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(54) Title: HIGH VOLTAGE X-RAY POWER SUPPLY SYSTEM WITH DUAL ENERGY STORAGE SYSTEM

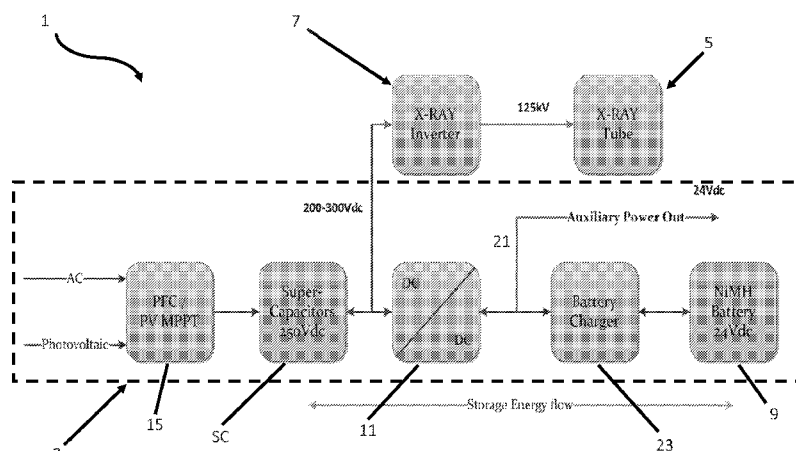


Figure 1

(57) Abstract: Medical X-ray power generator system comprising an energy storage section comprising at least one battery unit and at least one supercapacitor (SC) unit, wherein the SC unit and the battery unit are connected in a way as to allow a bidirectional exchange of energy.

High Voltage X-ray Power Supply system with dual energy storage system

Cross-reference to related applications

This application claims the benefit of international application No. PCT/IB2015/051656 filed March 6th 2015, the entire contents of which are incorporated herein by reference.

5 Field of invention

The present invention relates to radiography, in particular to X-ray radiography.

It more precisely relates to power generator systems for X-ray devices.

State of the art

Conventional X-ray devices receive their energy directly from the grid.

- 10 Those devices require a high-pulsed power that may be up to 100kW. Such a requirement may lead to voltage fluctuation and dysfunction, especially in weak and unstable grids or when a generator powers the devices. Those situations are particularly frequent in developing countries.

This problem may be partially solved with the help of energy storage in the form of batteries and capacitors. See for instance US patent 6,169,782.

- 15 There are however several problems that cannot be solved with the prior art devices.

For instance, if the energy from the grid is missing over a relatively long period, the low voltage elements of the X-ray device (computer, collimator, etc...) may not be supplied anymore when the battery is empty. Such situation makes it impossible to further use the X-ray device.

20 Summary of the invention

The present invention permits the above mentioned problems to be addressed and resolved. The present invention concerns an X-ray generator power supply system according to claim 1, an X-ray imaging system according to claim 15 and a method according to claim 16. The dependent claims include other advantageous features of the present invention.

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Brief description of the Figures:

The above object, features and other advantages of the present invention will be best understood from the following detailed description in conjunction with the accompanying drawings, in which:

- Figure 1 shows a bloc schematic of the system according to the present invention;
 - Figure 2 shows a schematic of a high voltage power converter of the system of the present invention;
 - and
 - Figure 3 shows an exemplary circuit diagram for an energy storage and supply section the system
- 5 according to the present invention.

Detailed description of the invention

Figure 1 shows a schematic layout of the system according to the present invention. Figures 2 and 3 present further details of the constituent elements of the system.

10 The present invention concerns an X-ray generator power supply system 1. The system includes an energy storage section 3 configured to receive electrical energy from an electrical power network or AC grid, a mobile electrical power generator or an array of photovoltaic cells. The energy storage section 3 is further configured to provide energy to an X-ray generator 5 for generating X-rays for medical imaging.

15 The X-ray generator 5 is, for example, part of an X-ray imaging system that uses the generated X-rays to produce X-ray images via an X-ray detector.

The system 1 further includes an X-ray power converter 7 configured to provide a high voltage to the X-ray generator 5 permitting to generate X-ray radiation. The X-ray power converter is configured to convert a variable input DC voltage into a high output voltage provided to X-ray generator 5.

20 The energy storage section 3 includes a first energy storage device that is at least one or a plurality of supercapacitors SC. The energy storage section 3 also includes a second energy storage device 9 that is a rechargeable battery pack, for example, a NiMH battery.

The supercapacitor SC (or ultra-capacitor) can be, for example, an electric double layer capacitor (EDLC), or an electrochemical pseudo-capacitor, or a hybrid capacitor.

25 The supercapacitor SC is interconnected to the battery 9 by a bi-directional energy transfer device 11. The bi-directional energy transfer device 11 is configured to transfer energy from the first supercapacitor SC to the battery 9 as well as from the battery 9 to the supercapacitor SC.

The bi-directional energy transfer device 11 is preferably a bi-directional isolated DC/DC converter.

The section 3 further includes a grid or photovoltaic array interface device 15 directly connected to the supercapacitor SC. The grid or photovoltaic array interface device 15 is configured to charge the

supercapacitor SC. The grid or photovoltaic array interface device 15 includes a rectifier 17 and a Buck-Boost circuit 19 to convert the input voltage to a voltage form adapted to charge the supercapacitor SC.

5 The grid or photovoltaic array interface device 15 is also directly connected to the bi-directional isolated DC/DC converter 11. The DC/DC converter 11 is configured to convert the input voltage provided by the grid or photovoltaic array interface device 15 to a substantially fix voltage value or level V_A , for example 24V. The DC/DC converter 11 is connected to an auxiliary device interface 21 and outputs the substantially fix voltage value or level V_A to auxiliary devices such as a computer for managing X-ray generation by the X-ray generator 5.

10 The section 3 additionally includes a battery charger 23 including a Boost circuit 25 configured to boost or increase the voltage V_A to a battery charging voltage level V_C , for example between 30V and 50V.

The section 3 includes a battery discharge circuit 27 configured to provide energy stored in the battery pack 9 to the supercapacitor SC and/or to the auxiliary device interface 21 to supply electrical energy to auxiliary devices such as a computer for managing X-ray generation by the X-ray generator 5 and
15 the X-ray machine in general.

The battery discharge circuit 27 is configured to convert the voltage level provided by the battery 9 to a lower substantially fix voltage value or level V_A , for example 24V, that is provided to the auxiliary device interface 21.

The section 3 is configured to direct energy from the rechargeable battery 9 to the supercapacitor SC
20 in the absence of an energy supply from the electrical power network, the mobile electrical power generator or the photovoltaic array.

Rectifier 17

The rectifier 17 is a full wave bridge rectifier configured to convert the alternating voltage of the AC grid to a direct or DC voltage U_{gl} . One of the diagonal diode groups will be active depending on the
25 polarity of the alternating voltage of the AC grid. The current will thus always circulate in the same direction, this assuring the rectification role. The U_{gl} residual frequency will be doubled with respect to that of the AC grid.

The choice of the primary energy source is assured by the switching of the switch K_{pv} for the photovoltaic energy source or K_{grid} for the AC grid network.

30 **Buck-Boost 19**

The voltage U_{gl} is rectified and variable between 0 and the AC grid peak value or a Photovoltaic array base value of, for example, 400Vp. This voltage is converted into a direct or DC voltage U_{prim} between 200 and 350 Vdc nominal value. During start up, if the supercapacitor bus is discharged, the circuit is to operate with a zero voltage. The Buck-Boost converter 19 is configured to lower or raise the voltage level while maintaining a current of predetermined quality.

The Buck-Boost converter 19 combines a buck structure (left) with a boost structure (right). The two structures share a common inductance 40. In accordance with the function required, the two power switches 42, 44 (for example of the type MosFet, IGBT, Sic,...) are simultaneously controlled or controlled in an individual manner.

- 10 This direct or DC voltage U_{prim} charges the supercapacitor SC and is also (simultaneously) provided to the DC/DC converter 11 to provide energy to the auxiliaries output 21 and any remaining energy to the battery 9.

PFC/ PV MPPT 15

- 15 The rectifier 17 and Buck-Boost converter 19 combination are configured to provide the two working operations of:

- A power factor corrector (PFC) if the energy is taken from the AC Grid with the current being taken with the minimum amount of harmonics in order to be compatible with the 61000-3-2 standard. In order to minimize the impact of the converter on the AC grid, the maximum current level is controllable.
- 20 - A Maximum point power tracker (MPPT), if the energy is provided by the PV array in order to maximize the use of the available solar energy.

The two switches 42, 44 of the converter 19 are driven based on knowledge of the energy source and measured voltage values U_{pv} , U_{grid} , U_{prim} as well as the current I_{pfc} .

DC/DC 11

- 25 This converter is configured to pass energy between the SC bus (U_{prim}) and the fixed and stable voltage interface or output port 21 (U_{sec}). Depending on the availability of the energy source, energy will be circulated either in one direction or the other.

- The converter is a flyback type converter including two groups of power switches in series (a primary group 46 and a secondary group 48). The converter also includes an active primary overvoltage limitation 50. The adjustment or rectification is controlled synchronously or simply by diode. The
- 30

adaptation of the voltage level as well as the energy storage is realized using the transformer 52. The activation of the control of the primary and secondary switches 54, 56 determines the direction of energy flow.

- Uprim towards Usec (energy from SC bus to battery charger 23 and energy from SC bus to auxiliaries interface 21)

By activation of primary switches 54a, 54b and synchronous adjustment/rectification, or via the secondary diode.

In the absence of energy available from the AC grid or photovoltaic array (primary energy source), the supercapacitor SC receives energy that transits to SC bus from the battery 9 through battery discharge circuit 27, battery charger 23 and converter 11.

- Usec towards Uprim (from battery 9 to supercapacitor SC)

By activation of secondary switches 56a, 56b and synchronous adjustment/rectification, or via the primary diode.

The active primary overvoltage limiter 50 is used in the two transfer directions.

15 **Auxiliary voltage 21**

Fixed voltage supply point for all internal and external electronic services. The external consumers are disconnected from the secondary bus Usec via switch Kload. This voltage is stabilized, for example, 24V DC and its energy can come from either the DC/DC converter 11 or the battery 9 through the discharge path.

20 **Battery charger 23, 25**

Voltage adaptation circuit to modify the voltage between the secondary bus Usec and the battery 9. A two quadrant chopper, reversible in current is used. It is thus possible to permit positive or negative current flow as a function of whether a charging mode or discharging mode is operating. The two power switches 58, 60 are controlled in a complementary manner with a short dead band time.

By adapting the periodic control ratio, it is possible:

- to raise the voltage for the charging mode $U_{sec} < U_{charge}$, for example 24Vdc increased towards 30 to 40Vdc.

- to lower the voltage during discharge mode $U_{\text{discharge}} \geq U_{\text{sec}}$ for example 30 to 40Vdc towards 24Vdc.

A supplementary pre-charge circuit is used at start up of the converter to supply a battery voltage to the auxiliary interface/output 21. The charge current is controlled by an active limitation transistor.

5 This circuit is disabled after start up when the U_{sec} voltage is ready.

The present invention thus concerns an X-ray generator power supply system 1 or a medical X-ray power generator system 1 with a dual energy storage section comprising at least one battery unit 9 and at least one supercapacitor unit SC, wherein the SC unit and the battery unit are connected in a way as to allow a bidirectional exchange of energy.

10 The SC unit and the battery unit 9 are connected in a way as to allow a bidirectional exchange of energy. The SC unit is used for delivering the required high-pulsed power to the X-ray tube 5. The battery unit 9 is used for delivering the energy to all the low-voltage auxiliaries of the X-ray machine in absence of the primary energy source. The battery 9 also supplies energy to the SC via converter 11 in the absence of the primary energy source.

15 This structure allows the system 1 to provide the high power pulses needed by standard X-ray tubes 5 without heavily affecting the utility grid as well as to work autonomously for a limited amount of time in case of utility grid outage.

The device 7 according to the invention is designed to convert the low voltage of the storage section 3 into the high voltage required by the tube 5 (e.g. up to 125kV) with very high dynamics, which allows
20 to minimize the useless X-ray dose that the patient will be exposed to.

Advantageously, the grid or photovoltaic array interface device or grid interface sub-system 15 has been designed to charge the batteries and SCs even with very low input power.

In the present invention, the SC unit may advantageously be used as a central energy storage system. The difference with the prior art is that the SC unit may be supplied by versatile electronics at a low
25 power, so that the energy source is not overloaded. The energy can be obtained from the AC power supply over a wide voltage range (75V-280V, 50/60Hz). On the other hand, the SC unit may be supplied from DC sources such as a photovoltaic cell array, for example, by rectifying the voltage of the generator of a wind turbine or by solar panels. The SC unit feeds the high-voltage X-ray generator 7 and electronics for controlling the motor or the rotating anode.

30

The system 1 according to the invention preferably comprises the bidirectional isolated DC/DC converter 11 that creates a stabilized supply voltage on the auxiliary level (for example 24V DC), to supply any additional devices such as a computer, monitor, collimator etc. As a result, momentary power interruptions or fluctuating mains voltages remain without influence.

5

In case of power failure, the power is supplied from the battery 9. Another advantage of the invention is that a charging / discharging electronics may connect the battery 9 unit to the SC unit to permit the SC to receive power supply during external power failure.

- 10 Preferably, the bidirectional isolated DC/DC converter 11 feeds the SC unit. These electronics avoids an overloading of the battery 9 and allows optimum battery management to ensure a long lifetime.

Universal power supply

- 15 The system 1 according to the invention is adapted to work under normal conditions, i.e. when the power is received from the grid. Thanks to the use of high-power storage (composed by the SCs) to supply the power peaks internally, the generator 15 takes a continuous power of a few hundred watts from the grid or from other sources to charge the SCs and batteries 9. If the grid fails, the energy is supplied internally from the (NiMH) batteries 9 as an energy backup function.

Energy storage

- 20 The energy storage section 3 is composed by two sub-systems: the SC storage unit and the battery unit 9. The SC storage unit is used for delivering the required high-pulsed power to the X-ray tube 5 during the radiation. The battery unit is used for delivering the energy to all the low-voltage auxiliaries of the X-ray machine and to SC unit in the case of grid or external input power failure.

High-voltage x-ray power converter

- 25 In order to reach the high voltages required to supply the X-ray tube 5, a suitable DC/DC converter 7 is provided. A specific characteristic of this converter 7, as it is supplied directly by the SC storage unit, is its ability to work with a variable input DC voltage. An LCC resonant converter with medium frequency transformer is included. This solution offers the advantage of reducing substantially the size and the costs of the whole power converter while allowing a very fast dynamic response. The latter is a competitive advantage because it allows to minimize the radiation dose received by the patient. Figure 30 2 shows a schematic of the high voltage power converter 7.

The X-ray power converter 7 is directly connected to the supercapacitor SC which provides input voltage to the X-ray power converter 7. The input voltage provided from the supercapacitor SC to the X-ray power converter 7 can vary in value, for example, between 200V to 300V. The X-ray power converter 7 is a high output voltage power converter working at variable input DC-link voltage

- 5 The X-ray power converter 7 is configured to operate as a DC to DC converter. It includes a DC/AC converter (an inverter) 29 to convert the input DC voltage to AC voltage, an LCC resonant circuit 31 and two medium frequency transformers 33 to increase the AC voltage provided by the LCC circuit 31 to a higher voltage alternating current. The transformers 33 are followed by two AC/DC converter (Diode rectifiers) 35, each one connected to one medium frequency transformer 33. The AC/DC
10 converter 35 converts the high voltage alternating current provided by the transformers 33 to a direct current and DC voltage that is supplied to the X-ray generator 5.

The LCC resonant circuit 31 allows the inverter 29 to achieve soft switching techniques in order to reduce losses and EMC parasitic emissions. The LCC resonant circuit is tuned to work properly at all operating points (i.e. SC charge status, X-ray exposure or kV).

- 15 The X-ray power converter 7 thus comprises a LCC resonant inverter structure followed by a two stage transformer-rectifier.

The medium frequency of the medium frequency transformers 33 can be any frequency that is above the grid/line usual frequency (i.e. 50/60/400Hz) in order to reduce the size/weight of transformers and passive components. For example, between 20kHz and 60kHz.

- 20 The elements of the LCC circuit 31 can, for example, be $4.65\mu\text{H}$, $2.2\mu\text{F}$ and $6.2\mu\text{F}$ for L_s , C_p and C_s . Capacitors C1 to C4 of the AC/DC converter (Diode rectifiers) 35 can be for example 2nF each in value. The value of n of the windings of the transformers 33 can be for example 110. Thus, a 1:110 turn ratio.

- Having described now the preferred embodiments of this invention, it will be apparent to one of skill in the art that other embodiments incorporating its concept may be used. This invention should not
25 be limited to the disclosed embodiments, but rather should be limited only by the scope of the appended claims.

Claims

1. X-ray generator power supply system (1) comprising:
 - an energy storage section (3) configured to receive energy from an electrical power network, a mobile electrical power generator or photovoltaic array and to provide energy to an X-ray generator (5) for generating X-rays for medical imaging;
- 5 the system (1) being characterized in that the energy storage section (3) includes a first energy storage device (SC) and a second energy storage device (9) interconnected by a bi-directional energy transfer device (11), the bi-directional energy transfer device (11) being configured to transfer energy from the second energy storage device (9) to the first energy storage device (SC) and/or from the first energy storage device (SC) to the second energy storage (9).
- 10
2. X-ray generator power supply system (1) according to claim 1, wherein the first energy storage device is a supercapacitor (SC) and the second energy storage device is a rechargeable battery (9).
3. X-ray generator power supply system (1) according to any one of the previous claims, wherein the bi-directional energy transfer device (11) is a bi-directional isolated DC/DC converter.
- 15 4. X-ray generator power supply system (1) according to anyone of the previous claims, further including a grid interface or photovoltaic array device (15) directly connected to the supercapacitor (SC), the grid interface or photovoltaic array device (15) being configured to charge the supercapacitor (SC).
- 20 5. X-ray generator power supply system (1) according to any one of the previous claims, further including an X-ray power converter (7) configured to provide a high voltage to an X-ray generator (5), the X-ray power converter (7) being configured to convert a variable input DC voltage into a high voltage output voltage.
6. X-ray generator power supply system (1) according to the previous claim, wherein the X-ray power converter (7) is directly connected to the supercapacitor (SC) which provides an input voltage to the X-ray power converter (7).
- 25 7. X-ray generator power supply system (1) according to previous claim 5 or 6, wherein the X-ray power converter (7) includes a DC/AC converter (29) an LCC resonant circuit (31), at least one medium frequency transformer (33) and at least one AC/DC converter (35).

8. X-ray generator power supply system (1) according to any one of the previous claims, further including an electrical discharge circuit (27) configured to provide energy from the rechargeable battery (9) to an auxiliary device interface (21) to provide energy to at least one auxiliary device of the X-ray generator (5).
- 5 9. X-ray generator power supply system (1) according to any one of the previous claims, wherein the system (1) is configured to direct energy from the rechargeable battery (9) to the supercapacitor (SC) in the absence of an energy supply from the electrical power network, the mobile electrical power generator or the photovoltaic array.
- 10 10. X-ray generator power supply system (1) according to any one of the previous claims 4 to 9, wherein the grid interface or photovoltaic array device (15) includes a rectifier (17) configured to convert an alternating voltage of an AC grid to a direct or DC voltage (U_{gl}).
- 15 11. X-ray generator power supply system (1) according to any one of the previous claims 4 to 10, wherein the grid interface or photovoltaic array device (15) includes a switching means (K_{pv} , K_{grid}) configured to switch between a photovoltaic energy source and an AC grid network to select a primary energy source for providing energy to the first energy storage device (SC).
- 20 12. X-ray generator power supply system (1) according to claim 10, wherein the grid interface or photovoltaic array device (15) includes a Buck-Boost converter (19) configured to lower or raise a voltage level received from the rectifier (17) to a DC voltage (U_{prim}) and to provide said voltage (U_{prim}) to charge the first energy storage device (SC) and is provided also said voltage (U_{prim}) to the DC/DC converter (11) to provide energy to the auxiliaries output (21) and/or battery (9).
- 25 13. X-ray generator power supply system (1) according to any one of the previous claims 3 to 12, wherein the bi-directional isolated DC/DC converter (11) includes primary and secondary switches (54, 56) to determines a first direction of energy flow from a SC bus to the auxiliaries interface (21) or a second direction of energy flow from the second energy storage device (9) to first energy storage device (SC).
14. X-ray generator power supply system (1) according to any one of the previous claims 3 to 13, wherein the system is configured to direct energy to the first energy storage device (SC) from the second storage device (9) through battery discharge circuit (27), battery charger (23) and bi-directional isolated DC/DC converter (11), in the absence of energy available from a primary energy source.
- 30 15. X-ray imaging system including the X-ray generator power supply system (1) according to any one of the previous claims.

16. Method of providing power to an X-ray generator (5), the method comprising the steps of:

- providing a first energy storage device (SC) configured to receive energy from an electrical power network or mobile electrical power generator and configured to provide energy to the X-ray generator (5) for generating X-rays for medical imaging;
- 5 - providing a second energy storage device (9) interconnected by a bi-directional energy transfer device (11) to the first energy storage device (SC), the bi-directional energy transfer device (11) transferring energy from the first energy storage device (SC) to the second energy storage (9) to provide energy to at least one auxiliary device of the X-ray generator (5), and/or
- transferring energy from the second energy storage device (9) to the first energy storage (SC) in the
10 absence of an energy supply from the electrical power network or mobile electrical power generator in order to provide energy to the X-ray generator (5) for generating X-rays for medical imaging.

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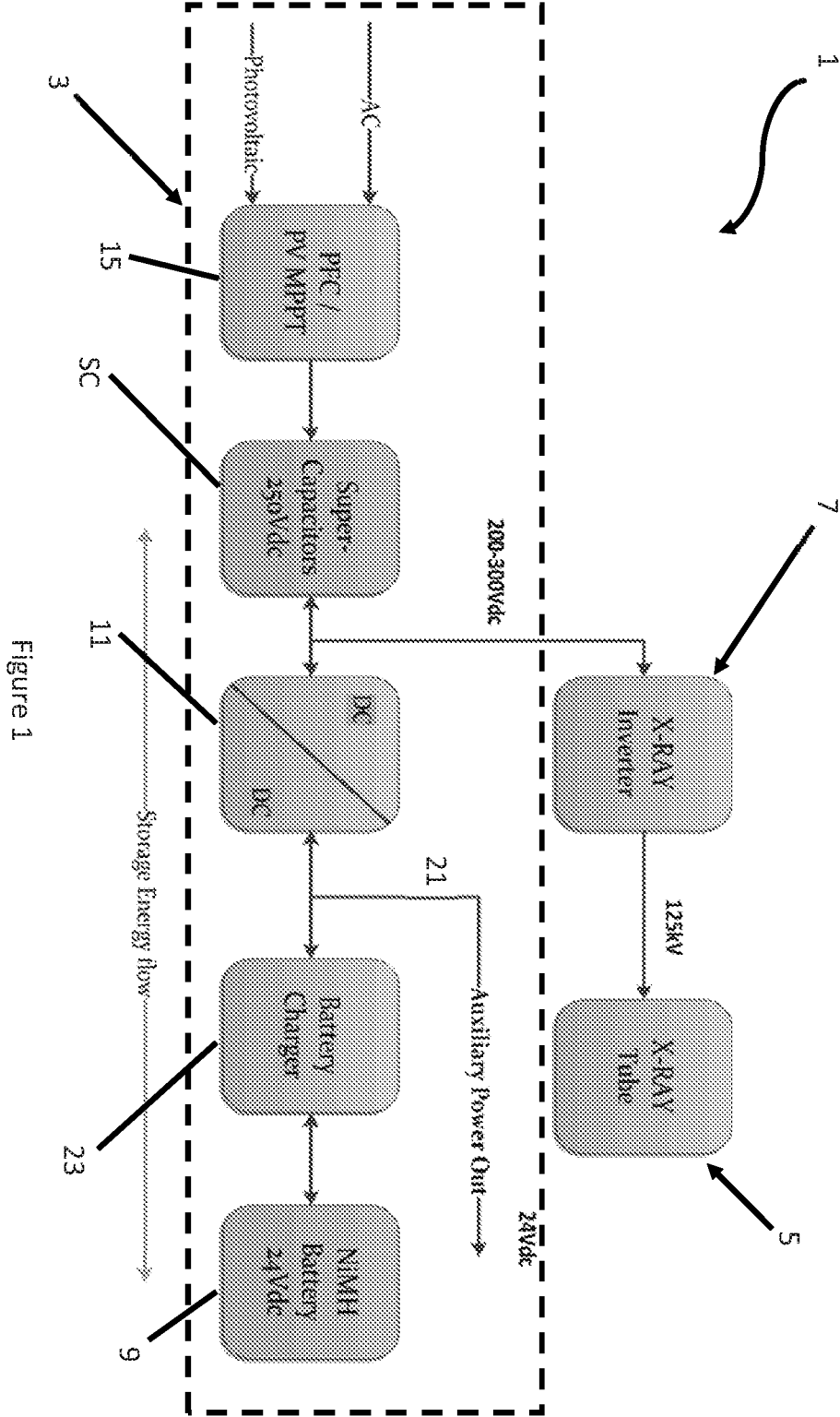


Figure 1

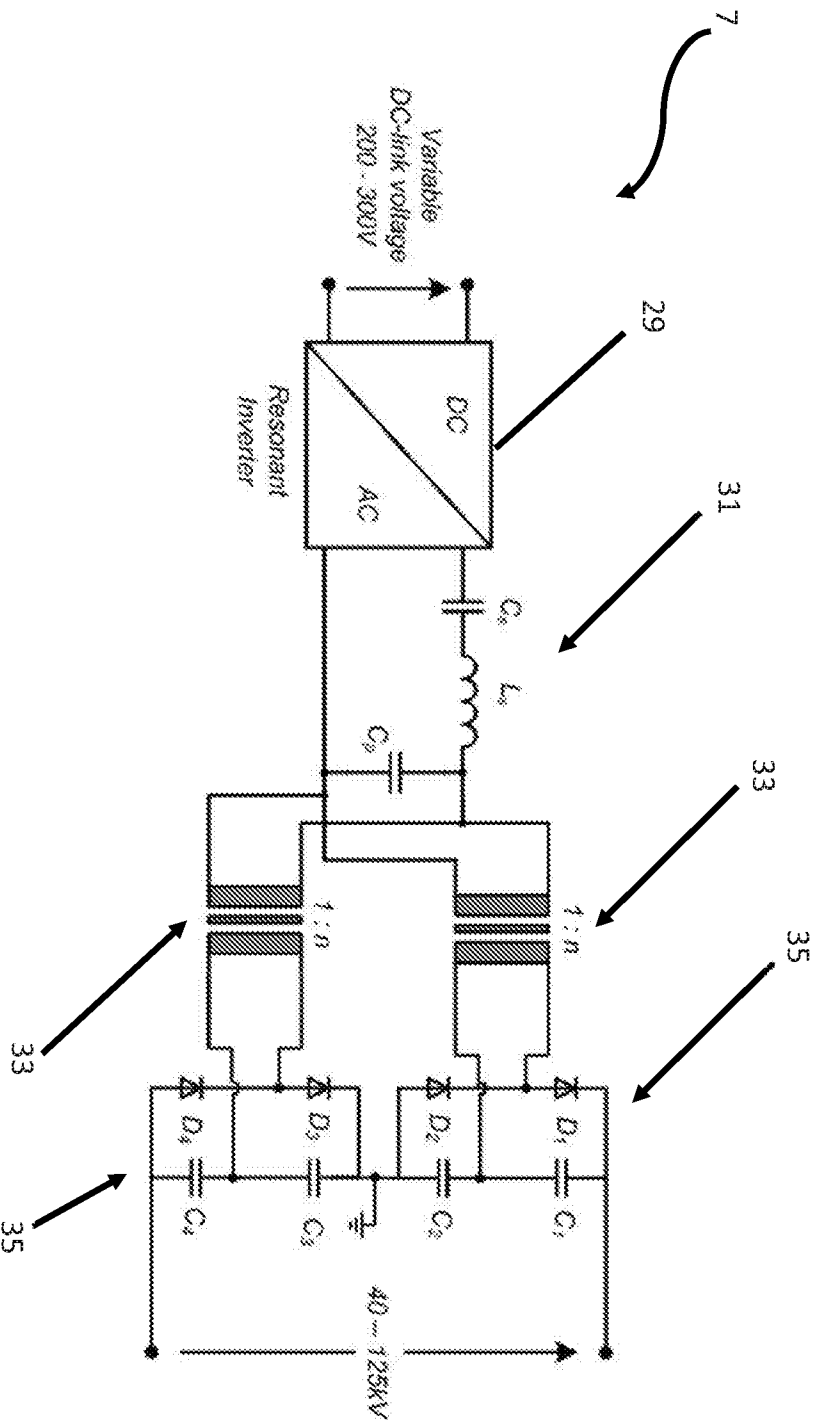


Figure 2

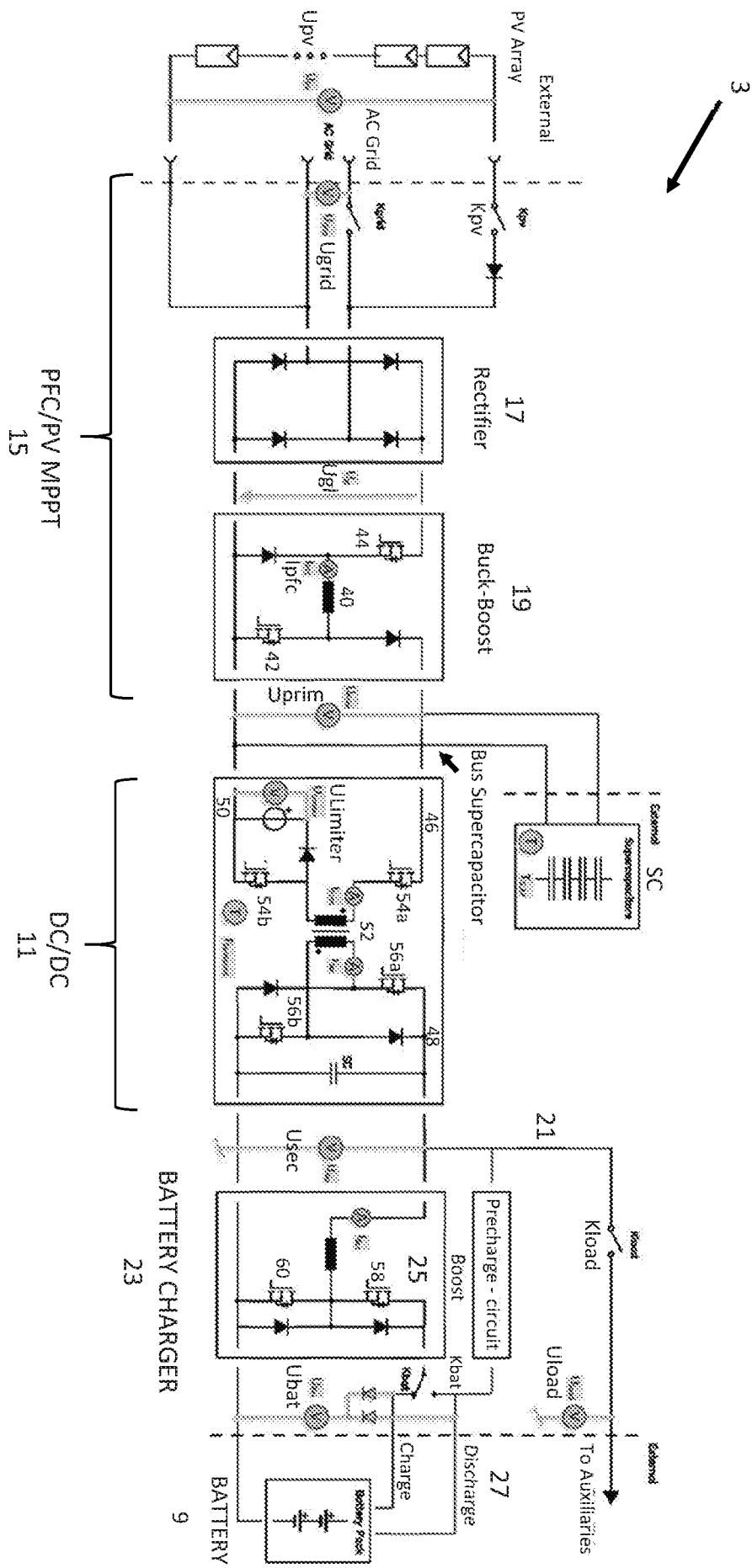


Figure 3