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The invention relates to a method for operating a modular current converter with a multiplicity of submodules, wherein the modular current converter generates an AC voltage at at least one AC voltage-side terminal by switching operations of power semiconductors of the submodules.

Current converters are used to convert electrical power with respect to voltage level, current level, frequency and phase angle. Current converters for the conversion of alternating voltage into direct voltage or from alternating current into direct current are referred to as rectifiers. In contrast, current converters for the conversion of direct voltage into alternating voltage or from direct current into alternating current are referred to as inverters. Current converters for the conversion of powers with voltages/currents from one frequency into another frequency are referred to as (frequency) converters.

Current converters are used to purposefully supply electrical energy to electrical machines and engines. As a result these electrical machines and engines can be controlled and regulated by the current converter. A further field of application is the control of energy flows, the compensation of harmonic waves and the provision of reactive power in power supply networks. Moreover current converters are involved in the low-loss transmission of energy by means of high voltage direct current transmission (HVDC).

A frequency converter with voltage link supplies a motor with a pulsed voltage, which contains the fundamental oscillation of the motor voltage in its pulse pattern. The high-frequency portions in the voltage generate leakage currents towards the reference earth, which are present as parasitic currents in the system. In order to limit these parasitic currents, filter

circuits must be used, which are known as EMC filters.

According to a first prior art, this problem is solved by the converter being embodied as a multilevel topology. In a preferred form of embodiment, in this context a converter phase is not embodied by an individual semiconductor or a series connection of semiconductors, but rather by a number of cells connected in series, which are referred to as submodules. In this case, the output voltage of the phase is dependent upon how many cells of the upper bridge branch and how many cells of the lower bridge branch are connected. A bridge branch is also referred to as a current converter valve. One such frequency converter is known from DE 101 03 031 A1, as well as from the publication "Modulares Stromrichterkonzept für Netzkupplungsanwendung bei hohen Spannungen" ["Modular current converter concept for mains connection application at high voltages"], by Rainer Marquardt, Anton Lesnicar and Jürgen Hildinger, printed in the conference proceedings of the ETG conference 2002. The output voltage corresponds to a voltage at the AC voltage-side terminal of the converter and is then no longer a pulsed voltage between the two DC potentials, but rather a stepped voltage, wherein the step height becomes smaller as the number of cells rises.

The disadvantage of said form of embodiment in relation to EMC parasitic currents is that an ultimate step height continues to remain even with many submodules. Although this small step height reduces the parasitic currents in proportion to the number of steps, very small parasitic currents are required in order to maintain SMV limit values. In order not to reach the height thereof, in particular without additional EMC filters, an extremely large number of steps is necessary. In order to halve the parasitic current (6dB reduction), it is necessary

to double the number of steps, which means a very large outlay when there is a large number of steps.

Furthermore, devices are known which work as linear amplifiers and are capable of providing an exact sinus voltage at the converter output. Such devices are known as linear artificial mains networks. They usually consist of a bridge connection of MOSFETs. These MOSFETs are not connected, however, but are actuated in linear operation, whereby any given voltage can be set at the converter output.

The advantage of this variant lies in the fact that the parasitic currents are minimal due to the truly sinusoidal course of the output voltage. The power loss of said solution is very high, however, as there is always a high voltage at the MOSFETs while they conduct current. The degree of efficiency of such devices is therefore below 30%.

A converter for application in a high voltage DC current transfer or a reactive power compensation is known from WO 2011/124260 A1. This converter comprises at least one chain converter, which is arranged between the AC and DC network. The chain converter contains a first and a second group of modules, which are arranged in series, wherein the individual modules have a large number of primary switch elements, which are connected to at least one energy storage unit. Here, the primary switch elements are able to be controlled such that the chain of modules in series can provide a stepped variable voltage source.

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An improved method and a system for increasing the effective electrical load capacity of a power converter is known from US 5 886 504. Potential damage caused by current spikes during load changes are avoided by capturing an imminent upstream

condition. Here, the output of the system is lowered by a predetermined amount or to a predetermined level and then gradually increased until the outputs of the system have reached the desired operating condition once more. One such  
5 controller can be influenced by a variation of the choke setting, in order to set the rotational speed of the rotor and in order to regulate the DC rail voltage level.

The object underlying the invention is to disclose a method  
10 for minimising parasitic currents of a modular current converter, which both causes low losses and is also able to be performed simply and reliably.

This object is achieved by a method for operating a modular  
15 current converter with a multiplicity of submodules according to claim 1 and a modular current converter corresponding thereto according to claim 6. Advantageous embodiments are defined in the dependent claims.

20 The invention is based on the knowledge that the minimisation of the parasitic currents is achieved in that a multilevel topology is used, wherein, however, at least one of the submodules connected in series in the current converter valves works in linear operation. Thus, in a current converter valve  
25 with  $n$  cells connected in series, the portion of  $(n-1)/n$  of the output voltage is realised in a low-loss manner by switched operation, while the portion of  $1/n$  is set in linear operation.

30 With this solution, as in the linear amplifier, it is possible to set any given voltage value exactly at the AC voltage-side terminal which represents the current converter output. Since only one cell works in linear operation, however, the relatively high power loss only occurs in this one cell. The

power loss is considerably lower than in the linear amplifier according to the prior art, because the individual submodule only absorbs a fraction of the intermediate circuit voltage.

5 The method according to the invention can be used for current converters both on the mains side and on the motor side. The invention is applicable for frequency converters which are intended to deliver exactly sinusoidal output voltage. It is likewise applicable for linear amplifiers, the losses of which  
10 are intended to be drastically reduced.

In an advantageous form of embodiment, the submodules operated in linear operation are actuated such that the voltage at the AC voltage-side terminal adopts a sinusoidal course over time.  
15 The particular advantage consists in the sinusoidal course being required for many applications and in the past having to be realised by more or less elaborate and cost-intensive filter circuits. It is now possible to dispense with this filter circuit. In the terminal, at a power supply network for  
20 example, no high-frequency parasitic currents occur as a result of the adequate sinusoidal course of the output voltage of the current converter circuit. The same behaviour takes place with loads connected to the current converter circuit. These are also partially sensitive to harmonics which are not  
25 suppressed to the greatest possible extent by the current converter circuit according to the invention and partially have to be eliminated in their entirety.

In a further advantageous form of embodiment, an allocation of  
30 which submodule is operated in linear operation is undertaken anew by way of at least one criterion after recurring points in time. If the development objective lies in implementing all submodules in the same manner, in order to achieve a high degree of uniformity of components in the current converter

for example, then it is possible for different submodules to be regulated linearly in an alternating manner, in order to distribute the power loss of the linear regulation as evenly as possible on all submodules. In this context, the recurring  
5 points in time result from a cyclically recurring review. Here, at particular points in time spaced apart from one another by the same amount of time, operating parameters of the submodules such as the current temperature of the power semiconductor for example, in particular at the depletion  
10 layer, and/or the current or predicted power loss are used as a criterion in order to make a decision as to which submodule is to be operated in linear operation as of a particular point in time. In addition to a cyclical review, this may also be controlled in an event-driven manner, for example by the  
15 exceeding of temperature values.

In a further advantageous form of embodiment, the allocation by way of the at least one criterion takes place such that the temperature and/or the power loss of the submodules adopt the  
20 same value on average over time. The objective of the even distribution of the energy loss over all submodules is to shape the heating of the submodules evenly on average over time, so that each module experiences the same loading during operation. Thus it is possible to ensure the maximum service  
25 life for the individual submodules. An early failure of modules is avoided as a result.

In a further advantageous form of embodiment, for the allocation of which submodule is operated in linear operation  
30 next, use is made of the submodule with the lowest temperature. In this preferred form of embodiment, it is always possible for the submodule whose temperature is the lowest to assume the linear regulation. This selection logic represents a simple criterion for the even thermal loading of

the submodules and contributes to a long service life of the current converter.

In a further advantageous form of embodiment, the modular  
5 current converter has

- a DC voltage terminal,
- at least one AC voltage-side terminal and
- at least one phase module,

10 wherein the phase module has a series connection of a first and a second current converter valve,

wherein an electrical connection between the first and the second current converter valve represents the AC side terminal,

15 wherein the terminals of the phase module are electrically connected to the DC voltage terminal,

wherein the first and the second current converter valve each have at least two submodules, which are arranged electrically in series,

20 wherein the submodules have at least one capacitor and at least one power semiconductor. The method according to the invention is in particular suitable for the M2C current converter which is described by the aforementioned features.

The current converter is suitable for both drive applications and also for connecting to a power supply network. The  
25 submodules of the converter are actuated by a regulation which is also able to assume the regulation/control of the linear operation in a simple manner. By applying the method, the aspects of the ideal sinusoidal shape can be realised with simultaneously low losses in a particularly simple manner.

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In a further advantageous form of embodiment, the modular current converter has at least one submodule, which is provided for the linear operation and wherein the submodule provided for the linear operation has a particularly effective

cooling. This individual, linearly regulated submodule can be provided with a particularly effective cooling, in order to dissipate the relatively high losses of said individual cell. This can be realised by larger or more powerful cooling elements, for example. Another possibility consists in arranging these at the start of a cooling circuit, in which the cooling medium such as air or water still has the lowest temperature without preheating by other components.

The invention is described and explained in more detail below on the basis of the exemplary embodiments shown in the Figures, in which:

FIG 1 shows an exemplary embodiment of a modular current converter with one submodule provided for the linear operation per current converter valve.

FIG 1 shows the construction of a modular current converter 1 which is embodied as a modular multilevel current converter (M2C). In this exemplary embodiment, this is equipped with three AC voltage-side terminals 12 for connection to a three-phase power supply network or to a three-phase consumer. On the DC voltage-side, this modular current converter 1 has a DC voltage terminal 13. The DC voltage terminal 13 comprises a positive and a negative terminal. The phase modules 10 are connected to the intermediate circuit 15 by the terminal points 14. The intermediate circuit 15 has a busbar with positive potential and a busbar with negative potential. The phase module 10 comprises a series connection consisting of an upper current converter valve 11a and a lower current converter valve 11b. The individual current converter valves 11a and 11b have a series connection of submodules 20, 30. The connecting point between the upper current converter valve 11a and the lower current converter valve 11b represents the AC

voltage-side terminal 12. In this exemplary embodiment, the phase module 10 has a submodule 30 provided for the linear operation. With this, it is possible to optimise the voltage present at the AC voltage-side terminal 12 with respect to a reference potential or the voltage present between two AC voltage-side terminals 12 in terms of their quality such that the harmonic content of said voltage is eliminated as a result of the sinusoidal shape of the voltage at the AC voltage-side terminal. As a result, it is possible to dispense with the use of a filter for reducing harmonics. It has proven positive for the regulation of currents if inductances are arranged between AC voltage-side terminal 12 and the busbar with positive potential, as well as between the AC voltage-side terminal 12 and busbar with negative potential in each case. These are not shown in FIG 1. Their task is to improve the ability for currents of the modular multilevel current controller to be regulated. The current converter circuit 1 represented in FIG 1 can be expanded by the parallel connection of further phase modules 10 to the already present phase modules 10 by further AC voltage-side terminals 12. The submodules 30 provided for the linear operation are in each case arranged in an upper current converter valve 11a and in a lower current converter valve 11b. The position in the series connection of the submodules 20, 30 at which the submodule 30 provided for the linear operation is located within the series connection of the current converter valve 11a, 11b is irrelevant for the operation of the current converter circuit 1. The fact that each of the two current converter valves 11a, 11b in each phase module 10 has a submodule 30 provided for the linear operation, which is operated in linear operation during operation of the modular current converter, means that the voltage at the AC voltage-side terminal 12 is able to be realised with an ideal sinusoidal course.

## Patentkrav

5 1. Fremgangsmåde til drift af en modulær omformer (1) med en flerhed af undermoduler (20,30), hvor den modulære omformer (1) ved mindst en tilslutning (12) på vekselspændingssiden genererer en vekselspænding ved omskiftningshandlinger af effekthalvledere (41) af undermodulerne (20,30), hvor mindst et undermodul (30) er anbragt mellem tilslutningen (12) på vekselspændingssiden og en positiv tilslutning af en mellemkreds (15), og mindst et undermodul (30) er anbragt mellem tilslutningen på vekselspændingssiden og en negativ tilslutning af mellemkredsen (15),

10 **kendetegnet ved, at**

det mindst ene undermodul (30) mellem tilslutningen (12) på vekselspændingssiden og den positive tilslutning af mellemkredsen (15) og det mindst ene undermodul (30) mellem tilslutningen på vekselspændingssiden og den negative tilslutning af mellemkredsen (15) drives i lineardrift.

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2. Fremgangsmåde til drift af en modulær omformer (1) ifølge krav 1, **kendetegnet ved**, at undermodulerne (30), der drives i lineardrift, styres på en sådan måde, at spændingen ved tilslutningen (12) på vekselspændingssiden antager et sinusformet tidsforløb.

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3. Fremgangsmåde til drift af en modulær omformer (1) ifølge et af kravene 1 til 2, **kendetegnet ved**, at der foretages en allokering af, hvilket undermodul (30) drives i lineardrift, på ny efter tilbagevendende tidspunkter ved hjælp af mindst et kriterium.

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4. Fremgangsmåde til drift af en modulær omformer (1) ifølge krav 3, **kendetegnet ved, at** allokeringen ved hjælp af det mindst ene kriterium sker ved, at undermodulernes (20,30) temperatur og/eller tabseffekt antager samme værdi i tidsmæssige midler.

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5. Fremgangsmåde til drift af en modulær omformer (1) ifølge et af kravene 3 eller 4, **kendetegnet ved**, at undermodulet (20,30) med den laveste temperatur inddrages til allokeringen af, hvilket undermodul (20,30) der drives som det næste i lineardrift.

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- 6.** Modulær omformer (1) med en flerhed af undermoduler (20, 30) til udførelse af fremgangsmåden ifølge et af kravene 1 til 5, hvor den modulære omformer (1) omfatter
- en jævnspændingstilslutning (13),
  - 5 - mindst en tilslutning (12) på vekselspændingssiden og
  - mindst et fasemodul (10),
- hvor fasemodulet (10) omfatter en seriekobling af en øvre og en nedre omformerventil (11a,11b),
- hvor en elektrisk forbindelse mellem den øvre og den nedre omformerventil
- 10 (11a,11b) udgør tilslutningen (12) på vekselspændingssiden,
- hvor fasemodulets (10) tilslutninger (14) er elektrisk forbundet med jævnspændingstilslutningen (13), hvor den øvre og den nedre omformerventil (11a,11b) hver især omfatter mindst to undermoduler (20,30), der er anbragt elektrisk på række,
- 15 hvor undermodulerne (20,30) omfatter mindst en kondensator (42) og mindst en effekthalvleder (21),
- hvor den modulære omformer (1) omfatter mindst et undermodul (30), der er beregnet til lineardrift, og hvor undermodulet (30), der er tilvejebragt til lineardrevet, omfatter en særligt god køling.
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- 7.** Modulær omformer (1) ifølge krav 6, hvor undermodulet (30), der er tilvejebragt til lineardrift, er anbragt i starten af et kølekredsløb.
- 8.** Modulær omformer (1) ifølge krav 6, hvor undermodulet (30), der er tilvejebragt til lineardrift, er forsynet med et mere effektivt kølelegeme.
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