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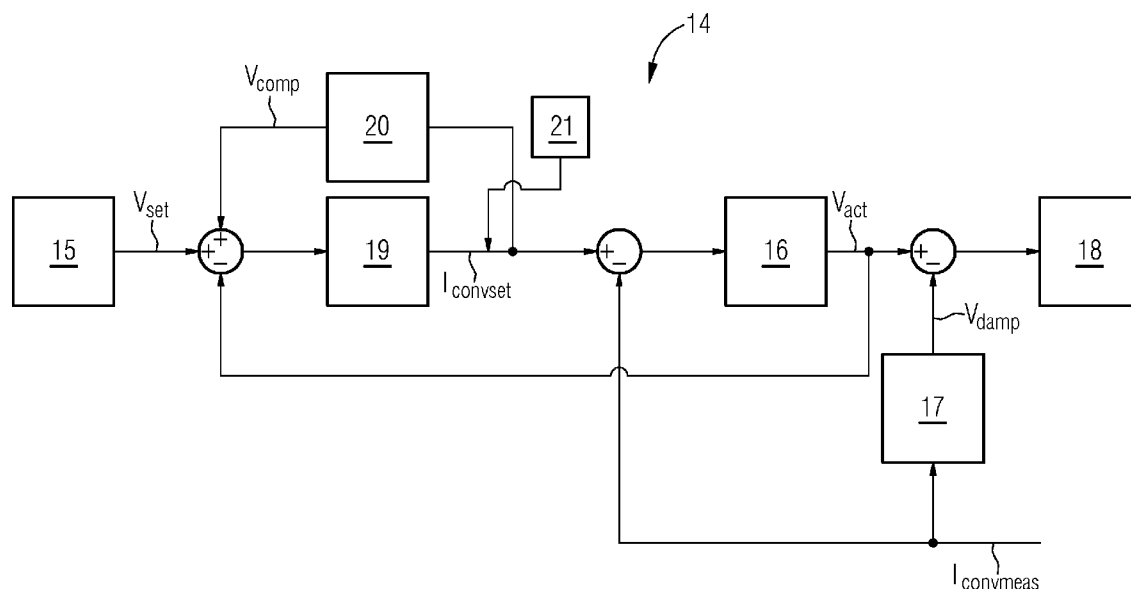
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(54) Title: CONVERTER AND A METHOD FOR CONTROLLING A CONVERTER

FIG 3



(57) Abstract: The present invention relates to a converter (1,7) with a converter control (14), wherein said converter control comprises a current controller (16), configured to receive at its input a difference between a current setpoint and a measured converter current, and to provide at its output a current controller output voltage, and a damping module (17), configured to receive at its input said measured converter current, and to provide at its output a damping voltage, wherein a sum of said damping voltage and said converter controller output voltage is provided to a converter modulator. The invention is characterized in that the converter control further comprises a virtual admittance module (19), configured to receive at its input a difference between a sum of a voltage setpoint and a compensation voltage, and said current controller output voltage, and to provide at its output said current setpoint, and a compensation module (20), configured to receive at its input said current setpoint, and to provide at its output said compensation voltage, wherein the compensation

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module is configured to counteract a damping effect of the damping module. The invention further relates to a control method for controlling the converter.

Converter and a method for controlling a converter

The present invention relates to a converter with a converter  
5 control, wherein said converter control comprises a current  
controller, configured to receive at its input a difference  
between a current setpoint and a measured converter current,  
and to provide at its output a current controller output  
10 voltage, and a damping module, configured to receive at its  
input said measured converter current, and to provide at its  
output a damping voltage, wherein a sum of said damping  
voltage and said converter controller output voltage is  
provided to a converter modulator.

15 Such converter with a current control is known from the EP 4  
057 500 A1. The known converter control achieves a damping of  
the converter voltages by applying a virtual impedance which  
adds a correcting voltage to the current controller output  
voltage. Thus, the damping module can act as a modifier of a  
20 converter input impedance, i.e., an impedance as measured at  
an AC side of the converter.

Usually, a converter in a so-called grid following mode uses  
a grid following controller to control the AC side current,  
25 and to follow a frequency and a phase angle of a grid voltage  
(of the AC network) through a phase-locked loop control (thus  
synchronizing to the grid). Currently, most of the existing  
converters in high-voltage applications operate in the grid  
following mode.

30 The high penetration of power electronics devices (such as  
HVDC, STATCOM) and renewable energy devices application usage  
in relatively weaker grid conditions has significantly in-  
creased the necessity for the implementation of grid forming  
35 converters (i.e., a converter operated in a grid forming  
mode) over the recent years. In the grid forming mode, the  
converter actively controls its frequency and voltage output.

In general, the known concepts to generate a synchronous voltage source that exhibits the desired grid forming properties are based on two key components: a software implementation of a swing equation to model the frequency behavior and inertia of a physical synchronous machine with a rotating space phasor, and a voltage controller for the voltage magnitude of that phasor. However, there are numerous challenges that arise when applying the theoretical control concept to real AC/DC converter hardware and the existing functional requirements of an HVDC converter station. For example, the current limitation of the converter hardware requires a fast current controller with a current source like behavior and a high input impedance, while the required voltage source behavior of a grid forming converter requires a very low input impedance. Furthermore, while the harmonic damping requires a high real component of the internal impedance, leading to a low X/R ratio, the voltage and angle stability criterion as well as the inherent reaction to grid voltage changes (angle and magnitude) require a very high X/R ratio.

The object of the invention is thus to propose an aforementioned converter that enables an X/R ratio which is high enough from the perspective of grid forming requirements, and simultaneously keeping the damping for a current controller at an operationally required level.

The object is achieved by a converter according to claim 1.

Accordingly, the converter control further comprises a virtual admittance module, configured to receive at its input a difference between a sum of a voltage setpoint and a compensation voltage, and said current controller output voltage, and to provide at its output said current setpoint, and a compensation module, configured to receive at its input said current setpoint, and to provide at its output said compensation voltage, wherein the compensation module is configured to counteract a damping effect of the damping

module, suitably for a predefined frequency range of current setpoint values (preferably for the full frequency range of current setpoint values). According to the invention, the compensation module is configured to model the behavior of the damping module to approximately compensate its effect. Within the predefined range of current setpoint values the output voltage of the compensation module (compensation voltage) approximates the output voltage of the damping module (damping voltage). At least apart from transient conditions, i.e., in a steady-state operation, the compensation voltage (ideally) equals the damping voltage (given that an ideal model of the current controller is implemented in the compensation module). If admissible current setpoint values are limited (e.g., to protect the converter hardware), then the compensation effect will not occur for currents above this value (the current setpoint limit value), because the compensation module receives current setpoints whereas the effect of the damping module depends directly on the measured currents.

The converter control thus comprises a specialized grid forming control system with an underlying fast-current controller playing a role of a current limiter. The grid forming system consists of specialized voltage, angle and frequency controller emulating a frequency behavior and inertia of a physical synchronous machine with a rotating space phasor and a voltage controller generating a voltage magnitude to that phasor. The interface between the grid forming controllers and a current controller is realized through the virtual admittance module, which may be interpreted as a RL grid model with a defined short circuit level and X/R ratio.

An advantage of the present invention is that high damping of the current controller is not limiting the grid forming response by decreasing the effective X/R ratio of the whole system. The current controller is realized in a way to provide a sufficient damping with rapid current limitation

capability (which is essential for power electronic devices).  
The behavior of the current controller, increasing the  
damping can be compensated (statically and dynamically) in  
the upper-level admittance of the grid forming control to  
5 achieve the desired high X/R ratio.

The current controller brings the converter current to a  
desired current setpoint in a very short time, by controlling  
the voltage at converter terminals. Therefore, it is possible  
10 to compensate the virtual voltage drop on the current  
controller damping through positive feedback to an input of  
the virtual admittance module.

With the described realization of the damping reduction  
15 system, the grid forming system keeps the ability of  
selective control of voltage components. Hence, it is  
possible to generate separate positive and negative phase  
current control setpoints. That way, the grid forming  
behavior is closer to an actual positive sequence voltage  
20 source, which is often desired behavior by our customers and  
desirable with regard to other control functions, such as  
active harmonic damping / filtering or voltage modulation.  
The proposed structure breaks the dependencies between  
current controller damping and desired X/R ratio and resolves  
25 the compromises that would need to be employed by a control  
designer for a system with very low effective X/R ratio. A  
converter operating in grid forming mode can be operated  
closer to an ideal voltage behavior in both operation  
directions (inverter and rectifier).

30 Preferably, said compensation module comprises a converter  
control model to determine a converter current based on a  
current setpoint and a damping model to model said damping  
module. The compensation model can comprise two  
35 mapping/function components applied subsequently. A first  
function component models the behavior of the converter and  
the converter control to obtain an actual converter current  
as function of a current setpoint. The model for the

converter control can be derived from known model equations that model the converter behavior (including the current controller). A second function component may be a transfer function, preferable copying the transfer function of the  
5 damping module.

The converter control can be configured to limit the values of said current setpoint, such that the value of said current setpoint does not exceed a predefined current setpoint limit,  
10 to prevent the value of said current setpoint from exceeding the current capability of the converter. Since the input to the compensation module is the current setpoint, the compensation voltage is not higher than the maximum voltage output that corresponds to the upper current setpoint limit.  
15 In contrast, since the input to the damping unit is the actual converter current, the damping voltage values can exceed said maximum voltage output. This situation occurs particularly for current values that might damage the converter. Such currents can thus be effectively damped.

20 According to an embodiment of the invention the compensation is performed separately for the positive and negative phase sequence voltages and currents. Accordingly, said virtual admittance module is a positive phase sequence virtual  
25 admittance module, configured to receive at its input a difference between a sum of a positive phase sequence voltage setpoint and a positive phase sequence compensation voltage, and a positive phase sequence current controller output voltage, and to provide at its output a positive phase  
30 sequence current setpoint, and wherein said compensation module is a positive phase sequence compensation module, configured to receive at its input a positive phase sequence current setpoint, and to provide at its output said positive phase sequence compensation voltage. With the separation of  
35 the control for positive and negative sequences it is possible to achieve a sequence selective control with different controller behavior for the positive phase sequence and the negative phase sequence current component.

Preferably the converter control further comprises a negative phase sequence virtual admittance module, configured to receive at its input a difference between a sum of a negative phase sequence voltage setpoint and a negative phase sequence compensation voltage, and a negative phase sequence current controller output voltage, and to provide at its output a negative phase sequence current setpoint, and a negative phase sequence compensation module, configured to receive at its input a negative phase sequence current setpoint, and to provide at its output said negative phase sequence compensation voltage, wherein said current setpoint is a sum of the positive and negative phase sequence current setpoints. This allows the division of the current reference/measurement in different components (positive phase sequence, PPS/negative phase sequence, NPS) for the grid forming control, which improves the compatibility with functions that affect individual components of the current, such as current limitation, current component prioritization (active and reactive current component) and supporting functions like active damping, voltage modulation, etc.

According to an embodiment the current controller is a positive phase sequence current controller, receiving at its input a difference between said current setpoint and a measured converter current, and providing at its output said positive phase sequence current controller output voltage, and the converter control further comprises a negative phase sequence current controller, receiving at its input a difference between said current setpoint and a measured converter current, and providing at its output said negative phase sequence current controller output voltage.

According to the aspect of the invention described above, the positive and negative sequence components can be controlled separately and the admittance for PPS and NPS can be set separately. This allows a separation of the inherent short circuit capability for PPS and NPS and therewith a

differentiate reaction during asymmetric grid states. The current controller can be tuned to PPS and NPS component resonant frequencies. In this way a PPS and NPS converter voltage is extracted and fed back to the input of virtual impedance separately for PPS and NPS component. Positive phase sequence component is being compared with the voltage generated by the grid forming voltage source model, and the negative phase sequence is compared with set point of zero or, equivalently a grid forming voltage source model for the NPS. Hence, through the virtual admittance the current setpoints for PPS and NPS are being generated and can be limited separately. At a subsequent step both setpoints are summed and used as an input signal for the current controller. An advantage of the separation of PPS and NPS is that a limitation of positive phase sequence current is possible to be realized in dq domain for d and q component separately without cross coupling to the NPS component and without generating undesired harmonics that would appear e.g., when the PPS and the NPS component are being transformed to and limited in a 50 Hz rotating frame as a combined signal. Another advantage is that it is possible to determine different admittance for positive and negative phase sequence and therefore to specify the NPS component injection gain more accurately.

The above-mentioned separation of the PPS and NPS can furthermore correspondingly take into consideration also the zero-sequence component of the respective signals.

Preferably, the damping module comprises a transfer function. The transfer function may be implemented as a linear amplification function. The damping module may further comprise an integrator.

The virtual admittance module may comprise a combination of a linear and a non-linear transfer function. The transfer functions of the damping module and/or the virtual admittance module can be implemented to act in the Laplace domain.

According to an embodiment the converter comprises controllable semiconductor switches of a switch-off type. The converter comprises an AC side to connect to an AC network and a DC side to be connected to a DC link or to an electrical energy storage device. The concept described herein can be used for an SVC Frequency Stabilizer device which is e.g., based on a B6 converter with ultracapacitors connected to the DC terminals. A B6 converter configuration is characterized by three converter phase branches each extending between the DC terminals. Each phase branch comprises two converter valves (thus six in total), wherein an AC terminal is arranged between the respective converter valves of every converter phase. The energy storage connected to the DC side of the converter enables several seconds of operation in active power range. When the voltage limits of the supercapacitor at the DC side are exceeded, the storage will be charged or discharged respectively, allowing the island operation of the SVC Frequency Stabilizer. The voltage setpoint can be calculated by an Automatic Voltage Regulator (AVR), which controls the voltage at the connecting point to the given reference. The speed of the response of the controller determines the stability of the converter during islanding condition. The active power of the frequency stabilizer in normal condition is zero. During frequency disturbances, the active power is injected/absorbed to counteract the frequency change.

The converter is preferably a modular multilevel converter. A modular multilevel converter (MMC) comprises a series of switching modules in each of the converter valves (sometimes also referred to as converter arms). Each of the switching modules comprises switch-off type semiconductor switches, like e.g., IGBT, and an energy store, like e.g., a capacitor. Every switching module can be individually controlled to provide certain module voltage at its terminals (e.g., the capacitor voltage or a zero voltage in case of a half-bridge

module, or the capacitor voltage, a negative capacity voltage or a zero voltage in case of a full-bridge module).

The invention further relates to a method for operating resp.  
5 controlling a converter according to the invention.

The object of the present invention is to provide such a method that enables an X/R ratio which is high enough from the perspective of grid forming requirements, and  
10 simultaneously keeping the damping for a current controller at an operation-ally required level.

The object is achieved by a converter according to claim 10.

15 Accordingly, the method comprises the steps of receiving at an input of a current controller a difference between a current setpoint and a measured converter current, and providing at its output a current controller output voltage, receiving at an input of a damping module said measured  
20 converter current, and providing at its output a damping voltage, wherein a sum of said damping voltage and said converter con-troller output voltage is provided to a converter modulator, receiving at an input of a virtual admittance module a difference between a sum of a voltage  
25 setpoint and a compensation voltage, and said current controller output voltage, and providing at its output said current setpoint, and receiving at an input of a compensation module said current setpoint, and providing at its output said compensation voltage, wherein said compensation module  
30 counteracts the damping effect of the damping module for a predefined range of current setpoint values.

The invention is explained below with reference to exemplary  
embodiments illustrated in the figures 1 to 5.

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Figure 1 shows a schematic view of a converter according to an embodiment of the invention;

Figure 2 shows another schematic view of the converter of figure 1;

Figure 3 shows a schematic view of an embodiment of a  
5 converter control for a converter according to the invention;

Figure 4 shows a schematic view of another embodiment of a converter control for a converter according to the invention;

10 Figure 5 shows a schematic view of yet another embodiment of a converter control for a converter according to the invention.

A converter 1 with an AC side 2 and a DC side 3 is depicted  
15 in figure 1. The converter 1 is a voltage source converter, in particular a modular multilevel converter (MMC). The AC side 2 of the converter 1 is connected to an AC grid 4 at a connecting point 2a. The DC side 3 of the converter is connected to an electrical energy storage device 5 via a DC  
20 link 6. The converter 1 is designed to stabilize the AC grid 4 by exchanging active and reactive power with the AC grid 4.

The MMC 7 shown in figure 2 comprises three phase branches 8a-c and six converter valves (also denoted as arm) 9a-f.  
25 Every converter arm 9a-f extends between one of the DC poles or terminals 10a,b, constituting a DC side of the converter 7, and one of the AC terminals 11a-c constituting an AC side of the converter 7. Each converter valve 9a-f comprises an arm inductance L and a number of switching modules 12  
30 connected in series. The number of switching modules 12 in every converter arm 9a-f is in general arbitrary (not restricted to two per valve) and can be adapted to the given application. According to the example shown in figure 2 all switching modules 12 are so-called full-bridge switching  
35 modules. A proper control of the semiconductor switches of a given switching module 12 creates a positive, a negative or a zero voltage across its terminals. The converter 7 comprises

a converter control 13 for controlling the operation of the converter 7.

The MMC 7 is suitable for grid stabilization applications (according to the configuration of figure 1). However, the present invention is also applicable to high-voltage direct current energy transmission (HVDC), e.g., using the MMC 7, wherein its DC side is connected to a DC transmission line. Particularly in HVDC applications each of the converter valves can comprise switching full-bridge switching modules, half-bridge switching modules, other switching module topologies or any combinations thereof.

Figure 3 shows a converter control system 14 suitable for the converter shown in figure 1 and/or figure 2. The converter control 14 comprises a grid forming control 15. The grid forming control 15 provides at its output a voltage setpoint  $V_{set}$ . The grid forming control 15 controls the converter to act as an ideal voltage source behind an impedance (as seen at a point of common coupling, e.g., point 2a in figure 1). The voltage setpoint is provided as a phasor with an angle and an amplitude.

The converter control 14 further comprises a current controller 16. At its input the converter controller 16 receives a current setpoint  $I_{convset}$  and a measured actual converter current  $I_{convmeas}$ , respectively the difference  $I_{convset} - I_{convmeas}$ . The currents can for example be the currents flowing at the converter ac terminals. The current controller can for example be, or comprise, a second order generalized integrator, a dq controller, a resonant controller or similar. At its output the current controller 16 provides a current controller output voltage  $V_{act}$ .

The converter control 14 further comprises a damping module 17. The damping module 17 receives at its input the measured converter current  $I_{convmeas}$  and provides at its output a damping voltage  $V_{damp}$  by means of a transfer function (that

can also be frequency selective). The current controller output voltage  $V_{act}$  is corrected by the damping voltage  $V_{damp}$  (e.g., by subtracting  $V_{act}-V_{damp}$ ) and provided to a converter modulator 18 which control the converter switches according to a modulation algorithm. Thus, the voltage to be generated by the converter is reduced in dependence of the actual converter current. That prevents the converter to generate voltages and thus to generate currents that might exceed its current capabilities.

10

The output of the grid forming control 15 is connected to the current controller 16 via a virtual admittance module 19 (e.g., implemented as a linear, a non-linear or a combined linear/non-linear transfer functions in a corresponding control module). This allows a very fast and effective limitation of the current in the converter. The virtual admittance module 19 provides at its output the current setpoint  $I_{convset}$ . The current setpoint  $I_{convset}$  is provided to the current controller 16 and to a compensation module 20.

20

The compensation module 20 comprises a model of the converter control. Using this model the current setpoint  $I_{convset}$  is translated into a actual current response of the converter that approximates the real converter response. This model response is further transformed by means of a transfer function to provide at an output of the compensation module 20 a compensation voltage  $V_{comp}$ . In a steady-state operation of the converter the compensation voltage  $V_{comp}$  is approximately equal to the damping voltage  $V_{damp}$ . To

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compensate the damping effect of the damping module 17 the compensation voltage  $V_{comp}$ , along with the voltage setpoint  $V_{set}$  and the current controller output voltage  $V_{act}$  is provided to the virtual admittance module 19. The current setpoint  $I_{convset}$  is limited by a limiting function 21, i.e., if the current setpoint  $I_{convset}$  exceeds a current setpoint limit, then the current setpoint  $I_{convset}$  is set to the current setpoint limit. This means, in particular, that for all measured currents above the current setpoint limit, the

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compensation module 20 does not compensate the damping effect of the damping module 17.

Figure 4 shows another variant of a converter control 30. The basic structure of the converter control 30 is similar to the control shown in figure 3. However, according to the embodiment of figure 4 the control of the converter is partly performed separately for positive and negative sequence components of the voltages and/or currents. It would also be possible to additionally implement a separate corresponding zero-sequence component in the converter control.

The converter control 30 comprises a grid forming control 31 to provide a positive phase sequence voltage references  $V_{set,pps}$  and  $V_{set,nps}$ . The grid forming control 31 is based on energy references and measured power and voltage values  $W_{0phmact}$ ,  $W_{wphm}$ ,  $V_{ref}$ ,  $Q_{ref}$ ,  $V_{act}$ ,  $Q_{act}$ . The grid forming control 31 comprises a transfer function 32 to control energy, a transfer function 33 to control reactive power, and an extended electromechanical and electromagnetic model 34 of the converter.

The converter control 30 further comprises a positive phase sequence virtual admittance module 35 comprising a transfer function and a negative phase sequence virtual admittance module 36 to couple the grid forming control and a current controller (e.g., as shown in figure 5). The sum of the positive phase sequence current setpoint  $I_{convset,pps}$  and the negative phase sequence current setpoint  $I_{convset,nps}$  is provided to the current controller for further processing.

To compensate the effect of a damping module (as depicted in figure 5) the converter control 30 further comprises a positive phase sequence compensation module 37 and a negative phase sequence compensation module 38. The implementation and effect of the positive and negative phase sequence compensation modules 37, 38 corresponds to the effect of the compensation module 20 as described in reference to figure 4.

Figure 5 shows a converter control 40 with a current control system, applicable e.g., to the converter control of figure 4. The converter control 40 comprises a positive phase sequence current controller 41, receiving at its input a difference between a current setpoint  $I_{convset}$  and a measured converter current  $I_{convmeas}$ , and providing at its output a positive phase sequence current controller output voltage  $V_{act,pps}$ , and a negative phase sequence current controller 42, receiving at its input a difference between the current setpoint  $I_{convset}$  and a measured converter current  $I_{convmeas}$ , and providing at its output a negative phase sequence current controller output voltage  $V_{act,nps}$ . The sum of the output voltages  $V_{act,pps}$  and  $V_{act,nps}$  is corrected by a damping voltage  $V_{damp}$  as provided by a damping module 43 and transmitted to a converter modulator. The implementation and effect of the damping module 43 is as described above with respect to the damping module 17 of figure 3.

A converter operating in grid forming mode is expected to act like a slow changing voltage source behind an impedance, similar to a physical synchronous machine. However, a power electronic, semiconductor-based device, does not have a current capability of a physical synchronous machine. Therefore, the superseding requirement is that the employed control structure is capable of limiting the current fast enough according to the capability of a converter. The above-described invention allows (at least to a certain extent) decoupling of these two requirements that had to be compromised before.

In particular, the enhancement of the X/R ratio brings improvement in terms of expected grid forming behavior as well as voltage/angle stability. Moreover, higher X/R ratio forces higher capacitive reactive current injection during remote faults, what leads to a greater voltage support during the fault ride through event. The damping of a current controller may remain unchanged, without the compromise of robustness.

## Claims

1. Converter (1,7) with a converter control (14), said  
5 converter control (14) comprising  
- a current controller (16), receiving at its input a  
difference between a current setpoint (Iconvset) and  
a measured converter current (Iconvmeas), and  
10 providing at its output a current controller output  
voltage (Vact),  
- a damping module (17), receiving at its input said  
measured converter current (Iconvmeas), and providing  
at its output a damping voltage (Vdamp), wherein a  
15 sum of said damping voltage (Vdamp) and said  
converter controller output voltage (Vact) is  
provided to a converter modulator, characterized by  
- a virtual admittance module (19), receiving at its  
input a difference (Vset+Vcomp-Vact) between a sum  
20 (Vset+Vcomp) of a voltage setpoint (Vset) and a  
compensation voltage (Vcomp), and said current  
controller output voltage (Vact), and providing at  
its output said current setpoint (Iconvset), and  
- a compensation module (20), receiving at its input  
25 said current setpoint (Iconvset), and providing at  
its output said compensation voltage (Vcomp), wherein  
said compensation module is configured to counteract a  
damping effect of said damping module (17).
2. Converter (1,7) according to claim 1, wherein said  
30 compensation module (20) comprises a converter control  
model to determine a converter current based on a  
current setpoint and a damping model to model said  
damping module (17).
3. Converter (1,7) according to any of the preceding  
35 claims, wherein the converter control (14) is  
configured to limit the values of said current

setpoint, such that the value of said current setpoint does not exceed a predefined current setpoint limit.

4. Converter (1,7) according to any of the preceding  
5 claims, wherein said virtual admittance module is a  
positive phase sequence virtual admittance module (35),  
receiving at its input a difference  
( $V_{set,pps} + V_{comp,pps} - V_{act,pps}$ ) between a sum  
( $V_{set,pps} + V_{comp,pps}$ ) of a positive phase sequence  
10 voltage setpoint ( $V_{set,pps}$ ) and a positive phase  
sequence compensation voltage ( $V_{comp,pps}$ ), and a  
positive phase sequence current controller output  
voltage ( $V_{act,pps}$ ), and providing at its output a  
positive phase sequence current setpoint  
15 ( $I_{convset,pps}$ ), and wherein  
said compensation module is a positive phase sequence  
compensation module (37), receiving at its input a  
positive phase sequence current setpoint  
( $I_{convset,pps}$ ), and providing at its output said  
20 positive phase sequence compensation voltage  
( $V_{comp,pps}$ ).
5. Converter (1,7) according to claim 4, wherein the  
converter control further comprises  
25 - a negative phase sequence virtual admittance module  
(36), receiving at its input a difference  
( $V_{set,nps} + V_{comp,nps} - V_{act,nps}$ ) between a sum  
( $V_{set,nps} + V_{comp,nps}$ ) of a negative phase sequence  
voltage setpoint ( $V_{set,nps}$ ) and a negative phase  
30 sequence compensation voltage ( $V_{comp,nps}$ ), and a  
negative phase sequence current controller output  
voltage ( $V_{act,nps}$ ), and providing at its output a  
negative phase sequence current setpoint  
( $I_{convset,nps}$ ), and  
35 - a negative phase sequence compensation module (38),  
receiving at its input a negative phase sequence  
current setpoint ( $I_{convset,nps}$ ), and providing at its

output said negative positive phase sequence  
compensation voltage ( $V_{comp,nps}$ ), wherein  
said current setpoint ( $I_{convset}$ ) is a sum of the  
positive and negative phase sequence current setpoints  
5 ( $I_{convset,pps}$ ,  $I_{convset,nps}$ ).

6. Converter (1,7) according to claim 5, wherein said  
current controller is a positive phase sequence current  
controller (41), receiving at its input a difference  
10 between said current setpoint ( $I_{convset}$ ) and a measured  
converter current ( $I_{convmeas}$ ), and providing at its  
output said positive phase sequence current controller  
output voltage ( $V_{act,pps}$ ), and the converter control  
further comprises a negative phase sequence current  
15 controller (42), receiving at its input a difference  
between said current setpoint ( $I_{convset}$ ) and a measured  
converter current ( $I_{convmeas}$ ), and providing at its  
output said negative phase sequence current controller  
output voltage ( $V_{act,nps}$ ).

20 7. Converter (1,7) according to any of the preceding  
claims, wherein the damping module (17) comprises a  
transfer function.

25 8. Converter (1,7) according to any of the preceding  
claims, wherein said virtual admittance module (19)  
comprises a combination of a linear and a non-linear  
transfer function.

30 9. Converter (1,7) according to any of the preceding  
claims, wherein the converter (1,7) is a modular  
multilevel converter configured to stabilize an AC  
high-voltage grid.

35 10. Method for controlling a converter (1,7), the  
method comprising the steps of  
- receiving at an input of a current controller (16) a  
difference between a current setpoint ( $I_{convset}$ ) and

- a measured converter current ( $I_{convmeas}$ ), and providing at its output a current controller output voltage ( $V_{act}$ ),
- 5       - receiving at an input of a damping module (17) said measured converter current ( $I_{convmeas}$ ), and providing at its output a damping voltage ( $V_{damp}$ ), wherein a sum of said damping voltage ( $V_{damp}$ ) and said converter controller output voltage ( $V_{act}$ ) is provided to a converter modulator,
  - 10       - receiving at an input of a virtual admittance module (19) a difference ( $V_{set}+V_{comp}-V_{act}$ ) between a sum ( $V_{set}+V_{comp}$ ) of a voltage setpoint ( $V_{set}$ ) and a compensation voltage ( $V_{comp}$ ), and said current controller output voltage ( $V_{act}$ ), and providing at  
15       its output said current setpoint ( $I_{convset}$ ), and
  - receiving at an input of a compensation module (20) said current setpoint ( $I_{convset}$ ), and providing at  
      its output said compensation voltage ( $V_{comp}$ ), wherein  
20       said compensation module (20) counteracts the damping effect of the damping module (17).

$\frac{1}{4}$ 

FIG 1

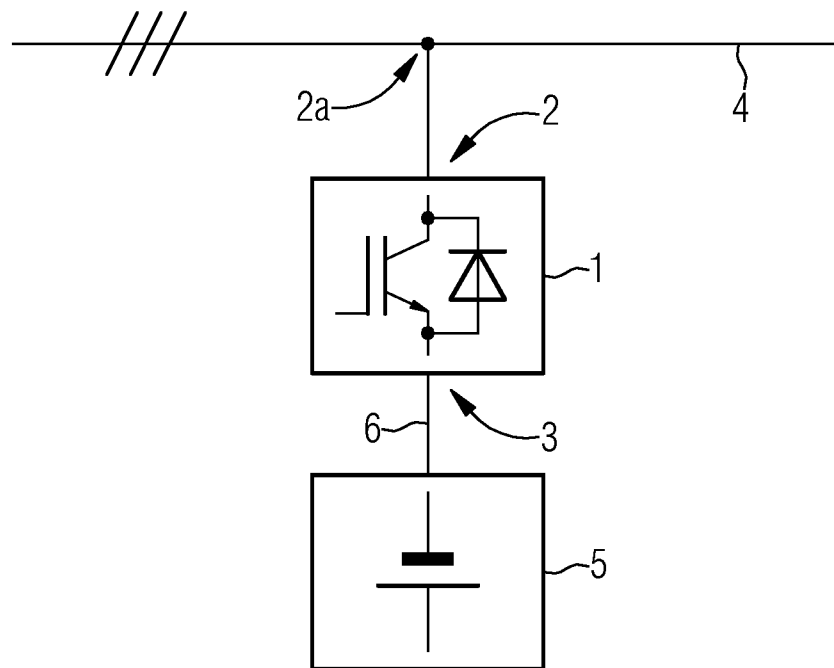


FIG 2

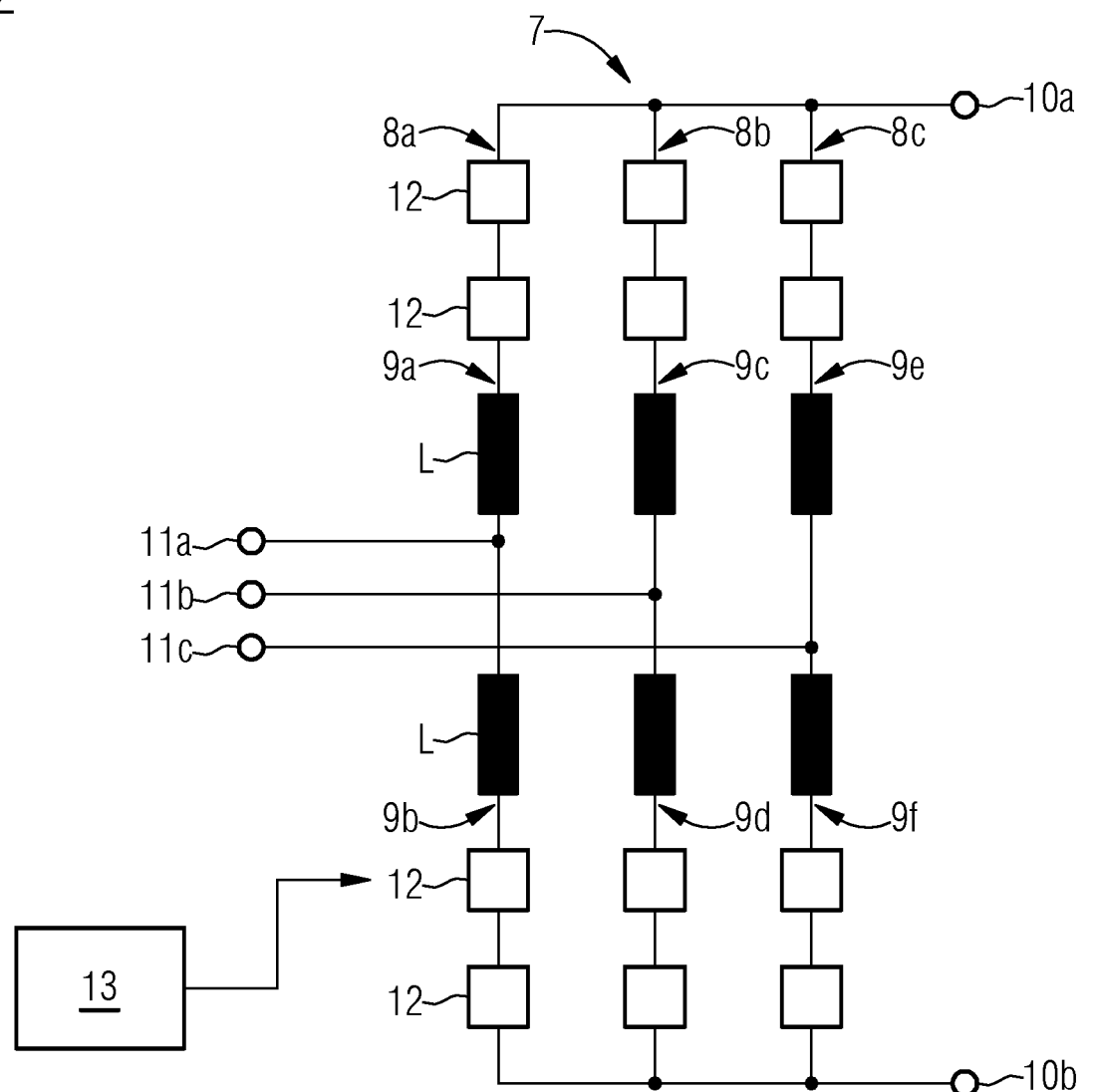


FIG 3

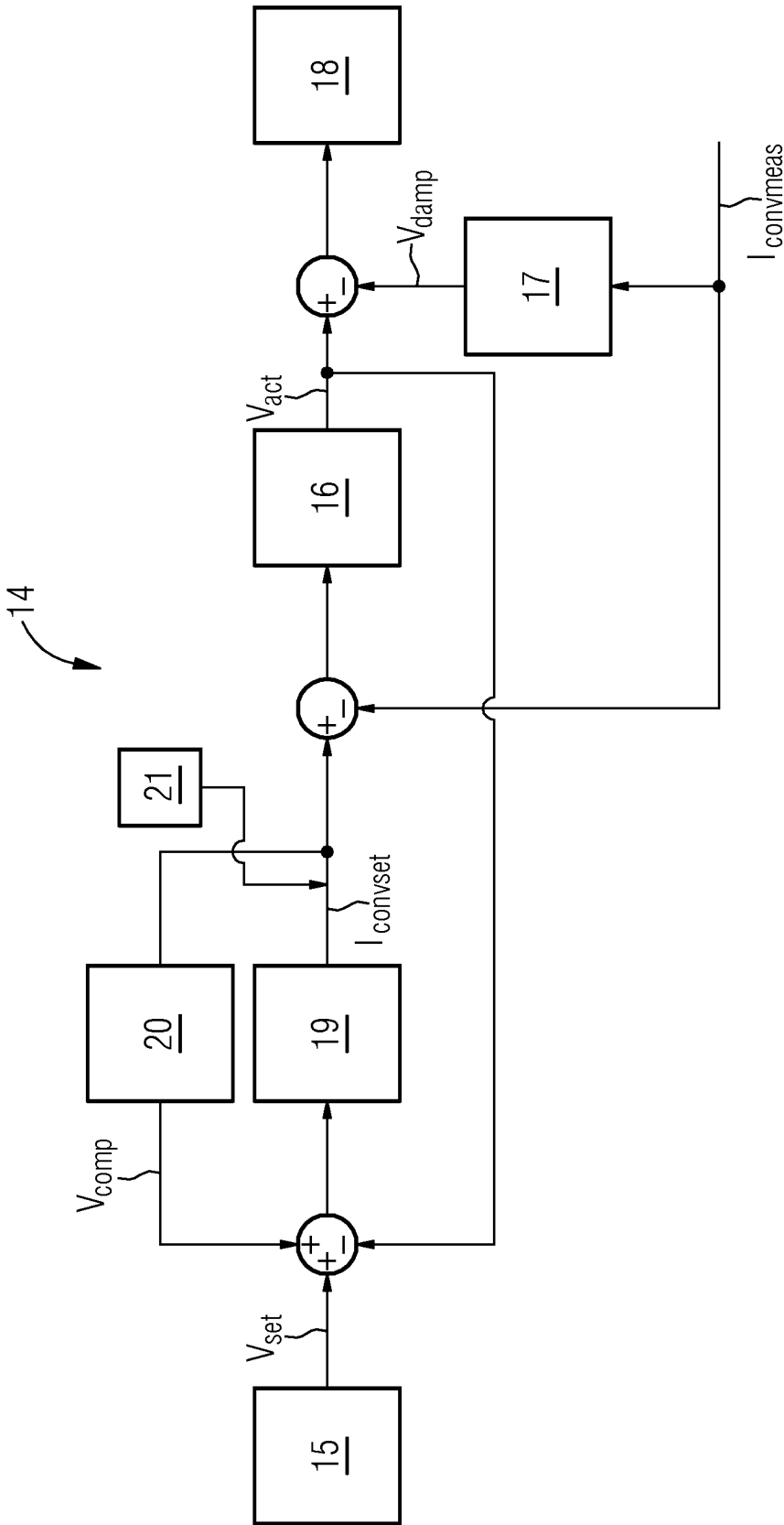


FIG 4

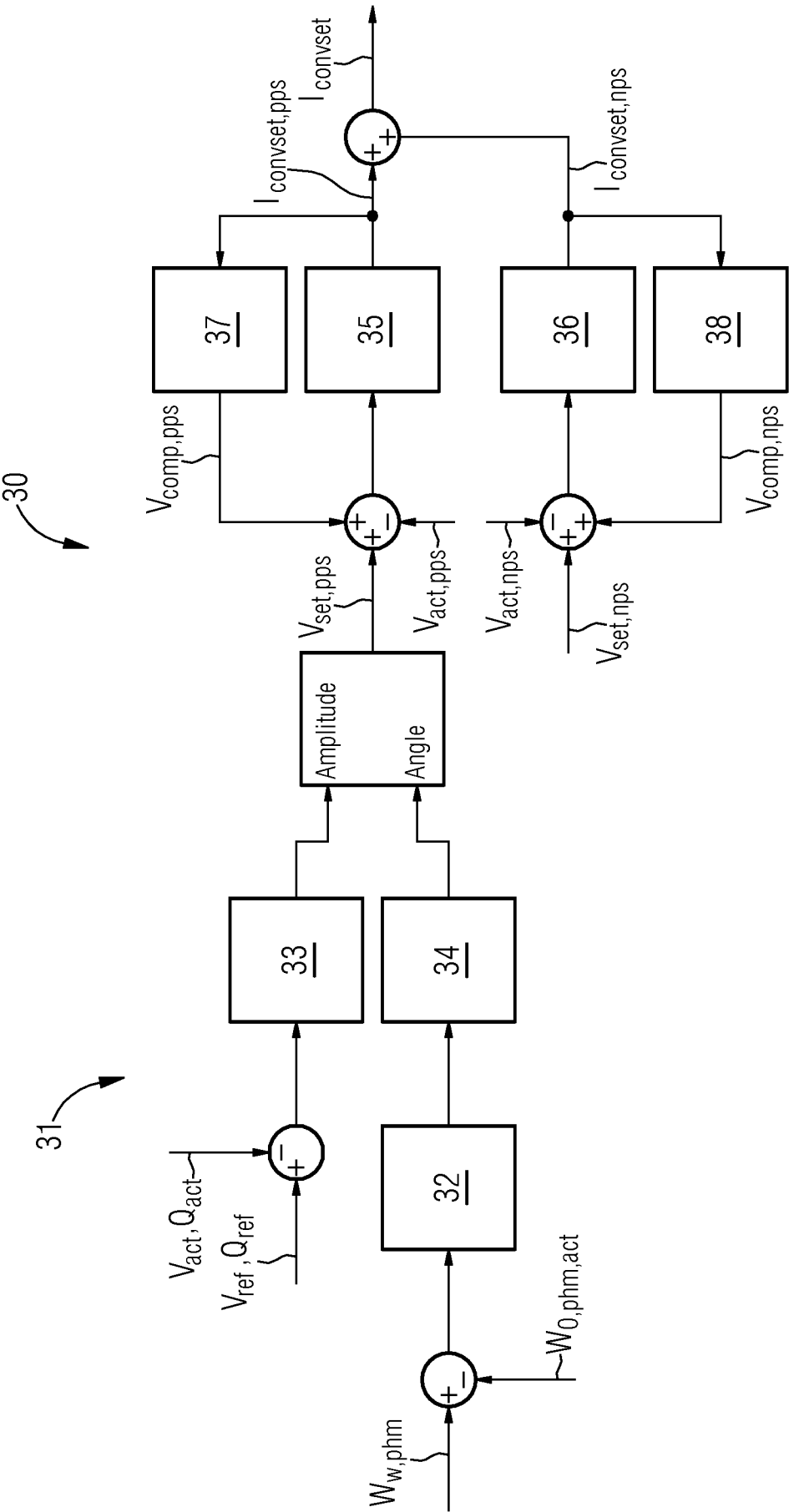
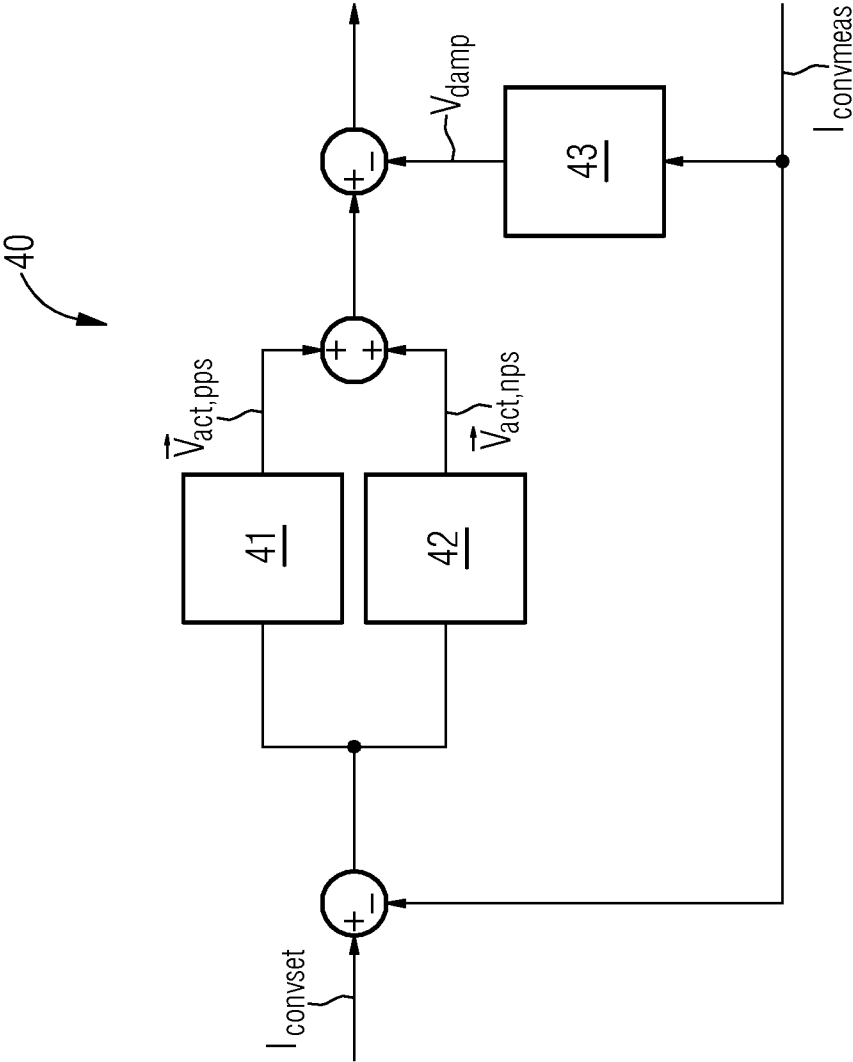


FIG 5



## INTERNATIONAL SEARCH REPORT

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| <b>A. CLASSIFICATION OF SUBJECT MATTER</b><br>INV. H02M7/5387 H02M7/483 H02M1/00 H02M1/12<br>ADD.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                              |                                                      |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------|
| According to International Patent Classification (IPC) or to both national classification and IPC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                              |                                                      |
| <b>B. FIELDS SEARCHED</b><br>Minimum documentation searched (classification system followed by classification symbols)<br><b>H02M</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                              |                                                      |
| 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)<br><b>EPO-Internal</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                              |                                                      |
| <b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                              |                                                      |
| Category*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Citation of document, with indication, where appropriate, of the relevant passages                                           | Relevant to claim No.                                |
| X                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | CN 103 529 858 A (UNIV BEIHANG)<br>22 January 2014 (2014-01-22)                                                              | 1-3,7,8,<br>10                                       |
| Y                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | abstract; figures 1,5                                                                                                        | 9                                                    |
| A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | -----<br>4-6                                                                                                                 |                                                      |
| Y                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | EP 4 057 500 A1 (SIEMENS ENERGY GLOBAL<br>GMBH & CO KG [DE])<br>14 September 2022 (2022-09-14)<br>paragraph [0029]; figure 4 | 9                                                    |
| A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | -----<br>CN 104 022 631 A (UNIV CHINA MINING)<br>3 September 2014 (2014-09-03)<br>abstract; figure 4                         | 1-10                                                 |
| A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | -----<br>CN 111 585 302 A (WUHAN TIANFUHAI TECH<br>DEVELOPMENT CO LTD)<br>25 August 2020 (2020-08-25)<br>abstract            | 1-10                                                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | -----<br>- / - -                                                                                                             |                                                      |
| <input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                                                                              |                                                      |
| * Special categories of cited documents :<br>"A" document defining the general state of the art which is not considered to be of particular relevance<br>"E" earlier application or patent but published on or after the international filing date<br>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)<br>"O" document referring to an oral disclosure, use, exhibition or other means<br>"P" document published prior to the international filing date but later than the priority date claimed<br>"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<br>"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone<br>"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<br>"&" 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 May 2024                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                                                                              | 05/06/2024                                           |
| Name and mailing address of the ISA/<br>European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040,<br>Fax: (+31-70) 340-3016                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                              | Authorized officer<br><br><b>Kanelis, Konstantin</b> |

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International application No

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| C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT |                                                                                                                          |                       |
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| Category*                                            | Citation of document, with indication, where appropriate, of the relevant passages                                       | Relevant to claim No. |
| A                                                    | US 2012/314466 A1 (GOERGES DANIEL [DE] ET AL) 13 December 2012 (2012-12-13) paragraphs [0091], [0144]; figure 1<br>----- | 1 - 10                |

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