

POWER SUPPLY SYSTEM

FIELD OF THE INVENTION

[0001] The invention relates to a power supply system. In particular, the invention relates, but is not limited, to a power supply system that utilises a statcom to manage energy generation and storage on a common DC bus and to manage power flow to and from an AC bus which is connected to an electricity network and an electrical load.

BACKGROUND TO THE INVENTION

[0002] Reference to background art herein is not to be construed as an admission that such art constitutes common general knowledge.

[0003] It is increasingly common for homes to have their own energy generation, such as a solar or wind generator, while also being connected to an electricity network grid. Before electricity can be exported to the electricity network it must be conditioned for export. For a DC generation system such as a solar generator with photovoltaic (PV) panels this task is usually performed by an inverter which converts DC electricity from the panels into AC electricity which substantially corresponds to the electricity network.

[0004] While effective, such systems are typically fairly rudimentary and do not provide additional features or enhancements. Furthermore, they are typically non-modular and for more complex systems multiple separate components are required. These components are typically tied to the AC network which is connected to the electricity network. For example, if a consumer has both a solar generator and a wind generator, both are typically

run independently of each other and simply output their respective electricity generation to the AC network.

OBJECT OF THE INVENTION

[0005] It is an aim of this invention to provide a power supply system which overcomes or ameliorates one or more of the disadvantages or problems described above, or which at least provides a useful alternative.

[0006] Other preferred objects of the present invention will become apparent from the following description.

SUMMARY OF INVENTION

[0007] In one form, although it need not be the only or indeed the broadest form, there is provided a power supply system comprising:

- an AC network connected to an electricity network and an electrical load;

- a DC bus;

- at least one energy generation system connected to the DC bus;

- at least one energy storage system connected to the DC bus; and

- a static synchronous compensator (statcom) connecting the DC bus to the AC network;

- wherein the statcom and the voltage of the DC bus control electricity flow on the DC bus.

[0008] The energy generation system preferably comprises renewable electricity sources such as, for example, solar panels and/or wind turbines. The energy generation system may also or instead comprise a hydro generator, biomass generator, fuel cell, and/or hydrocarbon generator. Preferably the

energy generation system is connected to the DC bus via an AC/DC converter or a DC/DC converter to match its voltage output to substantially accord with the voltage of the DC bus. The converters may comprise a communication system that communicates with the statcom. The communication system may be used to transfer information about the converters and/or to receive instructions from the statcom.

[0009] Preferably the energy storage system comprises one or more batteries, typically a battery bank. The energy storage system may be connected to a DC/DC converter which is in turn connected to a DC bus. The DC/DC converter is preferably a bidirectional. Preferably the statcom is programmed to prioritise available power flow from the DC bus to itself or to the energy storage system.

[0010] Preferably the system further comprises a power sensor. Preferably the power sensor is located on the AC network. Preferably the electricity network is connected to the AC network via the power sensor. Preferably the power sensor communicates a power measurement to the statcom. The power sensor may communicate the power measurement wirelessly or over a wired connection.

[0011] Preferably the statcom is configured to provide peak demand shifting, phase balancing of a multiphase AC network, export control to the electricity network, and/or an uninterruptable power supply that meets anti-islanding requirements for an electricity network connected generation system.

[0012] Preferably the statcom improves the quality of electricity imported from the electricity network for the electrical load. Preferably the statcom

improves the quality of electricity imported from the electricity network for the electrical load based on measurements the statcom takes at its connection to the AC network or the power measurement from the power sensor. The quality improvement of the electricity imported from the electricity network may comprise voltage control, harmonics suppression, and/or power factor correction. Preferably the statcom improves the quality of electricity imported from the electricity network for the electrical load by sourcing or sinking energy from or to the DC bus.

[0013] Preferably the DC bus has a voltage of greater than 100V, even more preferably greater than 200V, even more preferably greater than 300V, and even more preferably greater than 400V. The DC bus may have a voltage that varies within the range 200V to 600V, more preferably within the range 300V to 500V, more preferably in the range 400 to 500V, more preferably in the range 420V to 480V, and even more preferably between approximately 430V and 460V. The actual voltage of the DC bus preferably varies depending on whether the energy storage system is inputting or outputting energy.

[0014] Preferably the AC network is a low voltage AC network having a standard voltage for electricity supply to consumers. Preferably the AC network has a voltage of less than 400V, more preferably less than 300V, and typically around 200-250V or 100-150V depending on the country mains voltage electricity supply.

[0015] In another form, there is provided a method of improving the quality of an electricity network, the method comprising the steps of:

measuring electrical characteristics of the electricity network;

using a statcom connected to the electricity network to vary its output to improve the quality of the electricity network by implementing voltage control, harmonic suppression, and/or power factor correction.

[0016] The step of measuring may comprise measuring at the statcom or measuring at another point in the electricity network. Preferably the step of measuring at another point in the electricity network comprises measuring using a power sensor and communicating the power measurement to the statcom. A network profile may be generated and used to account for differences in impedance between the statcom and the point of measurement.

[0017] Further features and advantages of the present invention will become apparent from the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] By way of example only, preferred embodiments of the invention will be described more fully hereinafter with reference to the accompanying figures, wherein:

[0019] Figure 1 illustrates an overview of an example power supply system; and

[0020] Figure 2A illustrates a statcom area of operation with no DC bus power available;

[0021] Figure 2B illustrates a statcom area of operation with a DC bus operating as a source only; and

[0022] Figure 2C illustrates a statcom area of operation with a DC bus that can both source and sink power.

DETAILED DESCRIPTION OF THE DRAWINGS

[0023] Figure 1 illustrates an example power supply system having user equipment 10 connected to electricity transmission infrastructure 20. Central to the system is a static synchronous compensator (statcom) 140. The statcom 140 is connected between a DC bus 310 and an AC network 320. An electrical load 250, which in the case of a standard household consumer is the electrical load of their household, is connected to the AC network 320. It will be appreciated that the AC network 320 may be single phase or multiphase, typically depending on the size and capacity of the system.

[0024] The user equipment illustrated in figure 1 includes renewable electricity generation in the form of a solar generator 210 having a photovoltaic (PV) array of solar panels and a wind generator 220. Although the only electricity generators shown are solar and wind, it will be appreciated that other electricity generation sources could be connected such as, for example, a hydro generator, biomass generator, fuel cell, and/or hydrocarbon generator.

[0025] The solar generator 210 is connected to the DC bus 310 via a PV DC/DC converter 110 which matches the solar generator 210 DC output to the DC bus 310. The wind generator 220 is connected to the DC bus 310 via a wind generator AC/DC converter 120 which converts the wind generated AC electricity output to a DC output that is suitable for connection to the DC bus 310.

[0026] An energy storage system in the form of a battery bank 230 is provided. The battery bank 230 is connected to the DC bus 310 via a battery DC/DC converter 130. The battery DC/DC converter 130 matches the battery

bank 230 DC output to the DC bus 310. The battery bank 230 may be any suitable size, but is preferably selected based on at least characteristics of the electrical load 250. The battery DC/DC converter 130 is bidirectional to allow both charging and discharging of the battery bank 230 through the DC bus 310.

[0027] The PV DC/DC converter and wind AC/DC converter output generated electricity to the DC bus 310 which can then be managed by the statcom 140. The battery DC/DC converter can both output electricity to the DC bus 310 and input electricity from the DC bus 310, typically under control of the statcom 140. The statcom 140 uses a number of variables to which determine when and how it inputs and outputs electricity from the DC bus 310 into or from the battery bank 230. These variables include available electricity rates for import, available electricity rates for export, power being generated, energy storage system reserves; and/or current electrical load.

[0028] A power sensor is provided which provides a power measurement 330 to the statcom 140. The power sensor 150 measures real and reactive power of the AC network 320. The power sensor 150 measures both magnitude and direction to ascertain whether real power is being exported to the electricity network 240 or imported from the electricity network 240 and whether the reactive power is leading or lagging the real power. The power measurement 330 can be communicated to the statcom 140 using either wired or wireless communication systems.

[0029] The DC bus 310 is a common DC bus 310 such that all DC components, such as the solar generator 210, wind generator 220, and battery bank 230, are connected to the same bus. To match the voltage of each of

these DC components to the DC bus they each have a DC/DC converter or AC/DC converter.

[0030] Power flow between the converters 110, 120, 130 and the DC bus 310 is determined by the voltage of the DC bus 310. Converters sourcing power to the DC bus (e.g. the solar DC/DC converter 110 when the solar generator 210 is generating energy) pull the DC bus voltage up while converters sinking power from the DC bus (e.g. the battery bank 230 when charging) pull the DC bus voltage down. The actual voltage of the DC bus 310 at any given point in time depends on the balance of power being sourced to the DC bus 310, power being sunk from the DC bus 310, and whether the statcom is prioritising available power to itself or to the battery bank 230.

[0031] Example voltages of the common DC bus 310 in a preferred embodiment are shown in Table 1, below. Voltage level 1 is the highest voltage at 460V and voltage level 4 is the lowest voltage at 430V.

Voltage Level	Example Voltage	Statcom Priority	Power Transfer and Status
1	460V	Statcom or Battery Bank	Battery bank 230 and statcom 140 are consuming less power than what is being generated from the other energy sources on the DC bus 310.
2a	450V	Battery Bank	Battery bank 230 is consuming less power than what is being generated from the other energy sources on the DC bus 310 (excluding the statcom 140), and the statcom 140 is consuming the balance.
2b	450V	Battery Bank	Battery bank 230 is consuming more power than what is being generated from the other energy sources on the DC bus 310 (excluding the statcom 140), and the statcom 140 is providing the balance.

3a	440V	Battery Bank	Battery bank 230 is consuming all power that is being generated from the other energy sources on the DC bus 310, including the statcom 140.
3a	440V	Statcom	Statcom 140 is consuming less power than what is being generated from the other energy sources on the DC bus 310 (excluding the battery bank 230), and the battery bank 230 is consuming the balance.
3b	440V	Statcom	Statcom 140 is consuming more power than what is being generated from the other energy sources on the DC bus 310 (excluding the battery bank 230), and the battery bank 230 is providing the balance.
4	430V	Statcom	Statcom 140 is consuming all power that is being generated from the other energy sources on the DC bus, including the battery bank 230.

TABLE 1

[0032] For example, when the battery bank 230 has priority the statcom 140 maintains the DC bus voltage at voltage level 2. If the battery bank 230 is consuming all the power that the energy sources can provide to the DC bus 310, including the statcom 140, then this voltage is pulled down to voltage level 3. When the statcom 140 has priority, the battery bank 230 is used to maintain the DC bus 310 voltage at voltage level 3. If the statcom 140 is consuming all the power that the energy sources can provide to the DC bus 310, including the battery bank 230, then this voltage is pulled down to voltage level 4.

[0033] The statcom 140 priority is used to control whether it preferable for the battery bank 230 to store available energy on the DC bus 310, or whether it is preferable to supply the available energy to the DC bus 310 which the statcom 140 can then export to the AC network 320.

[0034] The statcom 140 priority mode can be used to provide different functions such as, for example, peak demand shifting. Other functions the statcom 140 may be able to provide include phase balancing of a multiphase AC network 320, export control to the electricity network 240, and/or an uninterruptable power supply that meets anti-islanding requirements for an electricity network 240 connected energy generation system and/or energy storage system.

[0035] The statcom 140 can also be configured to improve the quality of the electricity imported from the electricity network 240 for the electrical load 250, and to improve the quality of the electricity network 240 itself. The statcom 140 may improve the quality by implementing voltage control, harmonic suppression, and/or power factor correction.

[0036] The statcom 140 can sample the AC network 320 at its point of connection to improve the quality of the AC network 320 at this point, or it can receive a power measurement 330 from the power sensor 150 to improve the quality of the network at the point of the power sensor 150. The statcom 140 identifies power quality deficiencies and then compensates for the identified power quality deficiencies. The statcom 140 improves the electricity continuously, cycle by cycle. If there are variations in network impedance between the statcom 140 and the power sensor 150 then a network profile can be generated and used to cater for differences between the point of measurement, i.e. the power sensor 150, and the point of correction, i.e. the statcom 140.

[0037] The statcom 140 can be configured to provide a voltage control quality improvement. Voltage control is used to maintain the voltage of the AC network 320 or electricity network 240 within predetermined limits. The statcom 140 continuously measures the voltage and detects if the voltage falls outside predetermined limit. The statcom 140 then adjusts the voltage at the point of connection to the AC network 320 using a combination of real and reactive power to bring the measurement back within the predetermined limits.

[0038] To increase voltage the statcom 140 sources real power to and/or injects leading reactive power on the AC Network. To decrease the voltage the statcom 140 sinks real power from and/or injects lagging reactive power on the AC Network. These changes are implemented on a cycle by cycle basis.

[0039] The use of real and/or reactive power will depend on what real power is available on the DC bus 310, what compromise between voltage control and power factor correction is permitted, and whether voltage control or power factor correction has priority. Generally it is desirable to minimise reactive power on the electricity network 240 to improve efficiency of the electricity network 240 transmission system. To achieve this, the Statcom uses real power for voltage control as first priority, and only uses reactive power when there is insufficient real power available. Variations to this process might occur, for example, in applications where a specific power factor is to be maintained or an existing power factor issue is to be corrected.

[0040] The amount of real power available for use in voltage control is governed by the amount of power is available on the DC bus 310. For the statcom 140 to source real power to the AC network 320 it requires a

corresponding amount of power to be available on the DC bus 310 (e.g. from energy generation or storage). For the statcom 130 to sink real power from the AC network 320 it requires a corresponding amount of energy storage to be available on the DC bus 310 (e.g. in the battery bank 230).

[0041] The amount of reactive power available for use in voltage control is a combination of what power is available on the DC bus 310 and what power can be recirculated from or to the AC network 320. When real power is to be used, the DC bus 310 must have sufficient available power or energy storage to accommodate the amount of reactive power to be sourced or sunk to or from the AC network 320. Where DC bus 310 power is inadequate, real power can be sunk or sourced from or to the AC network 320 and used to generate leading or lagging reactive power.

[0042] Figures 2a to 2c illustrate a statcom 140 area of operation with different DC bus situations. The shaded areas illustrate the areas in which the real and reactive power of the statcom 140 can operate. The circle represents the rated power of the statcom 140, 'P' is real power, 'Q' is reactive power, positive is sourcing from the statcom 140 to the AC network 320, and negative is sinking from the AC network 320 to the statcom 140.

[0043] As illustrated in figure 2a, with no DC bus 310 power available the statcom 140 can only operate in a linear fashion with equal amounts of real power being sunk or sourced and reactive power being sourced or sunk, respectively.

[0044] As illustrated in figure 2b, with the DC Bus only being able to source power (i.e. there is no available energy storage) the statcom 140 can only

operate in an area where the amount of power being sourced to the AC network 320 equals or exceeds the amount of power being sunk from the AC network 320. As illustrated in figure 2C, with both a source of power and energy storage on the DC bus 310 the statcom 140 can provide any combination of real and reactive power up to the rated power.

[0045] The statcom 140 can be configured to provide a harmonics suppression quality improvement. Harmonics suppression is used to reduce harmonics on the AC network 310 or the electricity network 240 to within desired specifications. The statcom 140 has a real or reactive power controller that contains a number of parallel controllers that control harmonics of the electrical power at the point of connection with the AC network 320. The controllers operate on a sub-cycle basis allowing them to control high frequency harmonics.

[0046] The controller that operates at the fundamental frequency (i.e. 50Hz for a 50Hz AC network 320 supply) is used to maintain the amplitude of the power at that frequency which facilitates operation of the statcom 140 (i.e. sinking or sourcing power). The controllers that operate at multiples of the fundamental frequency are used to suppress any power at those multiples of the fundamental frequency, effectively suppressing any harmonics.

[0047] The statcom 140 can be configured to provide power factor correction. Power factor control is used to maintain the power factor of the AC network 320 or the electricity network 240 to within desired specifications. The statcom 140 continuously measures the power factor on a cycle by cycle basis. If the power factor is detected to be outside predetermined limits the statcom

140 adjusts the power factor at the point of connection to the AC network 240 using a combination of real and reactive power so as to bring it back within limits.

[0048] If the power factor is lagging behind where it should be, the statcom 140 will generate leading reactive power to compensate. If the power factor is leading ahead of where it should be, the statcom will generate lagging reactive power to compensate. Adjustment of reactive power generation is done on a cycle-by-cycle bases and effects the ratio between real and reactive power in the core of the real or reactive power controller. The adjustment is done in steps which are either fixed or dynamically adjusted based on statistical analysis of current power versus desired power factor. These adjustments are ongoing so as to compensate for variations in AC network 320 impedance and electricity network 240 power factor.

[0049] The use of real and/or reactive power to achieve the desired compensatory power factor will depend on what real power is available on the DC bus, what compromise between voltage control and power factor correction is allowed, and whether voltage control or power factor correction has priority. To achieve this without impacting on AC network 320 voltage, the Statcom uses a combination of real and reactive power for power factor correction with a zero net power being sourced or sunk to or from the AC network 320. Variations to this can occur where voltage control is also desired which will require power available on the DC bus 310.

[0050] Improving the quality of the network benefits the consumer by providing power with improved characteristics which can improving the

efficiency and operation of appliances in the electrical load 250. It also benefits the electricity network 240 by improving voltage, harmonics, and/or power factor which can result in improved transmission efficiency. It will be appreciated that the extent of correction the statcom 140 is able to achieve is dependent on the impedance of the electricity network 240, the extent of the deficiencies to be dealt with, and what power is available on the system. The system therefore needs to be sized appropriately to deal with anticipated deficiencies adequately.

[0051] Advantageously, the power supply system provides an improved integrated system with a common DC bus that is modular and simplifies connections between various components. The statcom 140 is able to provide advanced features such as peak demand shifting, phase balancing of a multiphase AC network, export control to the electricity network, and/or an uninterruptable power supply that meets anti-islanding requirements for an electricity network connected generation system. Furthermore, the statcom 140 is also able to improve power quality for the consumer and/or the electricity network 240. This can improve appliance and transmission efficiency and reduces side effects associated with power supply deficiencies.

[0052] In this specification, adjectives such as first and second, left and right, top and bottom, and the like may be used solely to distinguish one element or action from another element or action without necessarily requiring or implying any actual such relationship or order. Where the context permits, reference to an integer or a component or step (or the like) is not to be interpreted as being limited to only one of that integer, component, or step, but rather could be one or more of that integer, component, or step etc.

[0053] The above description of various embodiments of the present invention is provided for purposes of description to one of ordinary skill in the related art. It is not intended to be exhaustive or to limit the invention to a single disclosed embodiment. As mentioned above, numerous alternatives and variations to the present invention will be apparent to those skilled in the art of the above teaching. Accordingly, while some alternative embodiments have been discussed specifically, other embodiments will be apparent or relatively easily developed by those of ordinary skill in the art. The invention is intended to embrace all alternatives, modifications, and variations of the present invention that have been discussed herein, and other embodiments that fall within the spirit and scope of the above described invention.

[0054] In this specification, the terms 'comprises', 'comprising', 'includes', 'including', or similar terms are intended to mean a non-exclusive inclusion, such that a method, system or apparatus that comprises a list of elements does not include those elements solely, but may well include other elements not listed.

PROVISIONAL CLAIM:

1. A power supply system comprising:
 - an AC network connected to an electricity network and an electrical load;
 - a DC bus;
 - at least one energy generation system connected to the DC bus;
 - at least one energy storage system connected to the DC bus; and
 - a statcom connecting the DC bus to the AC network;wherein the statcom and the voltage of the DC bus control electricity flow on the DC bus.