Title: ELECTRICAL POWER CONVERTER

Abstract: Electrical power converter for converting electrical power of a power source connected or connectable at an input to electrical DC-power at an output, wherein between the input and the output a first circuit of submodules is provided, wherein said first circuit of submodules and the power source form a primary power loop and wherein each submodule comprises an energy storage component and each submodule is connected to a controller to drive the submodules in order to arrange that the electrical power at the output is DC-power, wherein the first circuit of submodules is provided with a parallel second electrical circuit so as to arrange that the first circuit and the parallel second circuit form a secondary power loop to enable the flow of local currents between the energy storage components of the submodules, wherein at the converter's output a blocking circuit is provided tuned to the operating frequency of the secondary power loop and that the secondary power loop is embodied as a current bypass circuit for the primary power loop so as to prevent that power from the converter flows to the input.
Electrical power converter

The invention relates to an electrical power converter for converting electrical power of a power source connected or connectable at an input to electrical DC-power at an output, wherein between the input and the output a first circuit of submodules is provided, wherein said first circuit of submodules and the power source form a primary power loop and wherein each submodule comprises an energy storage component and each submodule is connected to a controller to drive the submodules in order to arrange that the electrical power at the output is DC-power, wherein the first circuit of submodules is provided with a parallel second electrical circuit so as to arrange that the first circuit and the parallel second circuit form a secondary power loop to enable the flow of local currents between the energy storage components of the submodules.

WO2012/055435 teaches such a power electronic converter for use in high voltage direct current power transmission. It has converter limb portions that are connected in series between an AC-terminal and one of two DC terminals of opposing voltage polarities. The application of one positive and one negative DC terminal generating balanced positive and negative voltage half cycles at the output is required because of the need to have an alternating current output with a zero average value, equating to supplying zero average power over one full AC cycle to the energy storage elements in the converter limbs. This is a limiting factor.

DE 10 2008 014 898 A1 relates to a multiphase power converter and teaches to generate a low frequency alternating voltage at the output by superimposing an additional common mode alternating voltage to the outputs of the multiphase converter. This common mode voltage can cause undesirable currents to flow to the input dc source through the load and to earth.

The invention aims to provide a more versatile power converter.
To this end the power converter of the invention is embodied with the features of one or more of the appended claims.

In a first aspect of the invention at the converter's output a blocking circuit is provided tuned to the operation of the secondary power loop, and that the secondary power loop comprises a current bypass circuit for the primary power loop so as to prevent that power flowing in the secondary power loop will flow to the input.

With the converter according to the invention it is possible that the average power supplied to the primary loop output by an energy storage component, such as a capacitor in a submodule, can be different from zero. Although the sum of the power in the primary and secondary loop is zero, the measure that the secondary power is blocked or diverted from the output makes it possible to supply current to the output that has a nonzero average value. This means that the power converter of the invention can be applied to provide DC power at its output. At its input the power converter of the invention may also employ DC power.

Beneficially in accordance with the invention the local currents from the secondary power loop flowing between the energy storage components of the submodules are to charge and/or discharge said energy storage components.

The energy storage components of the submodules can be suitably selected from the group comprising capacitors, batteries, and solar cells. In case of any defective energy storage component, the same function can be electronically replaced by a redundant energy storage component.

There are several possible embodiments to arrange for the parallel second circuit. In one embodiment the parallel second circuit comprises a capacitor and an inductor in series that are connected at the converter's input and having a resonant frequency tuned to the operating frequency of the secondary power loop. Already with this very simple measure it is possible to implement a second circuit for the purpose of distributing the charging and discharging currents amongst the energy storage components within the secondary power
loop, whereby the operation of the primary power loop is unaffected by the operation of the secondary power loop. Preferably then the blocking circuit comprises a capacitor and an inductor in parallel having a resonant frequency tuned to the operating frequency of the secondary power loop in order to prevent power of the secondary power loop flowing to the output.

In another, more preferred embodiment, the parallel second circuit comprises a further circuit of submodules.

This provides a more complex construction of the power converter but is advantageous since the submodules of the first circuit and the parallel second circuit can each be implemented with the same capacity. In comparison with a conventional power converter of the same capacity, the capacity of the submodules can be halved. This embodiment is a preferred circuit for constructing a dc-dc converter. The function of blocking the secondary power loop frequency is then fulfilled by a centrally tapped inductor.

The invention will hereinafter be further elucidated with reference to the drawing.

In the drawing:
- figure 1 shows a circuit diagram of a conventional power converter;
- figure 2 shows a circuit diagram generally representing a power converter according to the invention;
- figure 3 shows a circuit diagram of a first embodiment of a power converter according to the invention;
- figure 4 shows a circuit diagram of a second embodiment of a power converter according to the invention; and
- figure 5 shows a part of the circuit diagram detailing the controller that drives a submodule of a power converter according to the invention; and
- figure 6 shows a detail of the secondary loop comprising a second electrical circuit of submodules, wherein the energy storage components are batteries and solar cells.

Whenever in the figures the same reference numerals are applied, these numerals refer to the same parts.

Figure 1 shows an DC-AC power converter in which a
voltage source is connected through an input inductor $L_{in}$ with a series of submodules $SM_i$, wherein $i=1,...,N$ and $N$-top and $N$-bot denote the number of applied submodules in the top and bottom submodule groups. Said submodules are part of a (primary) electrical loop and are distributed between a top section $M_{top}$ and a bottom section $M_{bot}$ normally having the same number of submodules in DC-AC power converters, although this is not a requirement of the invention. The top section $M_{top}$ and the bottom section $M_{bot}$ connect through an output inductor $L_{out}$ to the load that is connected to the power converter. The input inductor $L_{in}$ and the output inductor $L_{out}$ filter the currents to the load and from the voltage source. Figure 1 shows that each submodule $SM_i$ is provided with a capacitor for use as an energy storage component. $V_{load}$ is the voltage of the electrical load referred to the negative terminal of the DC source and the parameter $\delta$ indicates the ratio of the load current that returns to the negative and positive terminal respectively. In order to ensure balanced and symmetrical operation of DC-AC converters

$$\delta = 0.5,$$

and

$$V_{load}(t) = V_{source}/2 + V_{ac}\cos(2\pi ft),$$

where $V_{ac}$ is the alternating voltage amplitude and $f$ is the AC frequency.

Figure 1 shows the primary input and output power loops of the conventional DC-AC power converter are connected by the series connected submodules.

Referring to figure 2 a circuit diagram is shown generally representing the DC-DC power converter of the invention. According to the invention at the converter's output a blocking circuit is provided to prevent power flowing to the output, and the secondary power loop is embodied as a current bypass circuit for the primary power loop so as to prevent that power at the operating frequency of the secondary power loop flows to the input.

Referring to figure 3 the simplest embodiment of the power converter of the invention is shown in which different from the circuit diagram shown in figure 1- a parallel second circuit is applied that forms a secondary power loop for the
submodules. Also in this embodiment each submodule $S_M$ is pro-
vided with a capacitor for use as an energy storage compo-
nent. Conveniently return current of the DC loads flows to
the negative terminal of the DC source and $\delta = 1$.

The secondary power loop comprises a capacitor and
an inductor in series (indicated with $L_{\text{series}}$) that are con-
nected at the converter's input and that operate at a re-
nant frequency to close the secondary power loop. Further
this parallel second circuit includes an inductor $L_{\text{sec}}$ for
filtering the currents in the secondary power loop. The re-
mainder of the circuit diagram shown in figure 3 is the same
as the circuit diagram of figure 1, with one further excep-
tion being that at the converter's output a blocking circuit
indicated with $L_{\text{parallel}}$ is applied consisting of a capacitor
and an inductor in parallel, which blocking circuit is tuned
to the frequency of the secondary power loop in order to
block power of the secondary power loop from flowing to the
load. This enables that the converter is applied for convert-
ing DC power to DC power.

In figure 4 a preferred embodiment of the power con-
verter of the invention is shown which is particularly suita-
ble for converting DC power to DC power and in which parallel
to the first circuit of submodules (compare to figure 1), a
further circuit of submodules is applied. The two circuits of
submodules together form the secondary power loop which is
used as a loop for the local currents between the energy
storage components of the submodules and to charge and/or
discharge said energy storage components. In comparison with
the capacity of the submodules of the conventional power con-
verter shown in figure 1, the submodules used in the power
converter of the invention as shown in figure 4 can be half
the size. Figure 3 further shows that in this embodiment the
output is connected to the two circuits of submodules by
means of a centrally tapped inductor $L_{\text{out}}$. The centrally
tapped inductor $L_{\text{out}}$ has a large mutual inductor which in
practice will be as large as possible. The leakage inductor
$L_{\text{out}}$ is dimensioned to fulfil the filtering function of the
output current $I_{\text{load}}$ output, similar to what is shown in figure
2. Each of the submodules requires to be driven by a controller in order to implement the currents in the primary power loop and the secondary power loop. This is schematically shown in figure 5 depicting one single submodule. This submodule is driven by a pulse width modulation generator PWM which derives its modulation for the submodule from two separate controllers for the primary power loop and the secondary power loop, respectively. The requirements of the primary power loop are reflected by a voltage controller $v_{\text{prim}}$ controller operating at a DC reference value for the primary power loop that provides a setpoint $V_{\text{prim}}$. The requirements of the secondary power loop handling the power exchange between the top and bottom submodules and operating at a secondary frequency, are reflected by a power loop controller indicated with $P_{\text{sec}}$ controller. The $P_{\text{sec}}$ controller provides a setpoint $v_{\text{sec}}$ resulting eventually into a current $i_{\text{sec}}$ that is superposed to a current $I_{\text{prim}}$ resulting from the operation of the primary power loop. As figure 5 clearly shows the setpoints of the two controllers are combined to provide the setpoint that drives the pulse width modulation (PWM) generator for the individual submodule in relation to the primary power loop ($v_{\text{prim}}$) and the secondary power loop ($v_{\text{sec}}$), resulting in the required synthesized output voltage and output current of this module. At the input end the controller is shown with both a capacitor and a cell, which can be a battery cell or a solar cell. The embodiment with a cell corresponds to what is discussed hereinafter with reference to figure 6. The battery cell or solar cell is optional; if the cell is avoided the average current $I_{\text{cell dc}}$ equates zero and the submodule then corresponds to the submodules shown in figures 1-4. A zero average value of $I_{\text{cell dc}}$ results from the average primary power $P_{\text{prim}}$ and the average secondary power $P_{\text{sec}}$ opposing each other resulting in the average values of $i_{\text{sec dc}}$ and $I_{\text{prim dc}}$ being equal, but opposite.

It is explicitly pointed out that the foregoing description is not limiting as to the appended claims, but merely serves to elucidate these claims and to remove any
possible ambiguity of these claims. Many variations to the above given description are feasible without departing from the invention. The scope of protection that merits the invention is therefore exclusively determined by the appended claims, without being limited to what is explained in the foregoing with reference to the drawing.

As another example to the possible variations Figure 6 shows a secondary power loop of an electrical power converter of similar construction as the power converter shown in figure 3 or 4, wherein the capacitors that act as energy storage components are supplemented by batteries or solar cells. The solid black arrows in figure 5 represent the power flow in a leg of a power converter. The secondary power loop facilitates the extraction of power from submodules being embodied with solar cells and enables bidirectional power flow to and from submodules being embodied with batteries, for their charging and discharging. Finally it is remarked that when batteries or a solar cells are used, a proper operation of the circuit may require the application of a current bypass circuit between the first power connection the negative terminal, and a voltage blocking device in series with the second power connection.
CLAIMS

1. Electrical power converter for converting electrical power of a DC power source connected or connectable at an input to electrical DC-power at an output, wherein between the input and the output a first circuit of submodules is provided, wherein said first circuit of submodules and the power source form a primary power loop and wherein each submodule comprises an energy storage component and each submodule is connected to a controller to drive the submodules in order to arrange that the electrical power at the output is DC-power, wherein the first circuit of submodules is provided with a parallel second electrical circuit so as to arrange that the first circuit and the parallel second circuit form a secondary power loop to enable the flow of local currents between the energy storage components of the submodules, characterized in that at the converter's output a blocking circuit is provided tuned to the operation of the secondary power loop, and that the secondary power loop comprises a current bypass circuit for the primary power loop so as to prevent that power flowing in the secondary power loop will flow to the input.

2. Electrical power converter in accordance with claim 1, characterized in that the local currents from the secondary power loop flowing between the energy storage components of the submodules are to charge and/or discharge said energy storage components.

3. Electrical power converter in accordance with claim 1 or 2, characterized in that the energy storage components are selected from the group comprising capacitors, batteries, and solar cells.

4. Electrical power converter in accordance with any one of claims 1-3, characterized in that the parallel second circuit comprises a capacitor and an inductor in series that are connected at the converter's input and has a resonant frequency tuned to the operating frequency of the secondary power loop.
5. Electrical power converter in accordance with claim 4, characterized in that at the converter's output a blocking circuit is provided of a capacitor and an inductor in parallel having a resonant frequency tuned to the operating frequency of the secondary power loop.

6. Electrical power converter according to any one of claims 1-5, characterized in that it has an inductor connecting one or more of the submodules to the output.

7. Electrical power converter in accordance with any one of claims 1-6, characterized in that the parallel second circuit comprises a further circuit of submodules.

8. Electrical power converter in accordance with claim 6 and 7, characterized in that the inductor connecting one or more of the submodules to the output is centrally tapped and connected from its central tap to the output.

9. Electrical power converter in accordance with any one of claims 1-8, characterized in that the submodules of the first circuit and the parallel second circuit each have the same capacity.
Fig 3

- $V_{\text{source}}$
- $L_{\text{in}}$
- $L_{\text{out}}$
- $i_{\text{load}}$
- $V_{\text{load}}$
- $L_{\text{series}}$
- $L_{\text{sec}}$
- $M_{\text{top}}$
- $M_{\text{bot}}$
- $S\text{M}_{1}$
- $S\text{M}_{N,\text{top}}$
- $S\text{M}_{N,\text{bot}}$
- Secondary Power Loop