Resonant type power factor correction ac-dc converter and method for operating a resonant type power factor correction ac-dc converter

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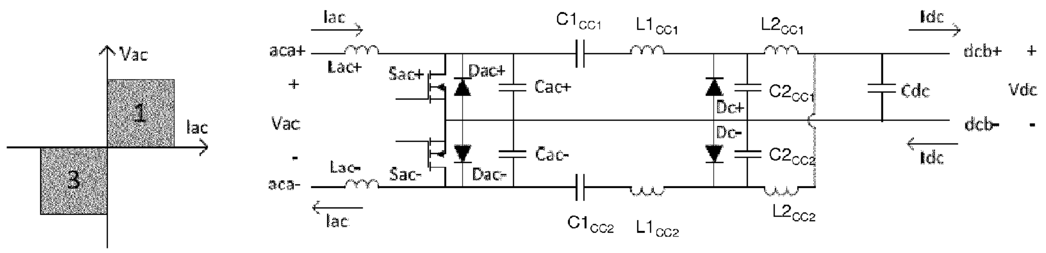

FIG. 3

(57) Abstract: The present disclosure relates to a resonant type power factor correction AC-DC converter comprising: an AC side circuit having a first AC connection (aca+) and a second AC connection (aca-) defining an AC side input port, wherein the first and second AC connection define an AC input voltage V_{ac} and an AC input current l_{ac} for the converter; a third AC connection (acb+) and a fourth AC connection (acb-) defining an internal AC coupling interface; and at least two AC power switch pairs comprising a diode and an active switch arranged in parallel, the at least two AC power switch pairs arranged between the AC side input port and the internal AC coupling interface; a DC side circuit having a first DC connection (dcb+) and a second DC connection (deb-) defining a DC side output port; a parallel DC side output capacitor (CDC); and a third DC connection (dca+) and a fourth DC connection (dca-) defining an internal DC coupling interface; a first coupling circuit (CC+) between the AC side circuit and the DC side circuit, connected to the third AC connection (acb+) and the third DC connection (dca+); a second coupling circuit (CC-) between the AC side circuit and the DC side circuit, connected to the fourth AC connection (acb-) and the third DC connection (dca+); wherein said first and second coupling circuits comprise: at least one coupling circuit diode, and resonant components configured to reduce switching losses in the AC power switch pairs and/or the at least one coupling circuit diode; a power factor control circuit configured to shape the AC input current l_{a_c} according to the AC input voltage V_{a_c}; and a control circuit configured to operate the resonant type power factor correction AC-DC converter in two different operation modes based on the polarity of the AC input voltage Vac and the AC input current lac by enabling only one of the

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first and second coupling circuits in each operation mode, the control circuit configured to control a resonant operation with resonant components in the first coupling circuit (CC+) in a first operation mode, wherein $V_{ac} > 0$ and $I_{ac} > 0$, the control circuit further configured to control a resonant operation with resonant components in the second coupling circuit (CC-) in a second operation mode, wherein $V_{ac} < 0$ and $I_{ac} < 0$. The present disclosure further elates to a method for operating a resonant type power factor correction AC-DC converter.

Resonant type power factor correction AC-DC converter and method for operating a resonant type power factor correction AC-DC converter

The present disclosure relates to an improved resonant type power factor correction AC-DC converter comprising an AC side circuit, a DC side circuit and two coupling circuits arranged between the AC side circuit and DC side circuit. The disclosure further relates to a method for operating a resonant type power factor correction AC-DC converter.

Background of invention

Switched mode circuits are widely used in a range of applications, notably for power supply purposes. Like other power supplies, a switched mode power supply may be operational to transfer power from an AC (alternating current) source (often mains power) to a DC load. Voltages are generated by performing an AC-DC conversion by operating a switch coupled to ideally lossless storage elements, such as inductors and capacitors. These systems can generally be considered to represent an efficient way of doing power conversions since the conversion is performed by controlled charging and discharging of relatively low-loss components.

It is, in general, desirable to address the efficiency of switched mode circuits, such as switched mode power supply circuits. High efficiency has always been a goal of power electronics, and efficiency goals for AC-DC converters continue to rise. Typical causes of power loss in a switched mode power supplies include switching losses, resistive losses in passive components and losses in the magnetic components.

Power factor of an AC electrical power system refers to the ratio of the real power flowing to the load to the apparent power in the circuit. More specifically, in AC-DC switched mode converters, a non-sinusoidal waveform is drawn, resulting in a phase angle between input current and voltage as well as distortion. When the current waveform does not follow the voltage waveform, it results in power losses. Active power factor correction (PFC) is the use of power electronics to change the waveform of current drawn by a load to improve the power factor. Some types of the active power factor correctors are buck, boost, and buck-boost. Active power factor correction can be single-stage or multi-stage.

Summary of invention

The present disclosure relates to a resonant type power factor correction AC-DC converter comprising:

- an AC side circuit having a first AC connection (aca+) and a second AC connection (aca-) defining an AC side input port, wherein the first and second AC connection define an AC input voltage V_{ac} and an AC input current I_{ac} for the converter; a third AC connection (acb+) and a fourth AC connection (acb-) defining an internal AC coupling interface; and at least two AC power switch pairs comprising a diode and an active switch arranged in parallel, the at least two AC power switch pairs arranged between the AC side input port and the internal AC coupling interface;
- a DC side circuit having a first DC connection (dcb+) and a second DC connection (deb-) defining a DC side output port; a parallel DC side output capacitor (CDC) ; and a third DC connection (dca+) and a fourth DC connection (dca-) defining an internal DC coupling interface;
- a first coupling circuit (CC+) between the AC side circuit and the DC side circuit, connected to the third AC connection (acb+) and the third DC connection (dca+);
- a second coupling circuit (CC-) between the AC side circuit and the DC side circuit, connected to the fourth AC connection (acb-) and the third DC connection (dca+); wherein said first and second coupling circuits comprise:
    - o at least one coupling circuit diode, and
    - o resonant components configured to reduce switching losses in the AC power switch pairs and/or the at least one coupling circuit diode,
- a power factor control circuit configured to shape the AC input current I_{ac} according to the AC input voltage V_{ac};
- a control circuit configured to operate the resonant type power factor correction AC-DC converter in two different operation modes based on the polarity of the AC input voltage V_{ac} and the AC input current I_{ac} by enabling only one of the first and second coupling circuits in each operation mode.

Fig. 1 (in the form of a block diagram) and fig. 3 show examples of the presently disclosed switched mode resonant type power factor correction AC-DC converter.

In the power factor correction mode the control circuit may be configured to shape the AC input current I_{ac} according to the AC input voltage V_{ac}. Thus, the resonant type power factor correction AC-DC converter may operate as an inverter and/or as a PFC rectifier. The control circuit may be configured to determine the power flow and which of the two two different operation modes resonant type power factor correction AC-DC converter shall operate in and control the coupling circuits and other components accordingly.

According to the first embodiment of the presently disclosed resonant type power factor correction AC-DC converter, the first and second coupling circuits comprise resonant components. It may be desirable to switch the transistors in the switching circuit when the voltage difference across the source and drain is at a minimum. Zero-voltage switching may be desirable to minimize energy waste in the transistors. ZVS can be used to improve the efficiency of the power converter and reduce stress in the switching transistors. Within the presently disclosed resonant type power factor correction AC-DC converter, the control circuit may be configured to, in a first operation mode, wherein V_{ac} >0 and I_{ac}>0, enable the first coupling circuit (CC+) and control a resonant operation with resonant components in the first coupling circuit (CC+) (fig. 4A), and, similarly, in a second operation mode, wherein V_{ac} <0 and I_{ac}<0, enable the second coupling circuit (CC-) and control a resonant operation with resonant components in the second coupling circuit (CC-) (fig. 4B). By embedding control of the resonant operation in this type of power factor correction AC-DC converter, and by configuring one of the switches in the two AC power switch pairs (one of Sac+, Sac-, figs. 4A-B) control the resonant operation, a more efficient converter, without the power loss caused by the two diodes that are conventionally used in rectifier of this type, is obtained. In the present invention only one of the coupling circuits is active.

The present disclosure further relates to a method for operating a resonant type power factor correction AC-DC converter, the converter comprising an AC side port having a first AC connection (aca+) and a second AC connection (aca-), the first and second AC connection defining an AC input voltage V_{ac} and an AC input current I_{ac}; a DC side port having a first DC connection (dcb+) and a second DC connection (deb-); a first and a second coupling circuit (CC+, CC-) arranged between the AC side port and the DC side port; at least two AC power switch pairs comprising a diode (Dac+, Dac-) and an active switch (Sac+, Sac-) arranged in parallel, the at least two AC power switch pairs preferably arranged between the AC side port and the first and second coupling circuits (CC+, CC-), said method comprising the steps of: in a first operation mode, wherein Vac>0 and lac>0: enabling the first coupling circuit (CC+), disabling the second coupling circuit (CC-) and using a first of the power switch pairs with the first coupling circuit (CC+) as a switched-mode AC-DC converter with a power flow from the AC side port to the DC side port, wherein a first switch (Sac+) controls a resonant operation with resonant components in the first coupling circuit (CC+);in a second operation mode, wherein Vac<0 and lac<0: disabling the first coupling circuit (CC+), enabling the second coupling circuit (CC-) and using a second of the power switch pairs with the second coupling circuit (CC-) as a switched-mode AC-DC converter with a power flow from the AC side port to the DC side port, wherein a second switch (Sac-) controls a resonant operation with resonant components in the second coupling circuit (CC-).

Preferably, the method further comprises the step of operating the resonant type power factor correction AC-DC converter in a normal mode and in a power factor correction mode.

'Arranged between', whether it refers to AC power switch pairs, coupling circuits or other components, shall be given the meaning that a component/block is arranged somewhere between two nodes or other components, not necessarily alone but optionally also in combination with additional components.

Description of drawings

Fig- 1 shows a block diagram of the presently disclosed resonant type power factor correction AC-DC converter.

Fig. 2A-B show two AC voltage polarity configurations of the presently disclosed resonant type power factor correction AC-DC converter.

Fig. 3 shows an embodiment of the presently disclosed resonant type power factor correction AC-DC converter.

Fig. 4A-B show two operation modes of the presently disclosed resonant type power factor correction AC-DC converter.

Fig. 5A-C show three different embodiments of the AC side circuit.

Fig. 6A-C show further embodiments of the AC side circuit with additional switches.

Fig. 7 shows an embodiment of the DC side circuit.

Fig. 8A-Q show embodiments of the coupling circuits.

Detailed description of the invention

The present disclosure relates to a resonant type power factor correction AC-DC converter comprising: an AC side circuit; a DC side circuit; first and second coupling circuits between the AC side circuit and DC side circuit. The AC side circuit comprises a first AC connection (aca+) and a second AC connection (aca-) defining an AC side port, wherein the first and second AC connection define an AC voltage V_{ac} and an AC current I_{ac} for the converter; a third AC connection (acb+) and a fourth AC connection (acb-) defining an internal AC coupling interface. Preferably the AC side circuit comprises at least two AC power switch pairs comprising a diode and an active switch arranged in parallel, wherein the at least two AC power switch pairs are arranged between the AC side port and the internal AC coupling interface. The active switches may be MOSFETs. ‘Arranged between’ means that the AC power switch pairs are arranged somewhere between the AC side port and the internal AC coupling interface, possibly in combination with additional components.

The DC side comprises a first DC connection (dcb+) and a second DC connection (deb-) defining a DC side port, and a third DC connection (dca+) and a fourth DC connection (dca-) defining an internal DC coupling interface. Preferably the DC side circuit comprises a parallel DC side output capacitor (CDC).

The first coupling circuit may be connected to the third AC connection (acb+) and the third DC connection (dca+).The second coupling circuit may be connected to the fourth AC connection (acb-) and the third DC connection (dca+). The first and second coupling circuits may comprise at least one coupling circuit diode, and preferably also resonant components configured to reduce switching losses in the AC power switch pairs and/or the at least one coupling circuit diode. The first and second coupling circuits operate in mutually exclusive configuration, wherein no current or power flows in the coupling circuit which is not enabled. A control circuit may be operable to control the resonant type power factor correction AC-DC converter to manage the two mutually exclusive configurations based on the AC voltage V_{ac} and an AC current I_{ac}. Preferably, the control circuit is configured to operate the resonant type power factor correction AC-DC converter in two different operation modes corresponding to combinations of polarity of the AC voltage V_{ac} and the AC current I_{ac} by enabling only one of the first and second coupling circuits. Preferably, the control circuit is further configured to operate the resonant type power factor correction AC-DC converter in a normal mode and a power factor correction mode. In the power factor correction mode the control circuit is preferably configured to shape the AC input current I_{ac} according to the AC input voltage V_{ac}.

AC reference

In order for the presently disclosed resonant type power factor correction AC-DC converter to function as described in the present disclosure, the arrangement may require an AC reference connection from the AC side circuit to the DC side circuit. The AC reference (acref) from the AC side circuit may be connected to the fourth DC connection (dca-) of the DC side circuit. The AC reference may be connected to ground as well as connected to a fifth AC connection (acref) of the AC side circuit. The AC reference may provide a reference voltage from a common coupling point node in the AC side circuit defined by a node connected to both the third AC connection (acb+) and a fourth AC connection (acb-) (internal AC coupling interfaces). The AC reference may be a reference voltage from a common coupling point node in the AC side circuit defined by a connection between nodes of the first and second AC inductors (Lac+, Lac-) beyond said AC inductors (Lac+, Lac-) in relation to the two AC power switch pairs, or defined by a connection between the first pair (Sac+, Dac+) of AC power switch pairs and the second pair (Sac-, Dac-) of AC power switch pairs. In a further embodiment the AC reference voltage is defined by a connection between a fifth pair (Sac1+, Dac1 +) of AC power switch pairs and a sixth pair (Sad-, Dad-) of AC power switch pairs. The AC reference may be connected to the fourth DC connection (dca-) or the second DC connection (deb-) of the DC side port and may serve as reference for both the path through the first and second coupling circuits in respective configurations.

AC side circuit - functionality, configurations, topology

In one embodiment of the presently disclosed resonant type power factor correction AC-DC converter, the AC side circuit may comprise a first pair (Sac+, Dac+) of AC power switch pairs comprising a first diode (Dac+) and a first switch (Sac+) and a second pair (Sac-, Dac-) of AC power switch pairs comprising a second diode (Dac-) and a second switch (Sac-). This embodiment is shown in fig. 3. The first pair (Sac+, Dac+) of AC power switch pairs may further comprise a serially coupled first AC inductor (Lac+). The second pair (Sac-, Dac-) of AC power switch pairs may accordingly further comprise a serially coupled second AC inductor (Lac-). The internal AC connections (acb+, acb-) towards the coupling circuits may correspond to nodes connected to the first and second pairs of the at least two AC power switch pairs.

One advantage of the presently disclosed resonant type power factor correction AC-DC converter is that it may be configured such that there is only one operating switching element and only one diode voltage drop at a time, wherein the resonant type power factor correction AC-DC converter is operable in two quadrants. In one embodiment the control circuit is therefore further configured to control the switches of the at least two AC power switches such that a first switch of the at least two AC power switch pairs is short circuited and a second switch of the at least two AC power switch pairs performs a switching process in an AC to DC power flow configuration.

In one embodiment of the presently disclosed resonant type power factor correction AC-DC converter, the first pair (Sac+, Dac+) of AC power switch pairs is arranged between the first AC connection (aca+) and the third AC connection (acb+), and the second pair (Sac-, Dac-) of AC power switch pairs is arranged between the second AC connection (aca-) and the fourth AC connection (acb-), as shown in fig. 5A. In another embodiment of the AC side circuit, as shown in fig. 5B, the AC side circuit further comprises a third AC power switch pair comprising a third diode (Dac2+) and a third active switch (Sac2+), and a fourth AC power switch pair comprising a fourth diode (Dac2-) and a fourth active switch (Sac2-), the third and fourth AC power switch pairs connected in series with the first and second AC power switch pairs, respectively. Optionally, only the third and fourth AC power switch pairs are present, as shown in fig. 5C.

DC side circuit

The DC side circuit has an outer DC interface comprising a first DC connection (dcb+) and a second DC connection (deb-) defining a DC side port, and an internal DC coupling interface towards the coupling circuits, said interface comprising a third DC connection (dca+) and a fourth DC connection (dca-). The DC side circuit preferably comprises a parallel DC side output capacitor (CDC) . In a preferred embodiment, the first DC connection (dcb+) is connected to the third DC connection (dca+), and the second DC connection (deb-) is connected to the fourth DC connection (dca-). The parallel DC side output capacitor (CDC) may thereby be arranged parallel with respect to both the DC side port and internal DC coupling interface.

Coupling circuits implementation details, resonant components

As stated above the first and second coupling circuits comprise at least one coupling circuit diode-switch pair, and resonant components configured to reduce switching losses in the AC power switch pairs and/or the at least one coupling circuit diode-switch pair.

The resonant components may be implemented in various embodiments and configurations, as shown in the examples of fig. 8A-Q. Typically the resonant operation is controlled by one of the switches in the AC side circuits. In one embodiment the resonant components of the first and second coupling circuits each comprise at least a first inductor ($L1_{Cci}$/ $L1_{CC_2}$) and a first capacitor ($C1_{cci}$/ $C1_{CC2}$) as shown in fig. 3. These resonant components may be arranged in series with the third AC connection (acb+) and fourth AC connection (acb-), respectively, on the AC side, and with a second inductor **($L2_{Cci}$/** $L2_{CC2}$), on the DC side. The resonant type power factor correction AC-DC converter may further comprise second capacitors **($C2_{Cci}$/ $C2_{Cc_2}$)** (in the first and second coupling circuits) arranged in parallel to the third AC connection (acb+) and the AC reference (acref) and the fourth AC connection (acb-) and the AC reference (acref), respectively. The second coupling capacitors **($C2_{Cci}$) ($C2_{Cc_2}$)** may be arranged in parallel with the first and second coupling circuit diodes (Dc+/Dc-). Preferably, the first coupling circuit and the second coupling circuit are identical and/or symmetrical with respect to the AC input voltage V_{ac}. The resonant components of the first and second coupling circuits may each comprise a second inductor **($L2_{Cci}$/ $L2_{CC2}$)** arranged in series with the third DC connection (dca+)

Modes of operation

The control circuit of the presently disclosed resonant type power factor correction AC-DC converter is configured to operate the converter in two different operation modes corresponding to combinations of polarity of the AC voltage V_{ac} and the AC current I_{ac} by enabling only one of the first and second coupling circuits.

With reference to an embodiment corresponding to fig. 3, or equivalent, the operation modes can be describes as follows:

1: The control circuit may be configured to, in a first operation mode, wherein $V_{ac} > 0$ and $I_{ac} > 0$, enable the first coupling circuit (CC+) and control a resonant operation with resonant components in the first coupling circuit (CC+). The first switch (Sac+) may thereby control the resonant operation. The second switch (Sac-) is short circuited (“on”) in this operation mode.

2: The control circuit may be configured to, in a second operation mode, wherein $V_{ac} < 0$ and $I_{ac} < 0$, enable the second coupling circuit (CC-) and control a resonant operation with resonant components in the second coupling circuit (CC-). The second switch

(Sac-) may thereby control the resonant operation. The first switch (Sac+) is short circuited ("on") in this operation mode.

'Power factor' refers generally to the ratio of the real power flowing to the load to the apparent power in an AC electrical power system. In a switched mode power supply a boost converter may be inserted between the bridge rectifier and the input capacitors in order to maintain a constant DC output while drawing a current that is in phase as the AC voltage. In the presently disclosed resonant type power factor correction AC-DC converter the control circuit may be configured to operate the resonant type power factor correction AC-DC converter in a normal mode and a power factor correction mode. In the power factor correction mode, power factor correction circuitry may be used to shape the AC input current I_{ac} according to the AC input voltage V_{ac}. Preferably the power factor correction circuitry is configured to maintain the AC input voltage and the AC input current substantially in phase.

The power factor correction may comprise integrated further support in the form of a voltage divider network for sensing the AC input voltage and/or circuitry for sensing the AC input current. Moreover, the resonant type power factor correction AC-DC converter may comprise an active inrush current circuit.

Method for operating a resonant type power factor correction AC-DC converter

The present disclosure further relates to a method for operating a resonant type power factor correction AC-DC converter as described above, wherein the converter comprises an AC side port, first and second coupling circuits and a DC side port. The AC side port has a first AC connection (aca+) and a second AC connection (aca-), the first and second AC connection defining an AC voltage V_{ac} and an AC current I_{ac}. The DC side port has a first DC connection (dcb+) and a second DC connection (deb-). The first and a second coupling circuit (CC+, CC-) are arranged between the AC side port and the DC side port. Preferably an AC side circuit comprises at least two AC power switch pairs comprising a diode (Dac+, Dac-) and an active switch (Sac+, Sac-) arranged in parallel, wherein the at least two AC power switch pairs arranged between the AC side port and the first and second coupling circuits (CC+, CC-).

In a first embodiment, the method comprises the steps of:

- in a first operation mode, wherein Vac>0 and Iac>0: enabling the first coupling circuit (CC+), disabling the second coupling circuit (CC-) and using a first of the power switch pairs with the first coupling circuit (CC+) as a switched-mode AC-DC converter with a power flow from the AC side port to the DC side port, wherein a first switch (Sac+) controls a resonant operation with resonant components in the first coupling circuit (CC+);

- in a second operation mode, wherein Vac<0 and Iac<0: disabling the first coupling circuit (CC+), enabling the second coupling circuit (CC-) and using a second of the power switch pairs with the second coupling circuit (CC-) as a switched-mode AC-DC converter with a power flow from the AC side port to the DC side port, wherein a second switch (Sac-) controls a resonant operation with resonant components in the second coupling circuit (CC-).

The method may be performed on any version of the presently disclosed resonant type power factor correction AC-DC converter, and may comprise the step of providing such a converter.

As described above, the control circuit of the resonant type power factor correction AC-DC converter may be further configured to operate the resonant type power factor correction AC-DC converter in a normal mode and a power factor correction mode. Consequently, the method for operating the resonant type power factor correction AC-DC converter may comprise the step of operating the resonant type power factor correction AC-DC converter in a normal mode and in a power factor correction mode. In the PFC mode, PFC circuitry may be configured to perform the step of shaping the AC input current I_{ac} according to the AC input voltage V_{ac} in the power factor correction mode in the first and second operation modes.

Detailed description of drawings

The invention will in the following be described in greater detail with reference to the accompanying drawings. The drawings are exemplary and are intended to illustrate some of the features of the presently disclosed resonant type power factor correction AC-DC converter, and are not to be construed as limiting to the presently disclosed invention.

Fig. 1 shows a block diagram of the presently disclosed resonant type power factor correction AC-DC converter comprising an AC side circuit, a DC side circuit, two coupling circuits and a control circuit.

Fig. 2A shows the disclosed resonant type power factor correction AC-DC converter, wherein the first coupling circuit is enabled/active and the second coupling circuit is inactive. This may be the case in operation mode 1. Fig. 2B shows the disclosed resonant type power factor correction AC-DC converter, wherein the second coupling circuit is enabled/active and the first coupling circuit is inactive. This may be the case in operation mode 2.

Fig. 3 shows an embodiment of the presently disclosed resonant type power factor correction AC-DC converter. The AC side circuit comprises a first pair (Sac+, Dac+) of AC power switch pairs and a second pair (Sac-, Dac-) of AC power switch pairs and AC capacitors (Cac+/Cac-) in parallel with the first and second pairs of AC power switch pairs, respectively. The AC side circuit of this example further comprises a serially coupled first AC inductor (Lac+) and a serially coupled second AC inductor (Lac-). The DC side circuit has an output capacitor (CDC) in parallel with the DC side port. The first coupling circuit (CC+) comprises a first coupling circuit diode (Dc+) and the second coupling circuit (CC-) comprises a second coupling circuit diode (Dc-). Each coupling circuit comprises a number of resonant components: fist coupling circuit (CC+): C1cci, L1cci, $C2_{C}$ci, $L2_{C}$ci; second coupling circuit (CC-): $1cc_{2}$, $L1_{CC2}$, $C2_{C}c_{2}$, L2CC2-

Fig. 4A-B show two operation modes of the presently disclosed resonant type power factor correction AC-DC converter. Fig. 4A shows the operation for Vac>0 and lac>0. The switch Sac+ controls the resonant operation. As Sac-=on the second coupling circuit (CC-) is inactive. Fig. 4B shows the operation for Vac<0 and lac<0. The switch Sac- controls the resonant operation. As Sac+ =on the first coupling circuit (CC+) is inactive.

Fig. 5A-C show three different embodiments of the AC side circuit. In fig. 5B there are additional third and fourth AC power switch pairs compared to fig. 5A. The third and fourth AC power switch pairs are arranged in series in relation to aca+ and aca-. In fig. 5C only the third and fourth AC power switch pairs are present and not the first and second AC power switch pairs.

Fig. 6A-C show further embodiments of the AC side circuit with additional diode-switch pairs with switches (Sr+, Sr-). The additional switches are only operated at the AC-side frequency, thus reducing switch losses, whereas the other switches preferably operate at a higher and resonant switching frequency.

Examples

The following examples are intended to explain possible operations for different embodiments of the presently disclosed resonant type power factor correction AC-DC converter. Table 1 represents a possible operation of the resonant type power factor correction AC-DC converter having an AC side circuit corresponding to that of fig. 5A or 6A. Table 2 represents a possible operation of the resonant type power factor correction AC-DC converter having an AC side circuit corresponding to that of fig. 5B or 6B. Table 3 represents a possible operation of the resonant type power factor correction AC-DC converter having an AC side circuit corresponding to that of fig. 5C or 6C.

Quadrant	Vac	Iac	Sr+	Sr-	Sac+	Sac-
1	>0	>0	off	on	res.sw.	on
2	>0	<0	off	on	off (sync.rec)	on
3	<0	<0	on	off	on	res.sw.
4	<0	>0	on	off	on	off (sync.rec.)

Table 1

Quadrant	Vac	Iac	Sr+	Sr-	Sac1+	Sac1-	Sac2+	Sac2-
1	>0	>0	off	on	res.sw1.	on	res.sw2.	on
2	>0	<0	off	on	off (sync.rec)	on	off (sync.rec)	on
3	<0	<0	on	off	on	res.sw1.	on	res.sw2.
4	<0	>0	on	off	on	off (sync.rec.)	on	off (sync.rec.)

Table 2

Quadrant	Vac	Iac	Sr+	Sr-	Sac2+	Sac2-
1	>0	>0	off	on	res.sw2.	on
2	>0	<0	off	on	off (sync.rec)	on
3	<0	<0	on	off	on	res.sw2.
4	<0	>0	on	off	on	off (sync.rec.)

Table 3

Further details of the invention

1. A resonant type power factor correction AC-DC converter comprising:
   - an AC side circuit having a first AC connection (aca+) and a second AC connection (aca-) defining an AC side input port, wherein the first and second AC connection define an AC input voltage V_{ac} and an AC input current I_{ac} for the converter; a third AC connection (acb+) and a fourth AC connection (acb-) defining an internal AC coupling interface; and at least two AC power switch pairs comprising a diode and an active switch arranged in parallel, the at least two AC power switch pairs arranged between the AC side input port and the internal AC coupling interface;
   - a DC side circuit having a first DC connection (dcb+) and a second DC connection (deb-) defining a DC side output port; a parallel DC side output capacitor (CDC) ; and a third DC connection (dca+) and a fourth DC connection (dca-) defining an internal DC coupling interface;
   - a first coupling circuit (CC+) between the AC side circuit and the DC side circuit, connected to the third AC connection (acb+) and the third DC connection (dca+);
   - a second coupling circuit (CC-) between the AC side circuit and the DC side circuit, connected to the fourth AC connection (acb-) and the third DC connection (dca+);

     wherein said first and second coupling circuits comprise:
     - at least one coupling circuit diode, and
     - resonant components configured to reduce switching losses in the AC power switch pairs and/or the at least one coupling circuit diode,

- a power factor control circuit configured to shape the AC input current I_{ac} according to the AC input voltage V_{ac};
- a control circuit configured to operate the resonant type power factor correction AC-DC converter in two different operation modes based on the polarity of the AC input voltage V_{ac} and the AC input current I_{ac} by enabling only one of the first and second coupling circuits in each operation mode.

2. The resonant type power factor correction AC-DC converter according to any of the preceding items, wherein the AC side circuit comprises a first pair (Sac+, Dac+) of AC power switch pairs comprising a first diode (Dac+) and a first switch (Sac+) and a second pair (Sac-, Dac-) of AC power switch pairs comprising a second diode (Dac-) and a second switch (Sac-).

3. The resonant type power factor correction AC-DC converter according to item 2, wherein the first pair (sac+, Dac+) of AC power switch pairs further comprises a serially coupled first AC inductor (Lac+) and the second pair (sac-, Dac-) of AC power switch pairs further comprises a serially coupled second AC inductor (Lac-).

4. The resonant type power factor correction AC-DC converter according to any of the preceding items, further comprising an AC reference (acref) from the AC side circuit connected to the fourth DC connection (dca-) or the second DC connection (deb-) of the DC side circuit.

5. The resonant type power factor correction AC-DC converter according to item 4, wherein the AC reference represents a reference voltage from a common coupling point node in the AC side circuit defined by a connection between nodes of the first and second AC inductors (Lac+, Lac-) beyond said AC inductors (Lac+, Lac-) in relation to the two AC power switch pairs, or defined by a connection between the first pair (Sac+, Dac+) of AC power switch pairs and the second pair (Sac-, Dac-) of AC power switch pairs, or defined by a connection between a fifth pair (Sac1 +, Dac1+) of AC power switch pairs and a sixth pair (Sad-, Dad-) of AC power switch pairs.

6. The resonant type power factor correction AC-DC converter according to any of the preceding items, wherein the resonant components of the first and second

coupling circuits each comprise at least a first inductor ($L1_{CC1}$/ $L1_{CC2}$) and a first capacitor ($C1_{CC1}$/ $C1_{CC2}$).

7. The resonant type power factor correction AC-DC converter according to item 6, wherein the first inductor ($L1_{CC1}$/ $L1_{CC2}$) and first capacitor ($C1_{CC1}$/ $C1_{CC2}$) are arranged in series with the third AC connection (acb+) and fourth AC connection (acb-), respectively.

8. The resonant type power factor correction AC-DC converter according to item 4, wherein the resonant components of the first and second coupling circuits each comprise a second capacitor ($C2_{CC1}$/ $C2_{CC2}$) arranged in parallel to the third AC connection (acb+) and the AC reference (acref) and the fourth AC connection (acb-) and the AC reference (acref), respectively, optionally wherein the resonant components of the first and second coupling circuits each comprise a second inductor ($L2_{CC1}$/ $L2_{CC2}$) arranged in series with the third DC connection (dca+).

9. The resonant type power factor correction AC-DC converter according to any of the preceding items, wherein the control circuit is configured to, in a first operation mode, wherein $V_{ac}>0$ and $I_{ac}>0$, enable the first coupling circuit (CC+) and control a resonant operation in resonant components in the first coupling circuit (CC+).

10. The resonant type power factor correction AC-DC converter according to items 2 and 9, wherein the first switch (Sac+) controls the resonant operation.

11. The resonant type power factor correction AC-DC converter according to any of items 9-10, wherein the second switch (Sac-) is inactive, short circuited in the first operation mode.

12. The resonant type power factor correction AC-DC converter according to any of the preceding items, wherein the control circuit is configured to, in a second operation mode, wherein $V_{ac}<0$ and $I_{ac}<0$, enable the second coupling circuit (CC-) and control a resonant operation in resonant components in the second coupling circuit (CC-).

13. The resonant type power factor correction AC-DC converter according to any of items 2 and 12, wherein the second switch (Sac-) controls the resonant operation.

14. The resonant type power factor correction AC-DC converter according to any of items 12-13, wherein the first switch (Sac+) is inactive, short circuited in the second operation mode.

15. The resonant type power factor correction AC-DC converter according to any of the preceding items, wherein the control circuit comprises power factor correction circuitry configured to shape the AC input current I_{ac} according to the AC input voltage V_{ac} in the power factor correction mode.

16. The resonant type power factor correction AC-DC converter according to item 15, wherein the power factor correction circuitry comprises a voltage divider network for sensing the AC input voltage and/or circuitry for sensing the AC input current.

17. The resonant type power factor correction AC-DC converter according to any of items 15-16, wherein the power factor correction circuitry is configured to maintain the AC input voltage and the AC input current substantially in phase.

18. The resonant type power factor correction AC-DC converter according to any of the preceding items, wherein the AC side circuit and DC side circuit are galvanic isolated.

19. The resonant type power factor correction AC-DC converter according to any of the preceding items, wherein the first pair (Sac+, Dac+) of AC power switch pairs is arranged between the first AC connection (aca+) and the third AC connection (acb+), and wherein the second pair (Sac-, Dac-) of AC power switch pairs is arranged between the second AC connection (aca-) and the fourth AC connection (acb-).

20. The resonant type power factor correction AC-DC converter according to any of the preceding items, wherein the AC side circuit further comprises a third AC power switch pair comprising a third diode (Dac2+) and a third active switch

(Sac2+), and a fourth AC power switch pair comprising a fourth diode (Dac2-) and a fourth active switch (Sac2-), the third and fourth AC power switch pairs connected in series with the first and second AC power switch pairs, respectively.

21. The resonant type power factor correction AC-DC converter according to any of the preceding items, wherein the first DC connection (dcb+) is connected to the third DC connection (dca+), and wherein the second DC connection (deb-) is connected to the fourth DC connection (dca-), and wherein the parallel DC side output capacitor (CDC) is arranged parallel with respect to both the DC side port and internal DC coupling interface.

22. The resonant type power factor correction AC-DC converter according to any of the preceding items, wherein each first coupling circuit comprises at least one coupling circuit diode (Dc+/Dc-), and a first coupling capacitor (C1 cci/ $C1cc_2$) connected to the third AC connection (acb+) and fourth AC connection (acb-), respectively.

23. The resonant type power factor correction AC-DC converter according to any of the preceding items, wherein the second capacitors ($C2_C$ci, $C2_Cc_2$) are arranged in parallel with first and second coupling circuit diodes (Dc+, Do-) .

24. The resonant type power factor correction AC-DC converter according to any of the preceding items, wherein the first coupling circuit and the second coupling circuit are identical.

25. The resonant type power factor correction AC-DC converter according to any of the preceding items, wherein the AC side circuit and/or the first and second coupling circuits is/are symmetrical with respect to the AC input voltage V_{ac}.

26. The resonant type power factor correction AC-DC converter according to any of the preceding items, wherein only one active switch at each point in time performs the resonant operation.

27. The resonant type power factor correction AC-DC converter according to any of the preceding items, wherein a voltage across the first switch (Sac+) and the

first coupling circuit diode (Dc+) has approximately the shape of a single way rectified sinusoid.

28. The resonant type power factor correction AC-DC converter according to any of the preceding items, wherein a voltage across the second switch (Sac-) and the second coupling circuit diode (Dc-) has approximately the shape of a single way rectified sinusoid.

29. The resonant type power factor correction AC-DC converter according to any of the preceding items, wherein the first and second coupling circuits operate in mutually exclusive configuration, wherein no current or power flows in the coupling circuit which is not enabled.

30. A method for operating a resonant type power factor correction AC-DC converter, the converter comprising an AC side port having a first AC connection (aca+) and a second AC connection (aca-), the first and second AC connection defining an AC input voltage V_{ac} and an AC input current I_{ac}; a DC side port having a first DC connection (dcb+) and a second DC connection (deb-); a first and a second coupling circuit (CC+, CC-) arranged between the AC side port and the DC side port; at least two AC power switch pairs comprising a diode (Dac+, Dac-) and an active switch (Sac+, Sac-) arranged in parallel, the at least two AC power switch pairs preferably arranged between the AC side port and the first and second coupling circuits (CC+, CC-), said method comprising the steps of:

- in a first operation mode, wherein Vac>0 and Iac>0: enabling the first coupling circuit (CC+), disabling the second coupling circuit (CC-) and using a first of the power switch pairs with the first coupling circuit (CC+) as a switched-mode AC-DC converter with a power flow from the AC side port to the DC side port, wherein a first switch (Sac+) controls a resonant operation with resonant components in the first coupling circuit (CC+);
- in a second operation mode, wherein Vac<0 and Iac<0: disabling the first coupling circuit (CC+), enabling the second coupling circuit (CC-) and using a second of the power switch pairs with the second coupling circuit (CC-) as a switched-mode AC-DC converter with a power flow from the AC side port to the DC side port, wherein a second switch (Sac-) controls a resonant operation with resonant components in the second coupling circuit (CC-).

31. The method for operating a resonant type power factor correction AC-DC converter according to item 30, further comprising the step of operating the resonant type power factor correction AC-DC converter in a normal mode and in a power factor correction mode.

32. The method for operating a resonant type power factor correction AC-DC converter according to any of items 30-31 , comprising the step of shaping the AC input current I_{ac} according to the AC input voltage V_{ac} in the power factor correction mode in the first and second operation modes.

33. The method for operating a resonant type power factor correction AC-DC converter according to any of items 30-32, wherein the resonant type power factor correction AC-DC converter is a resonant type power factor correction AC-DC converter according to any items 1-29.

Claims

1. A resonant type power factor correction AC-DC converter comprising:
   - an AC side circuit having a first AC connection (aca+) and a second AC connection (aca-) defining an AC side input port, wherein the first and second AC connection define an AC input voltage V_{ac} and an AC input current I_{ac} for the converter; a third AC connection (acb+) and a fourth AC connection (acb-) defining an internal AC coupling interface; and at least two AC power switch pairs comprising a diode and an active switch arranged in parallel, the at least two AC power switch pairs arranged between the AC side input port and the internal AC coupling interface;
   - a DC side circuit having a first DC connection (dcb+) and a second DC connection (deb-) defining a DC side output port; a parallel DC side output capacitor (CDC) ; and a third DC connection (dca+) and a fourth DC connection (dca-) defining an internal DC coupling interface;
   - a first coupling circuit (CC+) between the AC side circuit and the DC side circuit, connected to the third AC connection (acb+) and the third DC connection (dca+);
   - a second coupling circuit (CC-) between the AC side circuit and the DC side circuit, connected to the fourth AC connection (acb-) and the third DC connection (dca+);

     wherein said first and second coupling circuits comprise:
     - at least one coupling circuit diode, and
     - resonant components configured to reduce switching losses in the AC power switch pairs and/or the at least one coupling circuit diode,
   - a power factor control circuit configured to shape the AC input current I_{ac} according to the AC input voltage V_{ac};
   - a control circuit configured to operate the resonant type power factor correction AC-DC converter in two different operation modes based on the polarity of the AC input voltage V_{ac} and the AC input current I_{ac} by enabling only one of the first and second coupling circuits in each operation mode, the control circuit configured to control a resonant operation with resonant components in the first coupling circuit (CC+) in a first operation mode, wherein $V_{ac}>0$ and $I_{ac}>0$, the control circuit further configured to control a

resonant operation with resonant components in the second coupling circuit (CC-) in a second operation mode, wherein $V_{ac}<0$ and $I_{ac}<0$.

2. The resonant type power factor correction AC-DC converter according to any of the preceding claims, wherein the AC side circuit comprises a first pair (Sac+, Dac+) of AC power switch pairs comprising a first diode (Dac+) and a first switch (Sac+) and a second pair (Sac-, Dac-) of AC power switch pairs comprising a second diode (Dac-) and a second switch (Sac-), wherein the first switch (Sac+) controls the resonant operation with resonant components in the first coupling circuit (CC+), and wherein the second switch (Sac-) controls a resonant operation with resonant components in the second coupling circuit (CC-).

3. The resonant type power factor correction AC-DC converter according to any of the preceding claims, further comprising an AC reference (acref) from the AC side circuit connected to the fourth DC connection (dca-) or the second DC connection (deb-) of the DC side circuit.

4. The resonant type power factor correction AC-DC converter according to claim 4, wherein the AC reference represents a reference voltage from a common coupling point node in the AC side circuit defined by a connection between nodes of the first and second AC inductors (Lac+, Lac-) beyond said AC inductors (Lac+, Lac-) in relation to the two AC power switch pairs, or defined by a connection between the first pair (Sac+, Dac+) of AC power switch pairs and the second pair (Sac-, Dac-) of AC power switch pairs, or defined by a connection between a fifth pair (Sac1 +, Dac1+) of AC power switch pairs and a sixth pair (Sad-, Dad-) of AC power switch pairs.

5. The resonant type power factor correction AC-DC converter according to any of the preceding claims, wherein the resonant components of the first and second coupling circuits each comprise at least a first inductor ($L1_{C}ci$/ $L1_{CC2}$) and a first capacitor (C1 cci/ $C1_{CC2}$), wherein the first inductor (L1 cci/ $L1_{CC2}$) and first capacitor (C1 cci/ $C1cc_2$) are arranged in series with the third AC connection (acb+) and fourth AC connection (acb-), respectively.

6. The resonant type power factor correction AC-DC converter according to any of the preceding claims, wherein the control circuit is configured to, in a first operation mode, wherein $V_{ac} > 0$ and $I_{ac} > 0$, enable the first coupling circuit (CC+) and control a resonant operation in resonant components in the first coupling circuit (CC+).

7. The resonant type power factor correction AC-DC converter according to claims 2 and 6, wherein the first switch (Sac+) controls the resonant operation.

8. The resonant type power factor correction AC-DC converter according to any of the preceding claims, wherein the control circuit is configured to, in a second operation mode, wherein $V_{ac} < 0$ and $I_{ac} < 0$, enable the second coupling circuit (CC-) and control a resonant operation in resonant components in the second coupling circuit (CC-).

9. The resonant type power factor correction AC-DC converter according to any of claims 2 and 8, wherein the second switch (Sac-) controls the resonant operation.

10. The resonant type power factor correction AC-DC converter according to any of the preceding claims, wherein the control circuit comprises power factor correction circuitry configured to shape the AC input current I_{ac} according to the AC input voltage V_{ac} in the power factor correction mode.

11. The resonant type power factor correction AC-DC converter according to any of the preceding claims, wherein the AC side circuit and DC side circuit are galvanic isolated.

12. The resonant type power factor correction AC-DC converter according to any of the preceding claims, wherein the first pair (Sac+, Dac+) of AC power switch pairs is arranged between the first AC connection (aca+) and the third AC connection (acb+), and wherein the second pair (Sac-, Dac-) of AC power switch pairs is arranged between the second AC connection (aca-) and the fourth AC connection (acb-).

13. The resonant type power factor correction AC-DC converter according to any of the preceding claims, wherein the first and second coupling circuits operate in mutually exclusive configuration, wherein no current or power flows in the coupling circuit which is not enabled.

14. A method for operating a resonant type power factor correction AC-DC converter, the converter comprising an AC side port having a first AC connection (aca+) and a second AC connection (aca-), the first and second AC connection defining an AC input voltage V_{ac} and an AC input current I_{ac}; a DC side port having a first DC connection (dcb+) and a second DC connection (deb-); a first and a second coupling circuit (CC+, CC-) arranged between the AC side port and the DC side port; at least two AC power switch pairs comprising a diode (Dac+, Dac-) and an active switch (Sac+, Sac-) arranged in parallel, the at least two AC power switch pairs preferably arranged between the AC side port and the first and second coupling circuits (CC+, CC-), said method comprising the steps of:

- in a first operation mode, wherein Vac>0 and lac>0: enabling the first coupling circuit (CC+), disabling the second coupling circuit (CC-) and using a first of the power switch pairs with the first coupling circuit (CC+) as a switched-mode AC-DC converter with a power flow from the AC side port to the DC side port, wherein a first switch (Sac+) controls a resonant operation with resonant components in the first coupling circuit (CC+);
- in a second operation mode, wherein Vac<0 and lac<0: disabling the first coupling circuit (CC+), enabling the second coupling circuit (CC-) and using a second of the power switch pairs with the second coupling circuit (CC-) as a switched-mode AC-DC converter with a power flow from the AC side port to the DC side port, wherein a second switch (Sac-) controls a resonant operation with resonant components in the second coupling circuit (CC-).

15. The method for operating a resonant type power factor correction AC-DC converter according to claim 14, further comprising the step of operating the resonant type power factor correction AC-DC converter in a normal mode and in a power factor correction mode.

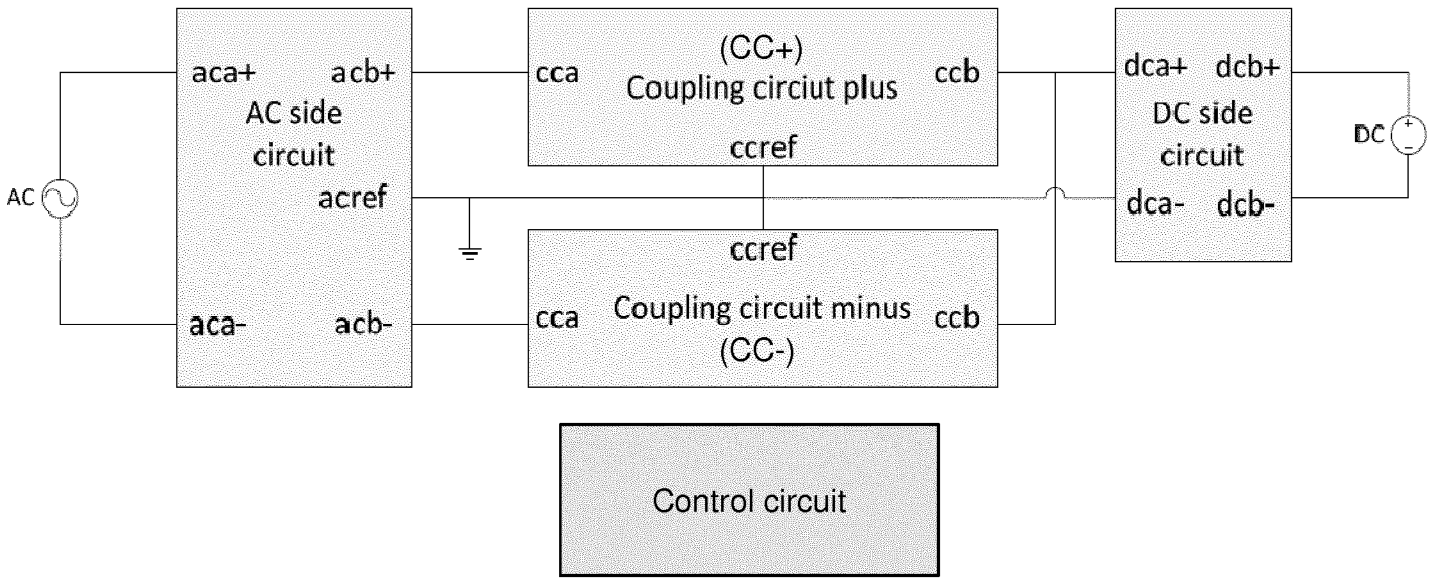
aca+
acb+
AC side
circuit
acref
aca-
acb-
AC
cca
(CC+)
Coupling circiut plus
ccb
ccref
ccref
cca
Coupling circuit minus
(CC-)
ccb
dca+
dcb+
DC side
circuit
dca-
dcb-
DC
Control circuit

FIG. 1

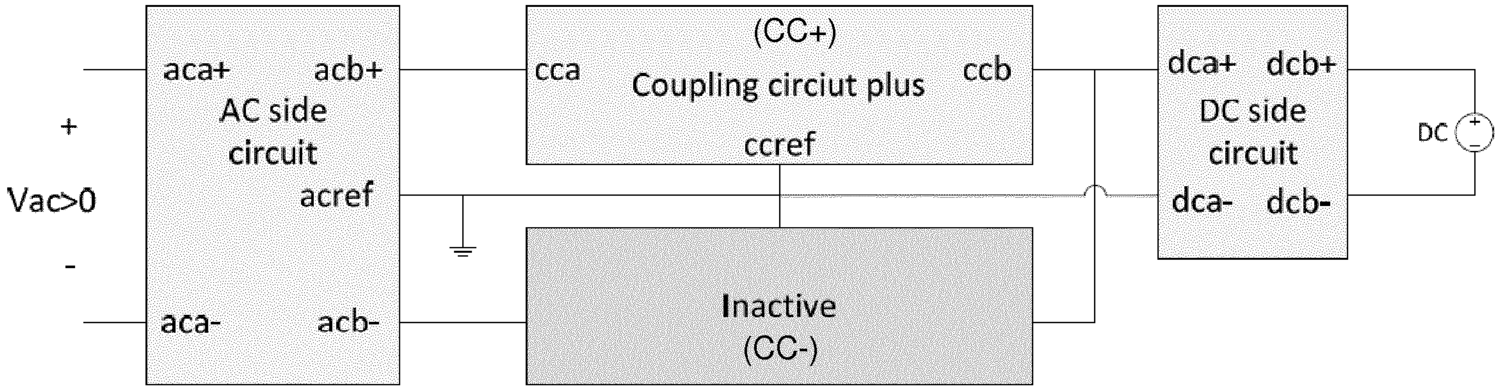
aca+
acb+
AC side circuit
acref
aca-
acb-
+
Vac>0
-
cca
(CC+)
Coupling circiut plus
ccb
ccref
Inactive
(CC-)
dca+
dcb+
DC side circuit
dca-
dcb-
DC

FIG. 2A

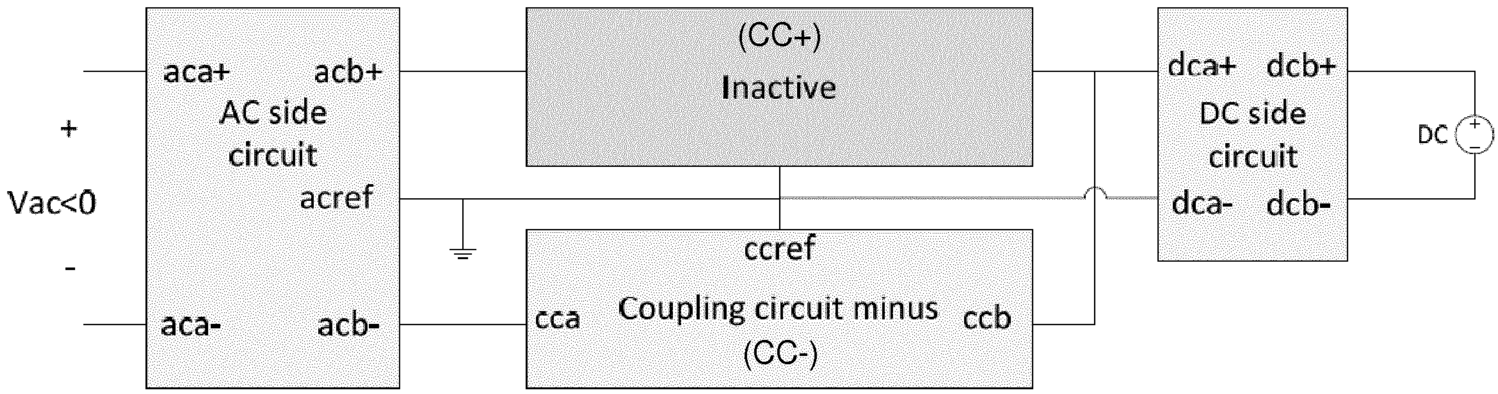
aca+
acb+
AC side circuit
acref
aca-
acb-
+
Vac<0
-
(CC+)
Inactive
ccref
cca
Coupling circuit minus
ccb
(CC-)
dca+
dcb+
DC side circuit
dca-
dcb-
DC

FIG. 2B

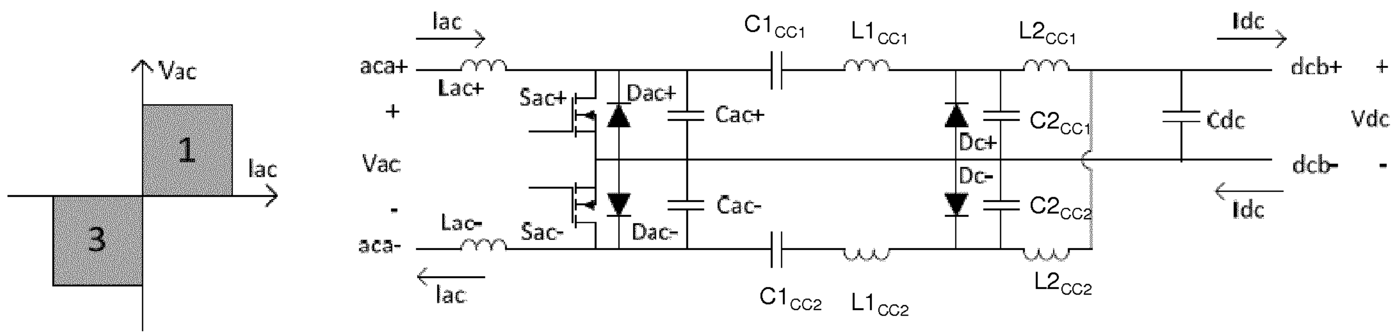

FIG. 3

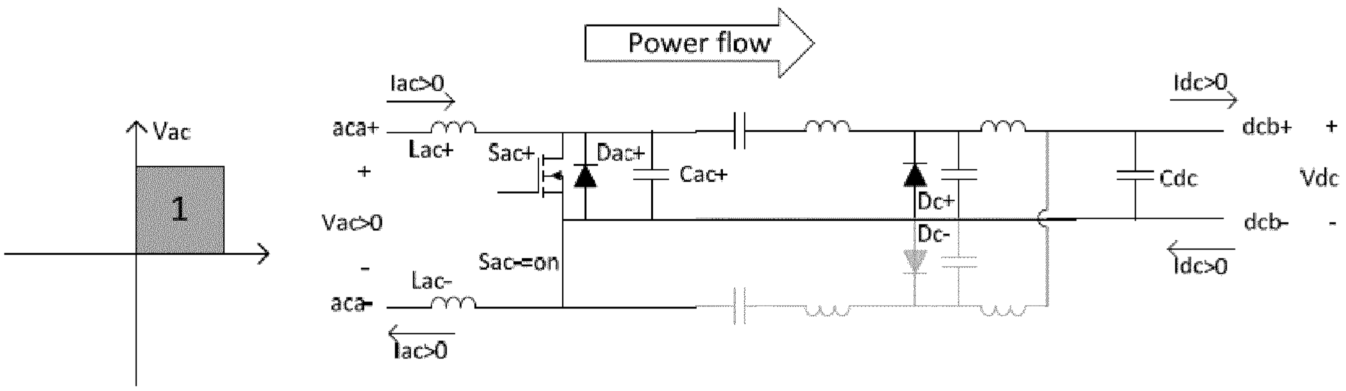

FIG. 4A

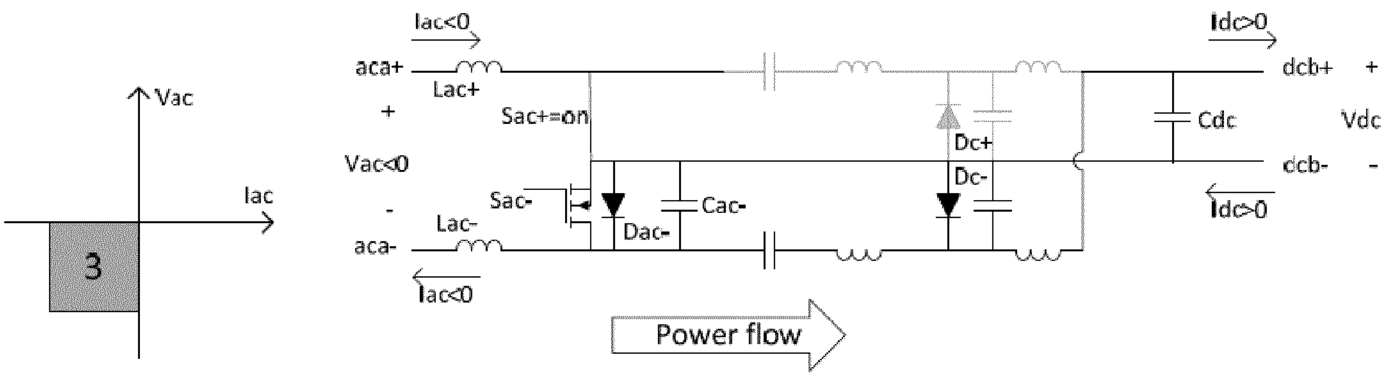

FIG. 4B

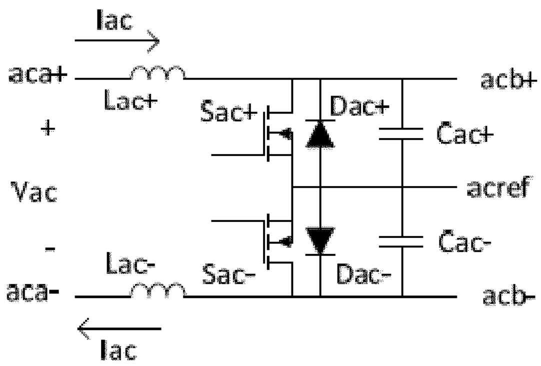

FIG. 5A

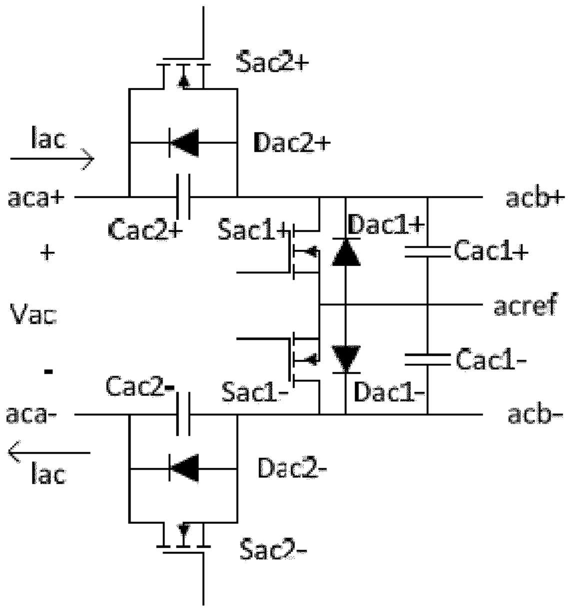

FIG. 5B

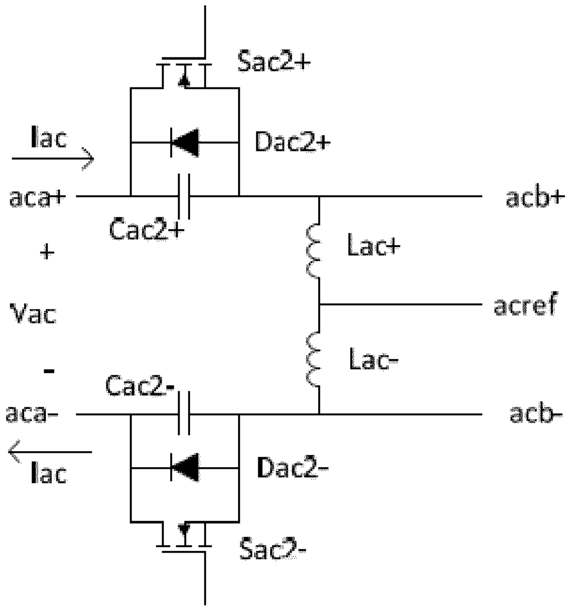

FIG. 5C

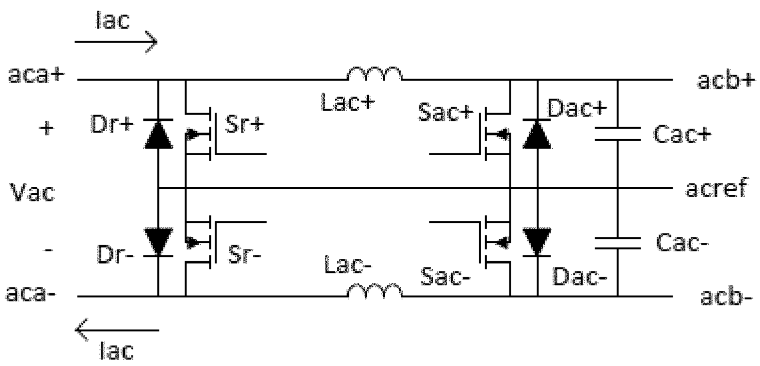

FIG. 6A

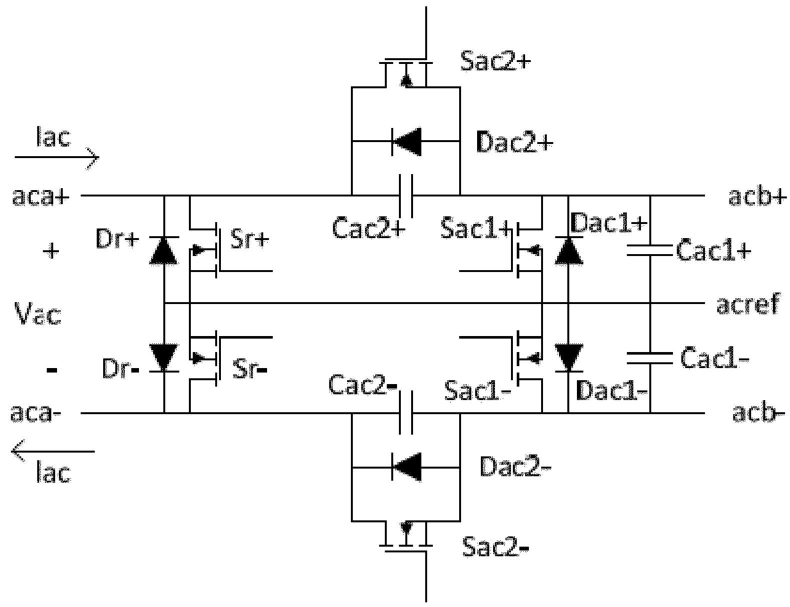

FIG. 6B

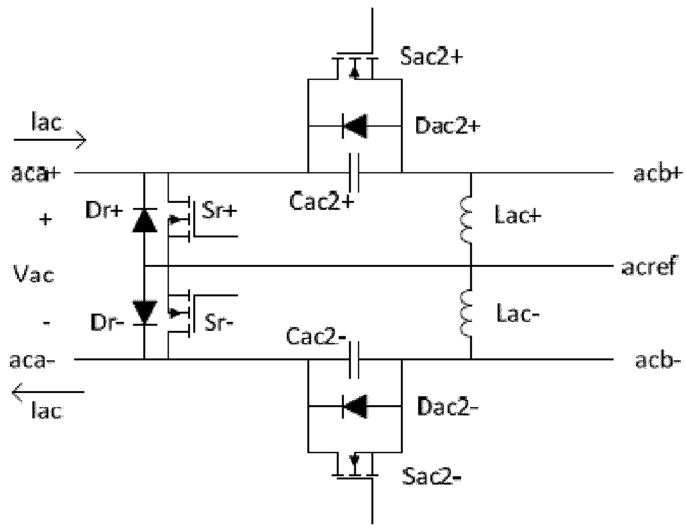

FIG. 6C

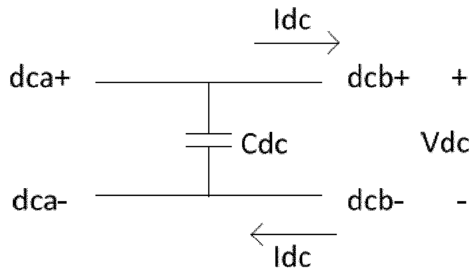

FIG. 7

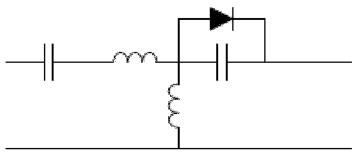

FIG. 8A

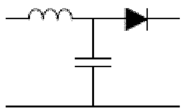

FIG. 8B

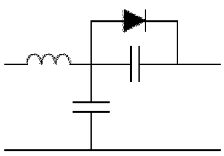

FIG. 8C

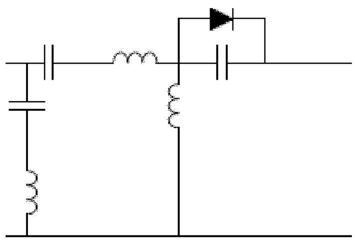

FIG. 8D

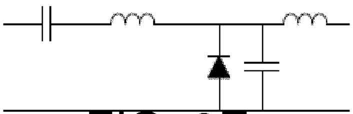

FIG. 8E

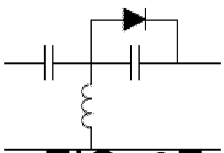

FIG. 8F

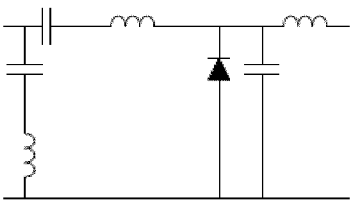

FIG. 8G

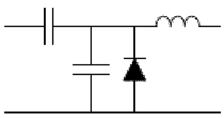

FIG. 8H

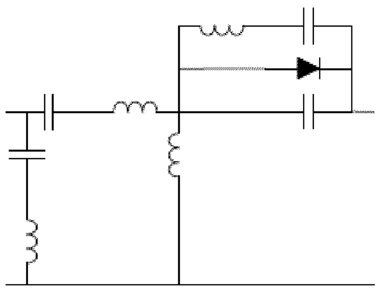

FIG. 8I

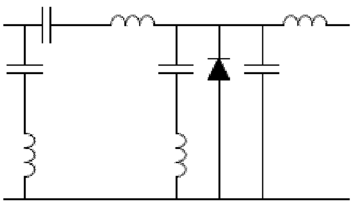

FIG. 8J

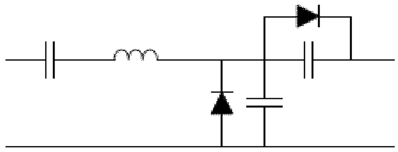

FIG. 8K

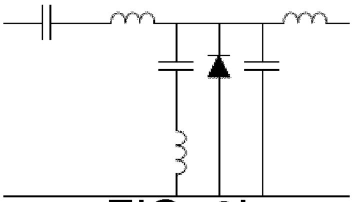

FIG. 8L

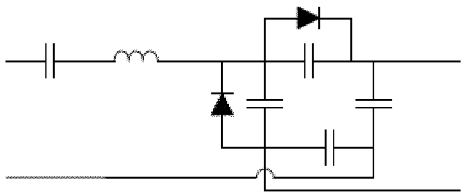

FIG. 8M

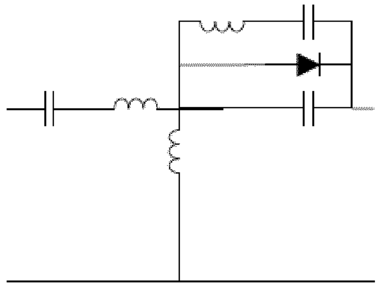

FIG. 8N

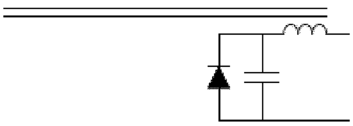

FIG. 8O

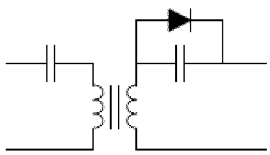

FIG. 8P

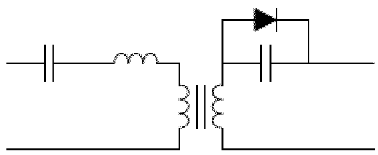

FIG. 8Q

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/061077

A. CLASSIFICATION OF SUBJECT MATTER
INV. H02M1/42
ADD. H02M5/297 H02M1/00 H02M3/155 H02M3/00 H02M7/23

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H02M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal , WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	SOUZA DE A F ET AL: "HIGH POWER FACTOR RECTIFIER WITH REDUCED CONDUCTION AND COMMUNICATION LOSSES", INTELEC '99. 21ST.INTERNATIONAL TELECOMMUNICATIONS ENERGY CONFERENCE. COPENHAGEN, JUNE 6 - 9, 1999; [INTELEC. INTERNATIONAL TELECOMMUNICATIONS ENERGY CONFERENCE], NEW YORK, NY : IEEE, US, 6 June 1999 (1999-06-06), pages 8-01/01, XP000868412, ISBN: 978-0-7803-5625-2 abstract figures 2, 3, 9 Sections I, II, IV -----	1-15

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 June 2019	04/07/2019

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Adami, Salah-Eddine

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Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 282 109 B1 (FRAIDLIN SIMON [US] ET AL) 28 August 2001 (2001-08-28) abstract figure 4 column 2, line 64 - line 67 column 3, line 1 - line 4 column 8, line 16 - line 67 column 9, line 1 - line 8 -----	1-15
X	AL-KAABI AYSHA KEMADISH ET AL: "Bridgeless high voltage battery charger PFC rectifier", RENEWABLE ENERGY, vol. 56, 23 October 2012 (2012-10-23), pages 24-31, XP028596723, ISSN: 0960-1481, DOI: 10.1016/J.RENENE.2012.09.050 abstract page 4; figure 2 Section 2.1 -----	1-15
X	WO 02/089303 A1 (POWERLAB AS [DK]; ANDERSEN TRULS MJELDE [DK]) 7 November 2002 (2002-11-07) abstract figure 13 page 7, line 1 - line 6 page 31, line 6 - line 18; figures 18, 20 -----	1-15
A	MADSEN MICKEY ET AL: "Low Power Very High Frequency Switch-Mode Power Supply With 50 V Input and 5 V Output", IEEE TRANSACTIONS ON POWER ELECTRONICS, INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, USA, vol. 29, no. 12, 19 February 2014 (2014-02-19), pages 6569-6580, XP011556099, ISSN: 0885-8993, DOI: 10.1109/TPEL.2014.2305738 [retrieved on 2014-08-13] abstract figures 1, 3, 7, 11 -----	1-15
A	US 2016/211759 A1 (LUCCATO DANIELE [IT]) 21 July 2016 (2016-07-21) abstract figures 3, 5, 6 -----	1-15

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1

International application No
PCT/ EP20 19/06 1077

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	TSAI-FU WU ET AL: "Design optimization for asymmetrical ZVS-PWM zeta converter", IEEE TRANSACTIONS ON AEROSPACE AND ELECTRONIC SYSTEMS, vol. 39, no. 2, 25 June 2003 (2003-06-25), pages 521-532, XP055056746, ISSN: 0018-9251, DOI: 10.1109/TAES.2003.1207264 abstract figures 1-3, 5-7 -----	1-15

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2019/061077

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 6282109	B1	28-08-2001	NONE			
WO 02089303	A1	07-11-2002	NONE			
US 2016211759	A1	21-07-2016	CN	105580497	A	11-05-2016
			EP	3050400	A2	03-08-2016
			US	2016211759	A1	21-07-2016
			WO	2015044846	A2	02-04-2015