the first array has a relatively higher temperature than the second array.

16. The system of claim 11, wherein the master control device is configured to receive temperature information from each cascaded module of the first and second arrays, determine if the first array or the second array has a relatively higher temperature, and cause the

energy source of the interconnection module to discharge more energy to the one of the first and second arrays having the relatively higher temperature.

17. The system of claim 11, wherein the control circuitry is configured to control a balance of interphase energy between the first and second arrays with the energy source of the interconnection module.

18. The system of claim 11, wherein the control circuitry is configured to control the balance of interphase energy between the first and second arrays with a shift to a neutral point of the first and second arrays.

19. The system of claim 11, wherein the system is configured to generate the first and second voltage waveforms according to a pulse width modulation technique.

20. The system of claim 19, wherein the control circuitry is configured to control the switch circuitry, under a balanced interphase condition, such that the interconnection module supplies energy for both the first and second arrays.

21. The system of claim 19, wherein the control circuitry is configured to modulate the frequency of operation of the switch circuitry to adjust the energy supplied by the energy source to the first array relative to that to the second array.

22. The system of claim 19, wherein the control circuitry is configured to cause relatively more energy to be output by the interconnection module to the first array under an unbalanced interphase condition as compared to a balanced interphase condition.

23. The system of claim 22, wherein the control circuitry is configured to cause relatively less energy to be output by one or more modules of the first array under the unbalanced interphase condition as compared to a balanced interphase condition.

24. The system of claim 23, wherein the control circuitry is configured to maintain the same energy output by one or more modules of the second array and by the interconnection module to the second array under the unbalanced interphase condition as compared to a balanced interphase condition.

25. The system of claim 23, wherein the control circuitry is configured to cause relatively less energy to be output by the interconnection module to the second array and to cause relatively more energy to be output by one or more modules of the second array under an unbalanced interphase condition as compared to a balanced interphase condition.

26. The system of claim 1, wherein the switch circuitry of the interconnection module is first switch circuitry, the first switch circuitry comprising:

a first transistor pair controllable to a first state where the energy source is connected to the first array and to a second state where the energy source is bypassed; and

a second transistor pair controllable to a first state where the energy source is connected to the first array and to a second state where the energy source is bypassed,

wherein the interconnection module comprises a third transistor pair connected to an inductor and controllable to regulate power for an auxiliary load,

wherein all cascaded modules of the first array are in series from the interconnection module to the load, and wherein all cascaded modules of the second array are in series from the interconnection module to the load,

wherein the master control device is configured to detect a charge imbalance between the first and second arrays and output information to a first local control device associated with the interconnection module, and

wherein the first local control device is configured to control the first and second transistor pairs, based on the information, to mitigate the imbalance.

27. A method of interphase balancing in a system comprising a first array of cascaded switchable modules configured to output a first multilevel voltage waveform for a load, a second array of switchable cascaded modules configured to output a second multilevel voltage waveform for the load, wherein the first and second multilevel voltage waveforms each have a

different phase angle, an interconnection module comprising an energy source and switch circuitry configured to selectively couple the energy source to the first and/or second arrays, and control circuitry configured to control the switch circuitry and comprising a master control device and a plurality of local control devices communicatively coupled with the master control device, wherein each module of the system is associated with one of the plurality of local control devices, the method comprising:

determining, by the master control device, that an unbalanced condition exists between the first array and second array; and

adjusting energy supplied from an energy source of the interconnection module to the first array.

28. The method of claim 27, wherein all cascaded modules of the first array and second array are positioned between the load and the interconnection module such that current from the interconnection module to the load will pass through all cascaded modules of the first array at a first time and all cascaded modules of the second array at a second time.

29. The method of claim 27, wherein:

a first connection node electrically connects a first switch circuitry output of the interconnection module to a first switch circuitry output of a first module of the first array;

the first switch circuitry output of the interconnection module and the first switch circuitry output of the first module are the only switch circuitry outputs of the energy system electrically connected to the first connection node without traversing another module;

the first array and second array each have the same quantity of cascaded modules;

all cascaded modules of the first array are in series from the interconnection module to the load; and

all cascaded modules of the second array are in series from the interconnection module to the load.

30. The method of claim 29, wherein adjusting energy supplied from the energy source comprises increasing net energy supplied from the energy source to the first array.

31. The method of claim 30, further comprising reducing net energy output by at least one module of the first array.

32. The method of claim 31, wherein the increase in net energy is equivalent to the reduction in net energy.

33. The method of claim 31, further comprising reducing net energy supplied by all modules of the first array.

34. The method of claim 31, further comprising maintaining relative amounts of net energy output from the interconnection module to the second array and from the modules of the second array at a constant level while reducing net energy output by at least one module of the first array.

35. The method of claim 30, further comprising reducing net energy output from the interconnection module to the second array and increasing net energy output by at least one module of the second array while the unbalanced condition persists.

36. The method of claim 30, further comprising:

increasing a modulation index for switch circuitry of the interconnection module coupled to the first array in order to increase net energy supplied from the energy source of the interconnection module to the first array; and

decreasing a modulation index for the at least one module of the first array to reduce net energy output by at least one module of the first array.

37. The method of claim 30, wherein the unbalanced condition is that the first array has a relatively lower overall energy level than the second array or a relatively higher temperature than the second array.

38. The method of claim 30, further comprising:

receiving, by the master control device, state of charge information from local control devices of the modules of the first and second arrays; and

determining, by the master control device, if the first array has a relatively lower overall state of charge prior to increasing net energy supplied from the energy source of the interconnection module to the first array.

39. The method of claim 30, further comprising:

receiving, by the master control device, temperature information from local control devices of the modules of the first and second arrays; and

determining, by the master control device, if the first array has a relatively higher temperature than the second array prior to increasing net energy supplied from the energy source of the interconnection module to the first array.

40. The method of claim 29, wherein the load is a primary load, and further comprising providing voltage from the interconnection module to an auxiliary load.

41. The method of claim 40, further comprising regulating the voltage provided by the interconnection module to the auxiliary load.

42. The method of claim 41, further comprising:

measuring a voltage and/or a current for the auxiliary load; and

controlling, with the local control device, switch circuitry of the interconnection module to regulate the voltage supplied to the auxiliary load based on the measured voltage and/or current.

43. The method of claim 27, further comprising causing a first local control device associated with the interconnection module to generate one or more control signals for the switch circuitry that cause adjustment of energy supplied by the energy source of the interconnection module to the first array.

44. The method of claim 43, further comprising modulating a normalized reference signal and outputting the modulated signal to the first local control device, wherein the modulated signal is used to generate the one or more control signals.

45. The method of claim 43, further comprising:

outputting a reference signal and a modulation index to the first local control device; and

adjusting, by the first local control device, the reference signal based on the modulation index, wherein the adjusted reference signal is used to generate the one or more control signals.

46. The method of claim 27, further comprising determining or estimating, by the master control device, energy output adjustments that cause the first and second array to converge to a balanced condition.

47. The method of claim 27, wherein the unbalanced condition relates to state of charge, temperature, capacity, state of health, voltage, and/or current.

48. The method of claim 27, further comprising operating the control circuitry to use the interconnection module and neutral point shifting to control a balance of interphase energy between the first and second arrays.

49. The method of claim 27, wherein the first and second multilevel voltage waveforms are generated according to a pulse width modulation technique.

50. The method of claim 27, further comprising supplying energy from the interconnection module to both the first and second arrays during a balanced condition.

51. The method of claim 27, wherein determining, by the master control device, that an unbalanced condition exists between the first array and second array comprises referencing a fault or degradation condition.

52. The method of claim 27, further comprising:

determining, with the master control device, an amount of interphase imbalance between the first and second arrays;

adjusting net energy output of the interconnection module to decrease the amount of interphase imbalance if below a threshold; and

shifting a neutral point of the system to adjust net energy output to decrease the amount of interphase imbalance if above the threshold.

53. The method of claim 52, further comprising adjusting net energy output of the interconnection module to assist in decreasing the amount of interphase imbalance if above the threshold.

54. A control system configured to provide control for a module-based energy storage system comprising a first array of cascaded switchable modules configured to output a first multilevel voltage waveform to a load, a second array of cascaded switchable modules configured to output a second multilevel voltage waveform to the load, wherein the first and second voltage waveforms each have a different phase angle, and an interconnection module comprising an energy source and switch circuitry configured to selectively couple the energy source to the first and/or second arrays, the control system comprising:

a plurality of local control devices associated with all modules of the energy storage system; and

a master control device communicatively coupled with the plurality of local control devices, the master control device comprising non-transitory memory, wherein a plurality of instructions are stored on the non-transitory memory that, when executed by the master control device, cause the master control device to:

determine that an unbalanced condition exists between the first array and second array; and

output information to a first local control device of the interconnection module that instructs the first local control device to cause adjustment of energy supplied from an energy source of the interconnection module to the first array.

55. The control system of claim 54, wherein the plurality of instructions cause the master control device to instruct the first local control device to cause an increase in net energy supplied from the energy source of the interconnection module to the first array during the unbalanced condition.

56. The control system of claim 55, wherein the plurality of instructions cause the master control device to instruct at least one module of the first array to reduce net energy output during the unbalanced condition.

57. The control system of claim 56, wherein the increase in net energy is equivalent to the reduction in net energy.

58. The control system of claim 55, wherein the plurality of instructions cause the master control device to instruct all modules of the first array to reduce their net energy output during the unbalanced condition.

59. The control system of claim 55, wherein the plurality of instructions cause the master control device to instruct the interconnection module to maintain constant net energy output to the second array and to instruct the modules of the second array to maintain constant net energy output during the unbalanced condition.

60. The control system of claim 55, wherein the plurality of instructions cause the master control device to instruct the interconnection module to reduce net energy output to the second array and to instruct at least one module of the second array to increase net energy output during the unbalanced condition.

61. The control system of claim 55, wherein the plurality of instructions cause the master control device to increase a modulation index for switch circuitry of the interconnection module coupled to the first array in order to increase net energy supplied from the energy source of the interconnection module to the first array during the unbalanced condition.

62. The control system of claim 61, wherein the plurality of instructions cause the master control device to decrease a modulation index for the at least one module of the first array to reduce net energy output by at least one module of the first array during the unbalanced condition.

63. The control system of claim 61, configured to provide control for the module-based energy storage system wherein all cascaded modules of the first array and second array are positioned between the load and the interconnection module such that current from the interconnection module to the load will pass through all cascaded modules of the first array at a first time and all cascaded modules of the second array at a second time.

64. The control system of claim 61, configured to provide control for the module-based energy storage system wherein:

a first connection node electrically connects a first switch circuitry output of the interconnection module to a first switch circuitry output of a first module of the first array;

the first switch circuitry output of the interconnection module and the first switch circuitry output of the first module are the only switch circuitry outputs of the energy system electrically connected to the first connection node without traversing another module;

the first array and second array each have the same quantity of cascaded modules;

all cascaded modules of the first array are in series from the interconnection module to the load; and

all cascaded modules of the second array are in series from the interconnection module to the load.

65. The control system of claim 55, wherein the unbalanced condition is that the first array has a relatively lower overall energy level than the second array.

66. The control system of claim 55, wherein the plurality of instructions cause the master control device to determine if the first array has a relatively lower overall state of charge prior to instructing the first local control device to cause an increase in net energy supplied from

the energy source of the interconnection module to the first array during the unbalanced condition.

67. The control system of claim 55, wherein the unbalanced condition is that the first array has a relatively higher temperature than the second array.

68. The control system of claim 55, wherein the plurality of instructions cause the master control device to determine if the first array has a relatively higher temperature than the second array prior to instructing the first local control device to cause an increase in net energy supplied from the energy source of the interconnection module to the first array during the unbalanced condition.

69. The control system of claim 54, wherein the plurality of instructions cause the master control device to modulate a normalized reference signal with a modulation index and output the modulated normalized reference signal as the information.

70. The control system of claim 54, wherein the plurality of instructions cause the master control device to output a normalized reference signal and a modulation index as the information.

71. The control system of claim 54, wherein the plurality of instructions cause the master control device to cause the interconnection module to supply energy for both the first and second arrays during a balanced condition.

72. The control system of claim 54, wherein the plurality of instructions cause the master control device to, during the unbalanced condition, determine or estimate energy output adjustments that cause the first and second array to converge to a balanced condition.

73. The control system of claim 54, wherein the unbalanced condition relates to state of charge, temperature, capacity, state of health, voltage, and/or current.

74. The control system of claim 54, wherein the plurality of instructions cause the master control device to control the energy storage system to generate the first and second voltage waveforms according to a pulse width modulation technique.

75. The control system of claim 54, wherein the plurality of instructions cause the master control device to control the system to converge towards an interphase balanced condition by adjustment of modulation indexes of the system.

76. The control system of claim 54, wherein the plurality of instructions cause the master control device to determine that the unbalanced condition exists between the first array and second array by reference to a fault or degradation condition.

77. The control system of claim 54, wherein the plurality of instructions cause the master control device to use the interconnection module and neutral point shifting to control a balance of interphase energy between the first and second arrays.

78. The control system of claim 54, wherein the plurality of instructions cause the master control device to:

determine an amount of interphase imbalance between the first and second arrays;

if the amount of interphase imbalance is below a threshold, then output information to the first local control device that instructs the first local control device to adjust net energy output to decrease the amount of interphase imbalance; and

if the amount of interphase imbalance is above the threshold, then cause a shift to a neutral point of the system to adjust net energy output to decrease the amount of interphase imbalance.

79. The control system of claim 78, wherein the plurality of instructions further cause the master control device to also use the interconnection module to adjust net energy output to decrease the amount of interphase imbalance if the amount of interphase imbalance is above the threshold.

80. The control system of claim 54, wherein the master control device comprises processing circuitry configured to execute the plurality of instructions.