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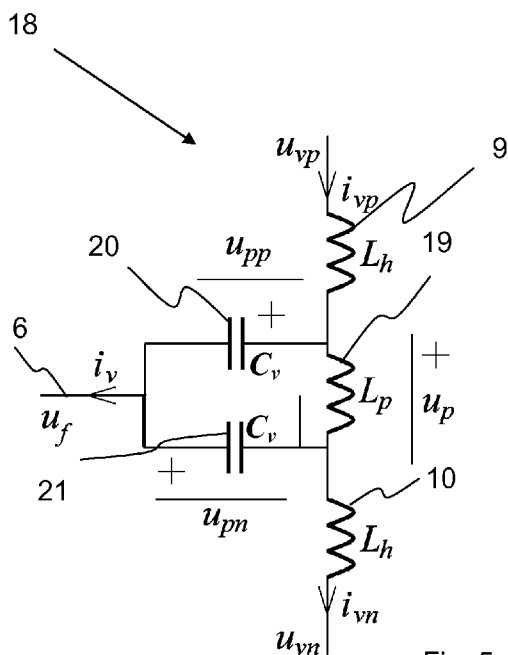


Fig. 5

(57) Abstract: A device for converting a DC voltage into an AC voltage comprises a passive electronic filter (18) having a first and a second energy storage element (9, 10), a third energy storage element (19) placed between the first and second energy storage elements, a fourth energy storage element (20) connected between a junction of the first energy storage element and the third energy storage element and an AC terminal and a fifth energy storage element (21) connected between a junction of the second energy storage element and the third energy storage element and the AC terminal. The energy storage elements are of two different types, capacitive and inductive, with values selected to provide reduction of components at two times the fundamental frequency of the AC voltage and at least one capacitive element (20, 21) is a DC blocking element for stopping DC components from reaching the AC terminal.

MODULAR MULTI -LEVEL POWER CONVERTER WITH HARMONICS REDUCTION AND DC BLOCKING FILTER

FIELD OF THE INVENTION

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The invention is related to a power converter with multi-level voltage output in the form of a device for converting a DC voltage into an AC voltage and vice versa comprising at least one phase leg with a first voltage source and a first passive energy storage element connected in series between a first DC terminal and a first AC terminal and
10 with a second passive energy storage element and a second voltage source connected in series between the first AC terminal and a second DC terminal, where each of the voltage sources comprises at least a first and a second submodule in series-connection, each submodule comprising at least one power electronic switch connected in parallel with at least one capacitor.

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BACKGROUND ART

In the art, multi-level converters are known to be used in order to reduce harmonic distortion in the output of voltage source converters. A multilevel converter is a
20 converter where the output voltage – or, in case of a multiphase converter, the voltages - can assume several discrete levels, as can be seen for example in DE10103031.

In WO 2008/067785 A1, a multi-level converter according to DE10103031 is disclosed
25 which in addition comprises at least one inductor in each phase leg as well as regulating means to regulate a circulating current flowing through the phase legs, i.e. the current that closes between the phase legs but does not enter the AC grid through the AC terminal.

30 If the circulating-current is controlled, as described in WO 2008/067785, the voltage rating of the power electronic switches of the converter must allow for the extra voltage needed to regulate the circulating currents in the desired manner.

These multilevel converters are furthermore normally connected to the AC grid via a transformer. It is in some cases also of interest to remove this transformer.

SUMMARY OF THE INVENTION

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It is therefore an object of the invention to propose a power converter which allows for regulation of the circulating currents in a desired manner, where the required voltage rating of the power semiconductor switches is affected as little as possible at the same time as the removal of a transformer can be done safely.

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This object is achieved by a device according to claim 1.

The device for converting a DC voltage into an AC voltage and vice versa as described above, comprises according to the invention a passive electronic filter
15 which is arranged between the voltage source and the AC terminal. The passive electronic filter is adjusted to reduce harmonics in a circulating current and to block DC components.

The invention is based on the recognition of the fact that the desired manner in which
20 the circulating currents should best be regulated is to reduce the harmonics which occur at specific frequencies in the circulating current, rather than to reduce the circulating currents in general. This is according to the invention furthermore combined with filtering of DC components. What the inventor realized is that at each switching event in the power electronic switches of the converter, harmonics appear in
25 the circulating current causing increased losses. As a worst case, some of the harmonics with distinctively high amplitude in the circulating currents could even lead to system instability. The introduction of additional inductors, as described in WO 2008/067785 A1, helps to obtain a general current limitation in the converter circuit but does nothing to avoid the distinctive harmonics as such.

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By introducing a passive electronic filter that reduces or in the best case completely blocks the harmonics with the highest amplitude, it is avoided that the control unit which controls the power semiconductor switches sees and takes into account the

most disturbing components of the circulating currents. The requirements on the voltage rating of the power semiconductor switches can thereby be reduced.

A closer look at the harmonics in the circulating currents revealed the following: The
5 sum of the voltage ripple over the submodules of both phase module branches in one phase leg shows in its frequency spectrum a main component at twice the fundamental frequency of the AC voltage. This main frequency component creates a parasitic harmonic component in the circulating current that is also of twice the fundamental frequency. Unless this component is somehow limited, increased losses
10 will result; possibly even loss of system stability.

Therefore, according to a preferred embodiment of the invention, the parameters of the electronic filter are chosen so that harmonics at twice the fundamental frequency of the AC voltage are reduced, thereby specifically reducing the main disturbing
15 component of the circulating current. This is furthermore combined with DC blocking so that it is possible to connected the converter to an AC grid without a transformer.

BRIEF DESCRIPTION OF THE DRAWINGS

20 Other features and advantages of the present invention will become more apparent to a person skilled in the art from the following detailed description in conjunction with the appended drawings in which:

- Fig. 1 shows a converter topology as is known from the art,
- Fig. 2 shows the setup of the voltage sources in the phase legs of the converter
25 of Fig. 1 as known from the art,
- Fig. 3 shows two different embodiments of the submodules in the converter of Figs. 1 and 2,
- Fig. 4 shows one phase leg of a converter with a schematically shown electronic filter according to the invention,
- 30 Fig. 5 shows an electronic filter according to a first embodiment of the invention,
- Fig. 6 shows an electronic filter according to a second embodiment of the invention,

- Fig. 7 shows an electronic filter according to a third embodiment of the invention,
- Fig. 8 shows an electronic filter according to a fourth embodiment of the invention,
- 5 Fig. 9 shows an equivalent common mode realization of the filter according to the fourth embodiment,
- Fig. 10 shows an equivalent differential-mode realization of the filter according to the fourth embodiment,
- Fig. 11 shows an electronic filter according to a fifth embodiment of the invention
- 10 Fig. 12 shows an electronic filter according to a sixth embodiment of the invention,
- Fig. 13 shows an electronic filter according to a seventh embodiment of the invention, and
- Fig. 14 shows an electronic filter according to an eighth embodiment of the
- 15 invention.

DETAILED DESCRIPTION OF THE INVENTION

The device for converting a DC voltage into an AC voltage and vice versa according to the invention can contain either a single phase leg or multiple phase legs, depending on how many phases the AC voltage has. Fig. 1 shows a three-phase converter known in the art. The three phase legs 1, 2 and 3 of the device of Fig. 1 each comprise two so-called arms in series-connection: a positive, upper arm which is connected to a first DC terminal 4 at a positive voltage level, and a negative, lower arm, which is connected to a second DC terminal 5 at zero or a negative voltage level. Each positive arm comprises a series-connection of an upper voltage source U_{vpi} and a first passive energy storage element, here in the form of an inductor 9, 11 or 13, respectively, and each negative arm comprises a second passive energy storage element, here also in the form of an inductor 10, 12 or 14, respectively, and a lower voltage source U_{vni} , where i stands for the number of the corresponding phase leg. The midpoint or connection point between the first and second energy storage elements of each phase leg is each connected to an AC terminal 6, 7 or 8, respectively. All the phase legs are connected in parallel to each other and to the two

DC terminals 4 and 5. By appropriately controlling the voltage sources of the phase legs over time, the AC to DC conversion is made.

As is shown in Fig. 2, each voltage source is made up of a series connected string of submodules 15, where at least two submodules 15 are comprised in one such string.

In fig. 3, two different embodiments 15a and 15b of the submodules 15, which are known in the art, can be seen. Any combination of the submodules is possible within each voltage source. The submodules have the form of commutation cells, each cell comprising two valves and a large DC capacitor holding a direct voltage. The main valves are equipped with a power electronic switch 16 with turn-off capability and a free-wheeling diode in anti-parallel connection to the switch. Depending on which of the two power electronic switches 16 is conducting, the corresponding submodule can assume one of two switching states, where in state one zero voltage or in state two the capacitor voltage is applied to the output.

According to the invention, the converter according to Figs. 1 to 3 is additionally equipped with a passive electronic filter in each phase leg, as is depicted in Fig. 4 for phase leg 1. In fig. 4, the filter 18 is shown as a dashed box. The filter includes three terminals a first terminal for being coupled to the first voltage source and first DC terminal 4, a second terminal for being coupled to the second voltage source and the second DC terminal 5 and finally a third terminal connected to the AC terminal 6 of the converter. As can be seen in fig. 4 the first and second passive energy storage elements are being included in the passive filter.

A first embodiment of the filter 18 is shown fig. 5. In between the first and second passive energy storage elements, 9 and 10, which are here both reactors having an inductance L_h , there is here provided a third passive energy storage element 19, in this first embodiment also in the form of a reactor having an inductance of L_p . This third passive energy storage element 19 is thus provided in series with the first and second energy storage elements.

There is furthermore a fourth energy storage element 20, having two ends, a first end connected to a junction between the first energy storage element 9 and the third energy storage element 19 and a second end connected to the AC terminal 6. The fourth energy storage element 20 is here a capacitor having a capacitance C_v . There is furthermore a fifth energy storage element 21 having two ends a first end connected to a junction between the second energy storage element 10 and the third energy storage element 19 and a second end connected to the AC terminal 6. The fifth energy storage element 21 is in this embodiment also a capacitor having a capacitance C_v . As can be seen in fig. 4, the filter includes two types of passive energy storage elements, inductive and capacitive energy storage elements. As is clear the third energy storage element 19 is of one of the types, here an inductive energy storage element, while the fourth and fifth energy storage elements 20 and 21 are of another type, here capacitive energy storage elements. It can therefore be seen that a filter is provided, which provides filtering in relation to one or more frequencies. Another feature that can be readily observed is that the provision of the fourth and the fifth energy storage elements as capacitive energy storage elements without any inductive or resistive branches in parallel with them, will stop any DC components appearing in the DC phase leg from reaching the AC terminal 6. It is therefore clear that the filter realized in fig. 5 has DC blocking capability. One further observation that can be made is that there is a first path provided from the first DC terminal to the AC terminal via the first and the fourth energy storage elements and a second path provided from the second DC terminal to the AC terminal via the second and the fifth energy storage elements. These paths are furthermore symmetrical, which means that the filter elements in them are provided of the same types in the same orders and with the same values in the first and the second paths.

As mentioned above the filter has filtering properties in relation to one or more frequencies. This filtering will now be described in more detail.

The symbols in Fig. 5 have the following meaning:

$u_{vp/n}$ voltage of the voltage source in positive or negative arm, respectively;

$i_{vp/n}$ current in positive/negative arm;

- i_v output current at AC terminal;
 u_f voltage at AC terminal (AC voltage);
 u_p voltage across the third energy storage element;
 i_p current through the third energy storage element;
5 L_h inductance of the first and second energy storage element;
 C_v capacitance of the fourth and fifth energy storage element;
 L_p inductance of the third energy storage element;
 r inner resistance of each inductor (not shown in figures).

- 10 In the following it is described, how the parameters of the electronic filter are chosen in order to reduce the most disturbing harmonics of the circulating current in the depicted phase 1.

- The governing equation for the circulating current $i_c = (i_{vp} + i_{vn})/2$ can be obtained by
 15 applying Kirchhoff's voltage law to the direct path from u_{vp} to u_{vn} , giving

$$u_{vp} - L_h \frac{di_{vp}}{dt} - ri_{vp} - u_p - L_h \frac{di_{vn}}{dt} - ri_{vn} = u_{vn}. \quad (1)$$

Introducing the differential voltage $u_{vc} = (u_{vp} - u_{vn})/2$ allows equation (1) to be simplified to

$$L_h \frac{di_c}{dt} = u_{vc} - \frac{1}{2}u_p. \quad (2)$$

- 20 It is seen that u_{vc} is the driving voltage for the circulating current. This voltage is controllable, i.e., it can be made to follow a reference u_{vc}^{ref} , but it also contains a parasitic term Δu_{vc} as

$$u_{vc} = u_{vc}^{\text{ref}} + \Delta u_{vc}. \quad (3)$$

Taking the paths from u_{vp} to u_f and u_{vn} to u_f , yields the following relations

$$\begin{aligned}
 u_{vp} - L_h \frac{di_{vp}}{dt} - u_{pp} &= u_f \\
 u_{vn} + L_h \frac{di_{vn}}{dt} + u_{pn} &= u_f
 \end{aligned} \tag{4}$$

which, with introduction of the output current $i_v = i_{vp} - i_{vn}$, the mean converter output $u_v = (u_{vp} + u_{vn})/2$ and the differential capacitor voltage $u_{pc} = (u_{pp} - u_{pn})/2$ can be combined to

$$5 \quad L \frac{di_v}{dt} = u_v - u_{pc} - u_f \tag{5}$$

It is seen that the filter quantities u_p and i_p do not affect the output current. Finally taking the loop around the circuit made up of the inductance L_p and the two capacitances C_v yields:

$$u_p = u_{cp} - u_{cn} \tag{6}$$

10 After differentiating equation (6) and rearranging the resulting equation yields

$$C_v du_p / dt = 2(i_c - i_p) \tag{7}$$

Equations (2) and (7) can be combined with the relation $L_p di_p / dt = u_p$ to form a third-order state-space system:

$$\begin{aligned}
 \frac{di_c}{dt} &= -\frac{1}{2L_h} u_p + \frac{1}{L_h} u_{vc} \\
 \frac{di_p}{dt} &= \frac{1}{L_p} u_p \\
 \frac{du_p}{dt} &= \frac{2}{C_v} (i_c - i_p).
 \end{aligned} \tag{8}$$

15 The system in equation (8) can be expressed as a Laplace function with d/dt expressed as s. This system is marginally stable, i.e. its poles are located on the imaginary axis of the s plane. The system can be made asymptotically stable by active damping in the form of feedback of i_c (cf. (3)):

$$u_{vc}^{\text{ref}} = -\alpha_{cc} L_h i_c \quad (9)$$

where α_{cc} is a bandwidth to be chosen. Substitution of (9) in (3) and, in turn, in (8) yields the modified state-space system

$$\begin{aligned} \frac{di_c}{dt} &= -\alpha_{cc} i_c - \frac{1}{2L_h} u_p + \frac{1}{L_h} \Delta u_{vc} \\ \frac{di_p}{dt} &= \frac{1}{L_p} u_p \\ \frac{du_p}{dt} &= \frac{2}{C_v} (i_c - i_p). \end{aligned} \quad (10)$$

5 With i_c as output signal, the following input –output relation is obtained:

$$i_c = \frac{s^2 + \frac{2}{L_p C_v}}{Y_c(s)} \Delta u_{vc} \quad (11)$$

$$\text{where } Y_c(s) = \left[s^3 + \alpha_{cc} s^2 + \frac{1}{C_v} \left(\frac{2}{L_p} + \frac{1}{L_h} \right) s + \frac{2\alpha_{cc}}{L_p C_v} \right] L_h \text{ and } s = d/dt \text{ as before}$$

10 From equation (11) it can be seen that the input signal Δu_{vc} consists of the following components:

- 1) a first, fairly strong component at twice the fundamental frequency of the AC voltage (but normally less than 0.1 p.u.);
- 2) a second weaker component (approximately 1/6th of the first component and thus in the range of 0.01 p.u.) at four times the fundamental frequency of the AC component;
- 15 3) switching harmonics having a wide frequency spectrum.

In order to properly attenuate the effect on the circulating current of these components, a careful selection of the circuit parameter and the bandwidth α_{cc} may be needed.

In order to block the strong component at twice the fundamental frequency the inductance L_p of the third energy storage element 19 in the filter in fig. 5 may be chosen so that the parallel resonances in fig. 5, i.e. the zeroes of the expression $Y_c(s)$ become tuned to twice the fundamental frequency. With ω_B as the nominal
 5 fundamental (base) angular frequency, we get

$$L_p = \frac{1}{2\omega_B^2 C_v} \quad (12)$$

It can be seen that the value of the third energy storage element is inversely proportional to the value of the fourth and fifth energy storage elements. The inverse of the value of the third energy storage element is furthermore equal to a fundamental
 10 frequency dependent constant times the value of the fourth and fifth energy storage elements, where this constant includes the square of the fundamental frequency times a factor that is a multiple of 2, which multiple is in this case 1. According to equation (12), C_v should be chosen as large as possible, because this allows a smaller value of L_p . Furthermore the inductance L_h of the first and second energy storage elements 9
 15 and 10 may need to be large enough to provide a satisfactory low short-circuit current for surviving diode surge currents during DC faults. Additionally L_h may also need to be large enough to provide adequate attenuation of the high-frequency switching harmonics in Δu_{vc} , since for large ω

$$Y_c(j\omega) \approx \frac{1}{j\omega L_h} \quad (13)$$

20 Moreover, for $\alpha_{cc} = 0$, $Y_c(j\omega)$ will have an infinitely high resonance peak at

$$\omega_0 = \sqrt{\frac{1}{C_v} \left(\frac{2}{L_p} + \frac{1}{L_h} \right)} = \{(12)\} = 2\omega_B \sqrt{1 + \frac{C_v}{4\omega_B^2 L_h}} \quad (14)$$

To satisfactorily suppress both the component at four times the fundamental frequency and high-frequency switching harmonics in Δu_{vc} , the circuit parameters may need to be selected such that $\omega_0 < 4\omega_B$ in order to prevent amplification at twice
 25 the fundamental frequency and at the switching harmonics.

With regard to the bandwidth it should be selected large enough to give adequate damping of the resonant peak at ω_0 . On the other it should be small enough to provide a low control effort, i.e. $|u_{cc}| \ll |\Delta u_{vc}|$ in order to avoid rating the voltage sources for a higher voltage than necessary. We have

$$u_{cc} = \alpha_{cc} L_h i_c = \frac{\alpha_{cc} \left(s^2 + \frac{2}{L_p C_v} \right)}{G(s)} \Delta u_{vc} \quad (15)$$

$$\text{where } G(s) = s^3 + \alpha_{cc} s^2 + \frac{1}{C_v} \left(\frac{2}{L_p} + \frac{1}{L_h} \right) s + \frac{2\alpha_{cc}}{L_p C_v}$$

It can be noted that $|G(j\omega)| = |G(j0)| = 1$, whereas $|G(j\omega)| < 1$ for all other frequencies and particularly $|G(j2\omega_B)| = 0$. This implies that the control effort can be made very low, especially for moderate α_{cc} .

If the fundamental frequency is 50 Hz it is possible to set $L_h = 50$ mH and $C_v = 1350$ mF, which will give $L_p = 3.7$ mH, which will block or reduce the component at twice the fundamental frequency.

It is possible to vary the filter in many ways. Another realization providing the same effect is shown in fig. 6. Fig. 6 thus shows a filter according to a second embodiment of the invention having a first 9', second 10', third 19', fourth 20' and fifth 21' energy storage element in the same positions as the corresponding elements in the first embodiment. Here the first, second and third energy storage elements 9', 10', 19' are capacitive, while the fourth and fifth 20' and 21' are inductive.

Fig. 7 discloses a filter according to a third embodiment having the first 9, second 10, third 19', fourth 20 and fifth 21 energy storage element in the same positions as the corresponding elements in the first embodiment. Here the first and second elements 9 and 10 are again inductive, while the third 19' is capacitive. The fourth and fifth elements 20, 21 are inductive. These elements are not enough for performing DC blocking. Therefore this third embodiment has a sixth passive energy storage element 22 that is capacitive and at one end connected to both the second ends of the fourth and the fifth energy storage elements 20 and 21 and at a second end connected to the AC terminal 6. This sixth passive energy storage element 22 thus functions as the DC blocking element.

For this third embodiment it is possible to obtain the following relationship in an analogous way

$$C_p = \frac{1}{8\omega_B^2 L_v} \quad (16)$$

The resonance frequency of the filter according to the third embodiment can in a similar manner be obtained as

$$\omega_0 = \sqrt{\frac{1}{2C_p} \left(\frac{1}{L_v} + \frac{1}{L_h} \right)} = \{(6)\} = 2\omega_B \sqrt{1 + \frac{L_v}{L_h}}. \quad (17)$$

The inductance L_v may also here be selected such that $\omega_0 < 4\omega_B$ in order to prevent amplification at twice the fundamental frequency and at the switching harmonics. This implies that the inductance L_h of the first and the second inductors and the inductance L_v of the third and the fourth inductors could be selected in the same region, possibly as $L_h = L_v$.

For a fundamental frequency $\frac{\omega_B}{2 \cdot \pi} = 50 \text{ Hz}$, a total inductance of $L_v + L_h = 50 \text{ mH}$ per arm may be desired. For equally sized inductors, this results in $L_v = L_h = 25 \text{ mH}$. Equation (16) would then yield $C_p = 50.66 \text{ }\mu\text{F}$.

It is in many cases of interest to add and remove a wave provided at three times the
 5 fundamental frequency of the AC voltage. Such adding has the effect of raising the efficiency of the power transmitted. Such an added component of the AC voltage needs to be removed so that it is not present in the AC voltage when conversion is made between AC and DC. This removal is often performed using a transformer. However, if no such transformer is to be present, this component would have to be
 10 removed in another way. The filter according to the invention can be designed for also removing harmonics at three times the fundamental frequency from the AC voltage. Fig. 8 – 15 are directed towards various such solutions.

In fig. 8 there is shown a filter according to a fourth embodiment of the invention. This filter includes the first, second, third, fourth and fifth energy storage elements 9, 10,
 15 19, 20 and 21 of the first embodiment. The filter thus includes the same elements of the same types at the same positions as in fig. 5. However the filter here includes at least one parallel connection of the two types of elements, inductive and capacitive, in the paths between the DC terminals and the AC terminal, where each path between a DC terminal and the AC terminal includes one such parallel connection. In this fourth
 20 embodiment, these parallel connections are provided through the first and second energy storage elements 9 and 10 being connected in parallel with a respective further element 23 and 24 of the opposite type. This means that there is one further passive energy storage element 23 in parallel with the first energy storage element 9 and another further passive energy storage element 24 in parallel with the second
 25 energy storage element 10. Since the first and the second energy storage elements 9 and 10 are inductive, this means that the further energy storage elements 23 and 24 are here capacitive and each have a capacitance C_p .

When combining removal of harmonics at two and three times the fundamental frequency in this way it is of interests to study the common and differential modes of the converter voltages, where

$$\begin{aligned} u_{vp} &= u_v + u_{vc} \\ u_{vn} &= u_v - u_{vc} \end{aligned} \quad (18)$$

- 5 where u_{vp} is the voltage of the positive DC terminal, u_{vn} is the voltage of the negative DC terminal, u_v is the common mode component and u_c is the differential mode component.

- 10 The harmonics at three times the fundamental frequency appears in the common-mode component u_v , while the harmonics at two times the fundamental frequency appears in the differential-mode component u_{vc} .

- 15 Due to symmetry, the common-mode component u_v does not drive any current through the third energy storage element 19, because the potential on each side of this element 19 are affected equally by this component. This allows this element to be removed when the effect of the common-mode component is considered. The branches of the two arms in fig. 8 thus reduce to two identical circuits in parallel and this can be simplified into the equivalent circuit diagram of the common-mode case shown in fig. 9. There is here a parallel LC circuit where a capacitance $2C_p$ is
- 20 connected in parallel with an inductance $L_h/2$, which parallel circuit is then connected in series with a capacitance $2C_v$. This circuit in fig. 9 should be tuned to block the third harmonic component. This implies that

$$\frac{1}{L_h C_p} = (3\omega_1)^2 \Rightarrow C_p = \frac{1}{9\omega_1^2 L_h} \quad (19)$$

- 25 The capacitance of the parallel connection is thus inversely proportional to the inductance of the parallel connection, where the inverse of the capacitance is equal to a fundamental frequency dependent constant times the inductance. It can also be seen that the constant is the square of the fundamental frequency times a factor that

is a multiple of the number 3 and here a multiple of one of the number 3. If then the differential-mode component u_{vc} is considered, it can be seen that due to the symmetry, this component does not affect the voltage u_f of the AC terminal and therefore not the grid current i_v , only the circulating current i_c . An equivalent circuit for the filter in this differential mode is shown in fig. 10, where it can be seen that there is a first parallel connection of a capacitance $C_p/2$ and an inductance $2L_h$ connected between the positive differential mode voltage u_{vc} and a junction. Between this junction and the negative differential mode voltage $-u_{vc}$ there is a second parallel connection of an inductance L_p and a capacitance $C_v/2$. In order to block the second harmonics component, the first parallel connection should be set as

$$\frac{1}{L_p(C_v/2)} = (2\omega_1)^2 \Rightarrow C_v = \frac{1}{2\omega_1^2 L_p} \quad (20)$$

In this way there is provided a filter, which blocks or reduces the frequencies at two or three times the fundamental frequency as well as blocks DC components. There are a number of variations that are possible to make of the filter for removing harmonics at two and three times the fundamental frequency together with DC blocking.

One such first variation is shown in fig. 11. Fig. 11 shows a filter according to a fifth embodiment that is based on the second embodiment. This filter includes the first, second, third, fourth and fifth energy storage elements 9', 10', 19', 20', 21' of the second embodiment. The filter thus includes the same elements of the same types at the same positions as in fig. 6. The parallel connections are here provided via the fourth and fifth energy storage elements 20' and 21'. There is therefore a first further storage element 25 being capacitive and having a capacitance C_v connected in parallel with the fourth inductive storage element 20' and a second further storage element 26, also capacitive with a capacitance C_v , connected in parallel with the fifth energy storage element 21'.

Fig. 12 shows a filter according to a sixth embodiment of the two invention that is a further variation of the first embodiment. This filter includes the first, second, third,

fourth and fifth energy storage elements 9, 10, 19, 20, 21 of the first embodiment. The filter thus includes the same elements of the same types at the same positions as in fig. 5. However the filter here additionally includes only one parallel connection of the two types of elements, inductive and capacitive, in the paths between the DC terminals and the AC terminal, through providing an additional parallel connection of inductor 27 with inductance L_{3h} and capacitor 28 with capacitance C_{3h} . This additional parallel connection is here provided in series between the AC terminal 6 and a junction between the parallel fourth and fifth energy storage elements 20 and 21.

Fig. 13 shows yet another filter according to a seventh embodiment of the invention. This filter is based on the filter according to the third embodiment. This filter thus includes the first, second, third, fourth, fifth and sixth energy storage elements 9, 10, 19', 20, 21, 22 of the third embodiment. The filter thus includes the same elements of the same types at the same positions as in fig. 7. The filter here includes two parallel connections of the two types of elements, inductive and capacitive, in the paths between the DC terminals and the AC terminal through a first further energy storage element 25, here capacitive with capacitance C_v , connected in parallel with the fourth energy storage element 20' and through a second additional energy storage element 26, also capacitive with a capacitance C_v , in parallel with the fifth energy storage element 21'. In the filter according to fig. 13, the capacitor value of the third energy storage element 19' may be set according to $C_p = \frac{5}{72\omega_1^2 L_v}$, while the value of the first and second additional energy storage elements 25 and 26 may be set according to $C_v = \frac{1}{9\omega_1^2 L_v}$. These values are obtained using the same type of analysis as described above in relation to the fourth embodiment. From that analysis, it is also evident that the provision of the sixth energy storage element will not influence the selection of the other storage element values.

The values of the various energy storage elements of the fifth, sixth and seventh embodiments can all be made in line with the setting according to the fourth embodiment.

5 When providing filtering of harmonics at three times the fundamental frequency there are some details that may need to be considered. The requirements for low injection of zero-sequence third-harmonic current into the grid may be strict, much more so than the requirements for suppression of the harmonic component at twice the fundamental frequency from the circulating current. Since there are always tolerances
10 associated with the parameter values of the inductors and capacitors, as specified by the manufacturer in the case, it may be necessary to introduce an on-line tuning facility to some of the energy storage elements, for instance the ones involved in blocking second harmonics. It may also be necessary to tune the filter for tracking changes in grid frequency. It is here possible to provide an inductor with tap changers.

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Take the filter in fig. 13 as an example. Here it is possible to provide the fourth and fifth energy storage elements 20' and 21' with tap changers of a suitably selected number of steps and step sizes. As an alternative it is also possible to have the first and second further energy storage elements 25 and 26 variable, for instance through
20 using capacitor banks, the capacitances of which can be modified in suitably selected steps through circuit breakers and/or switching semiconductors.

The example above essentially provided two parallel variable elements, one in each path from a DC terminal to the AC terminal. It should here be realized that it may be
25 advantageous to have only one such variable energy storage element in the filter, because then the provision of the same variation in relation to the two paths is easier to control. An example on this is shown in an eighth embodiment of the filter in fig. 14, which is based on the seventh embodiment. The only elements that differ from the seventh embodiment are here the third energy storage element and the additional
30 energy storage elements. Otherwise all elements are of the same type and provided in the same position as in the seventh embodiment. Here the third energy storage

element has been split into two energy storage elements 19a and 19b of the same type, i.e. capacitive. The second further energy storage element has furthermore been deleted, while the first further energy storage element 26 is adjustable and at a first end connected to a midpoint of the third energy storage element and at a second
5 opposite end connected to the sixth energy storage element 22. Here the midpoint of the third energy storage element is provided as the junction between the two energy storage elements 19a and 19b resulting from the splitting. This filter functions in the same way as the filter according to the seventh embodiment, but here only one energy storage elements is adjusted.

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Another way to provide only one further variable capacitive energy storage element without using the sixth energy storage element is to split the third energy storage element 19' of the fifth embodiment shown in fig. 11 in half, remove the second further energy storage element 21' and connect the first end of the first adjustable further
15 energy storage element 25' to the junction between the two energy storage elements resulting from the split.

The invention has a number of advantages. It blocks circulating currents without having to resort to removing the current through the control of the voltage sources.
20 This is combined with blocking a DC component from reaching the grid, which is of advantage if there is no transformer between grid and voltage source converter. In some variations of the invention this blocking is also obtained using a filter element involved in blocking or limiting of components at two times the fundamental frequency. There may thus be a dual use of such an element. The integration of two types of
25 filtering functionalities, at two and three times the fundamental frequency, has the advantage of allowing the use of zero sequence third harmonics in the AC grid without having to use a transformer between the converter and the AC grid. In some embodiments this is also performed using only a few additional filter elements, while some filter elements are used in relation to more than one function. All phase
30 inductances can furthermore be concentrated to the phase arms and the number of inductors used reduced, which is cost-effective. The use of two elements in two paths

for performing the same function also reduces the losses incurred by the inner resistances of the inductors. This is due to the fact that each arm only takes half the grid current, while full grid current would pass through an inductor placed at the grid interface. The combination of second and third harmonics removal enables reduction
5 in the size of the capacitances used. There are also advantages of using two capacitors, both for blocking DC components and blocking of third harmonics components. They will each take half the current, which reduces the capacitor rating. The blocking of DC components can also be made without using additional capacitors. If the first and second energy storage elements are inductors, these are
10 normally very large, which enables the keeping of a capacitive third energy storage element to be very small and thus costs are saved.

It should finally be mentioned that the element values C_v , C_p , L_v , L_p etc. are in the figures used to indicate that there is a value associated with the element of the
15 position. It is not intended to mean that the same type of element in the same position has the same value in the different embodiments. These values will normally differ from each other.

CLAIMS

1. Device for converting a DC voltage into an AC voltage and vice versa comprising at least one phase leg (1, 2, 3), each phase leg having a first (Uvp1, Uvp2, Uvp3) voltage source and a first passive energy storage element (9, 11, 13; 9') connected in series between a first DC terminal (4) and a first AC terminal (6) and a second passive energy storage element (10, 12, 14; 10') and a second (Uvn1, Uvn2, Uvn3) voltage source connected in series between the first AC terminal (6) and a second DC terminal (5), where each of the voltage sources comprises at least a first and a second submodule (15) in series-connection, each submodule (15) comprising at least one power electronic switch (16) connected in parallel with at least one capacitor (17), **characterized in that** a passive electronic filter (18) comprising passive energy storage elements is arranged between the first and second voltage sources as well as the first AC terminal, said filter comprising said first and second energy storage elements, a third energy storage element (19; 19'; 19a, 19b) connected in series between the first and second energy storage elements, a fourth energy storage element (20; 20') having two ends, a first end connected to a junction between the first energy storage element and the third energy storage element and a second end coupled to the AC terminal and a fifth energy storage element (21; 21') having two ends, a first end connected to a junction between the second energy storage element and the third energy storage element and a second end coupled to the AC terminal, wherein the energy storage elements comprise elements of two different types, capacitive and inductive energy storage elements, with values selected to provide reduction of frequency components at two times the fundamental frequency of the AC voltage and at least one capacitive element (20, 21; 9', 10'; 22) of the filter is a DC blocking element for stopping DC components from reaching the AC terminal.
2. Device according to claim 1, wherein the third energy storage element is of one of the types and the fourth and fifth energy storage elements are of

another type.

3. Device according to claim 1 or 2, wherein at least one of the passive energy storage elements of the filter is a combined DC blocking and frequency filtering element.
4. Device according to any previous claim, wherein the fourth and the fifth energy storage elements (20, 21) are capacitive and function as DC blocking elements.
5. Device according to any of claims 1 - 3, wherein the first and the second energy storage elements (9', 10') are capacitive and function as DC blocking elements.
6. Device according to claim 1 or 2, further comprising a sixth passive energy storage element (22) that is capacitive and at one end connected to both the second ends of the fourth and the fifth energy storage elements and at a second end coupled to the AC terminal, where this sixth passive energy storage element functions as the DC blocking element.
7. Device according to any previous claim, wherein the third, fourth and fifth energy storage elements are provided in a filter section providing filtering at two times the fundamental frequency of the AC voltage.
8. Device according to claim 7, wherein the value of the third energy storage element is inversely proportional to the value of the fourth and fifth energy storage elements, where the inverse of the value of the third energy storage element is equal to a fundamental frequency dependent constant times the value of the fourth and fifth energy storage elements.
9. Device according to claim 8, wherein said constant includes the square of the fundamental frequency times a factor that has a dependence of a multiple of

the number of 2.

10. Device according to any previous claim, wherein the filter comprises passive energy storage elements providing reduction of frequency components at three times the fundamental frequency of the AC voltage.
11. Device according to claim 10, wherein the energy storage elements providing said blocking include at least one parallel connection of the two types of elements, where each path between the DC terminals and the AC terminal includes such a parallel connection.
12. Device according to claim 11, where such parallel connections are provided through the first and second energy storage elements (9, 10) being connected in parallel with a respective further element (23, 24) of the opposite type in order to provide two parallel connections.
13. Device according to claim 11, where at least one of the elements of the filter is a combined filtering element assisting in filtering at both two times and three times the fundamental frequency of the AC voltage.
14. Device according to claim 13, wherein such parallel connections are provided through at least one further energy storage element of another type than the fourth and fifth energy storage elements is connected in a branch provided in parallel with the fourth energy storage element.
15. Device according to claim 14, wherein the further element (25') is also connected in a branch being parallel with the fifth element and connected to the mid point of the third energy storage element (19a, 19b).
16. Device according to claim 14, wherein there is provided a first further element (25; 25') in parallel with the fourth element and a second further element (26; 26') in parallel with the fifth element.

17. Device according to claim 11, wherein said parallel connection is provided through the parallel connection of one further element (28) of the capacitive type with one further element (27) of the inductive type being coupled in a common connection joining both the fourth and the fifth elements to the AC terminal:
18. Device according to any of claims 11 - 17, wherein the value of one energy storage element of such a parallel connection is inversely proportional to the value of the other energy storage element of the parallel connection, where the inverse of the value of said one storage element is equal to a fundamental frequency dependent constant times the value of the other energy storage element.
19. Device according to claim 18, wherein said constant includes the square of the fundamental frequency times a factor that is a multiple of 3.
20. Device according to any of claims 10 – 19, wherein at least one of the elements providing filtering at two times the fundamental frequency is adjustable.

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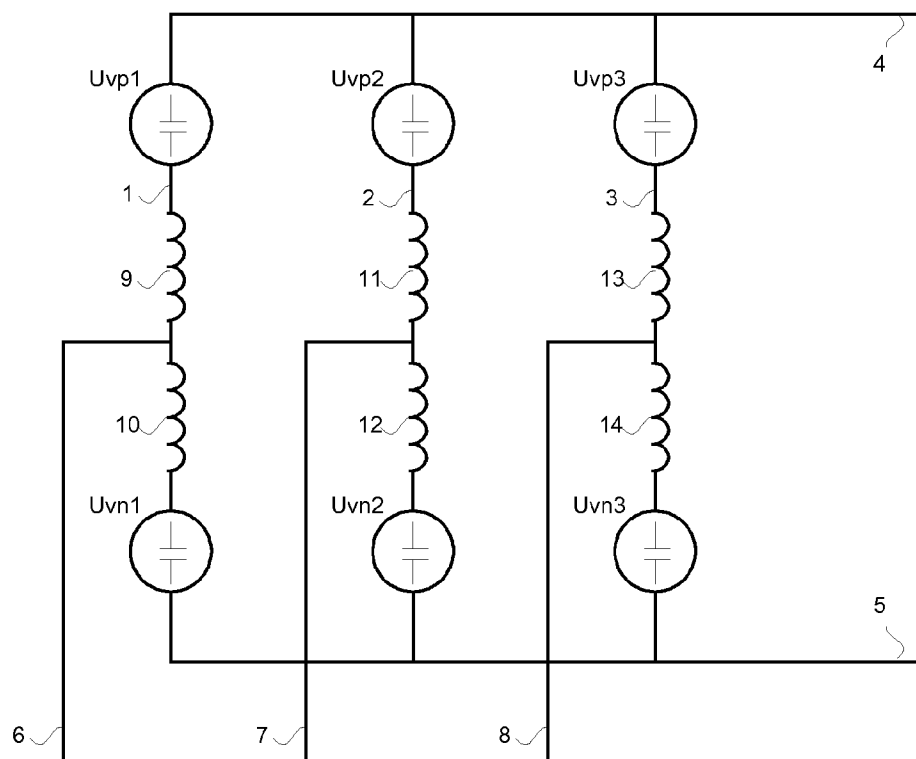


Fig. 1

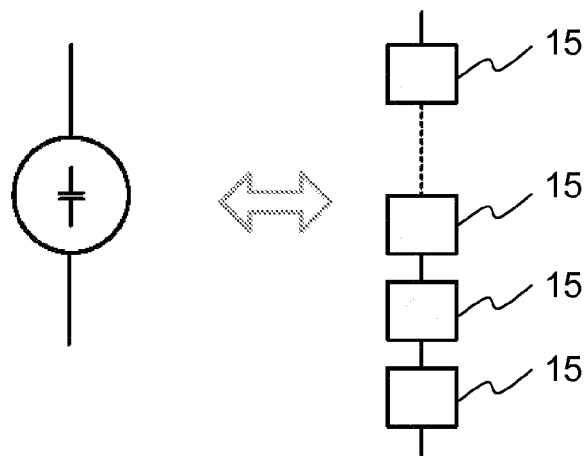
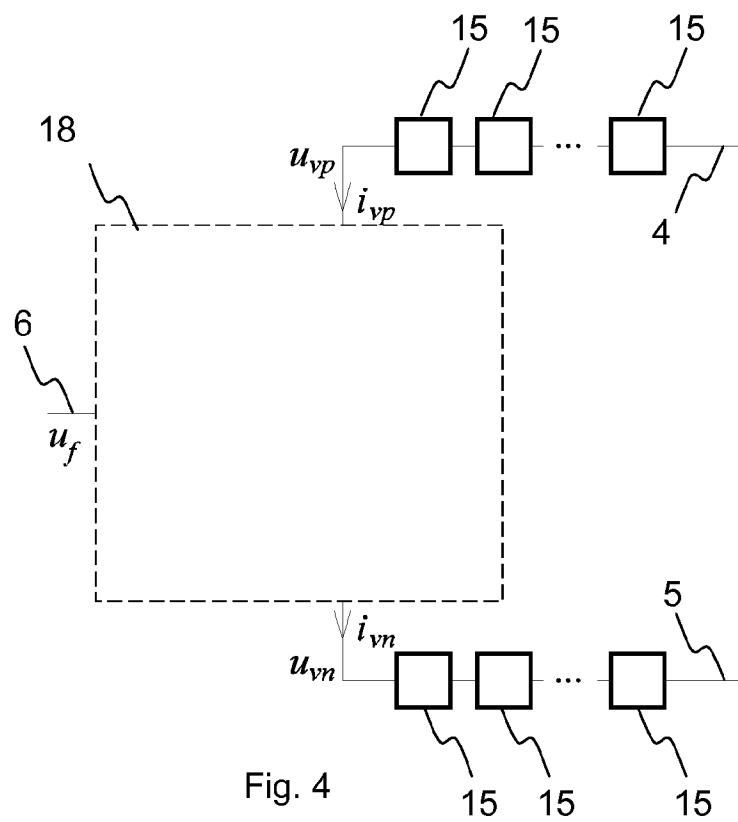
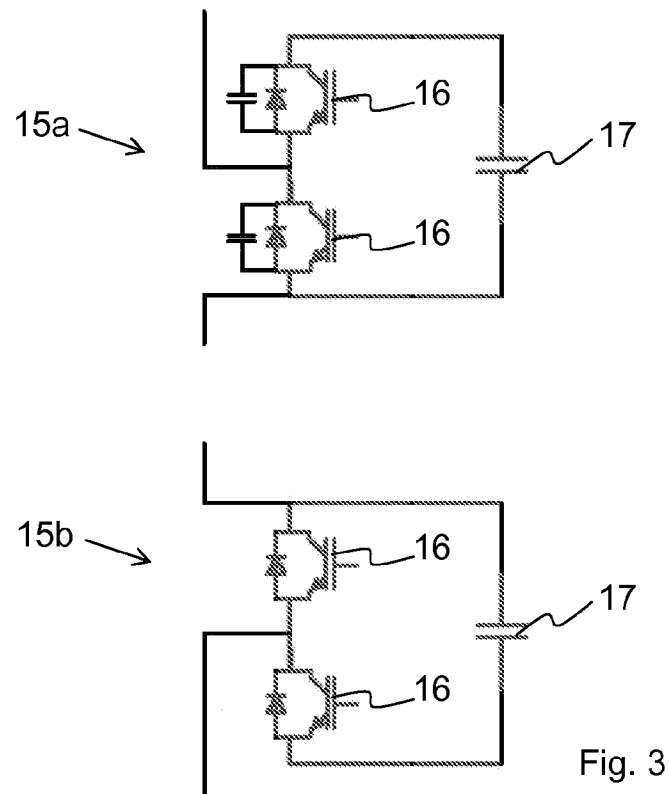


Fig. 2

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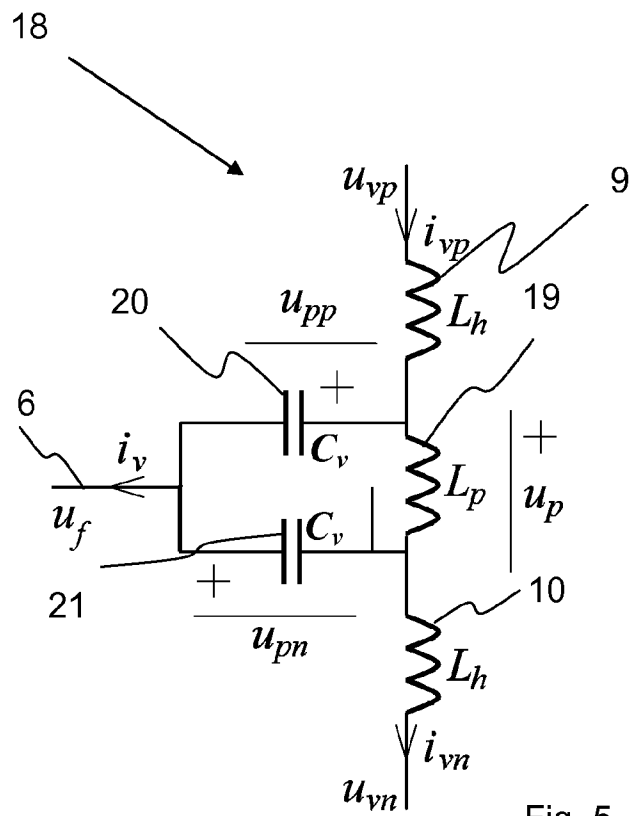


Fig. 5

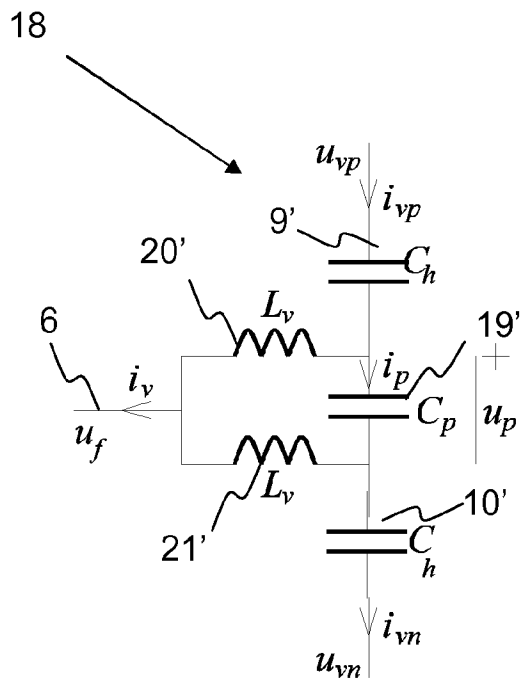


Fig. 6

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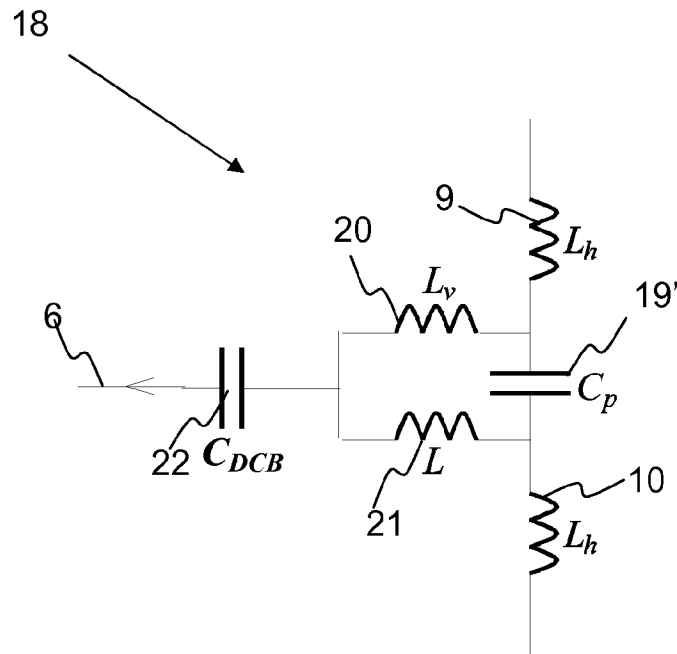


Fig. 7

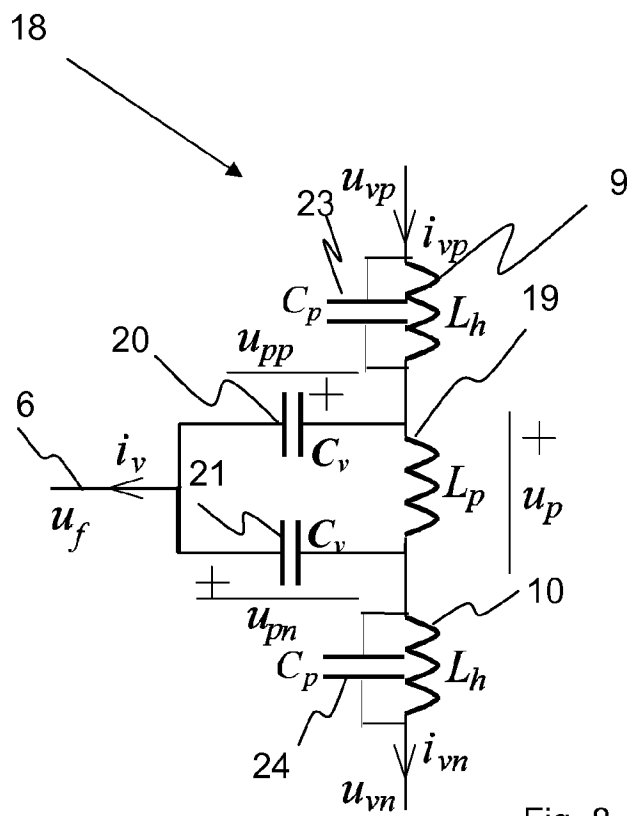


Fig. 8

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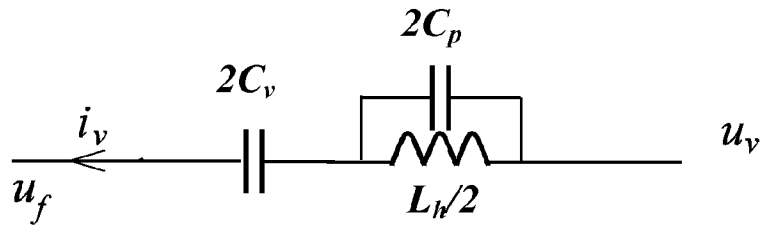


Fig. 9

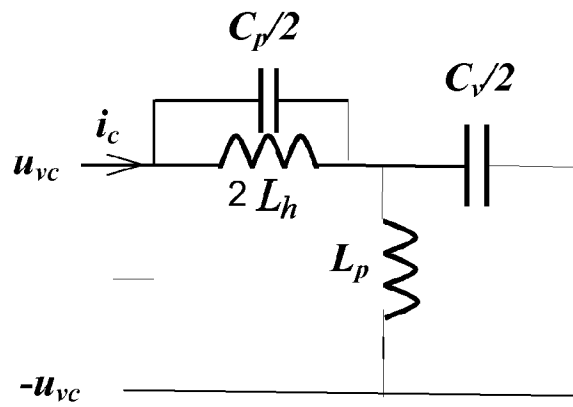


Fig. 10

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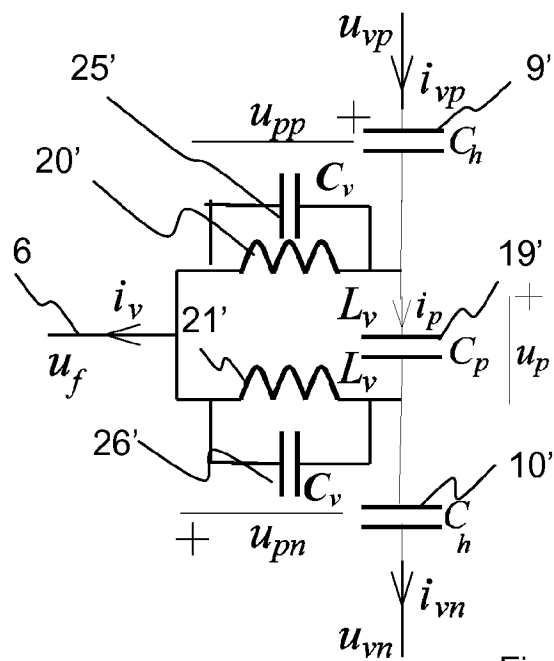


Fig. 11

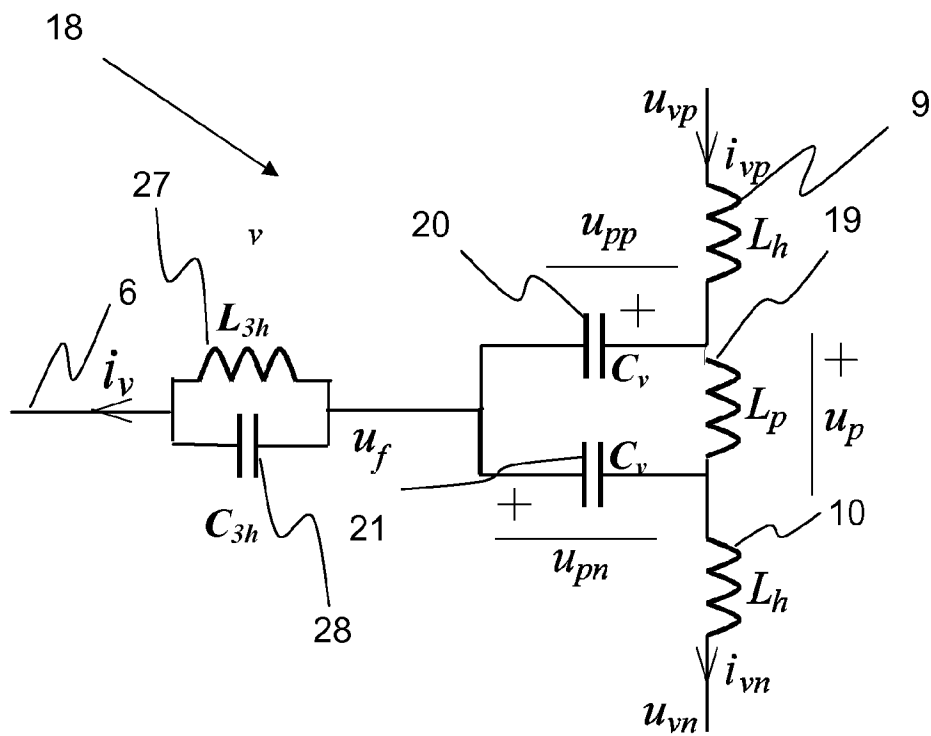


Fig. 12

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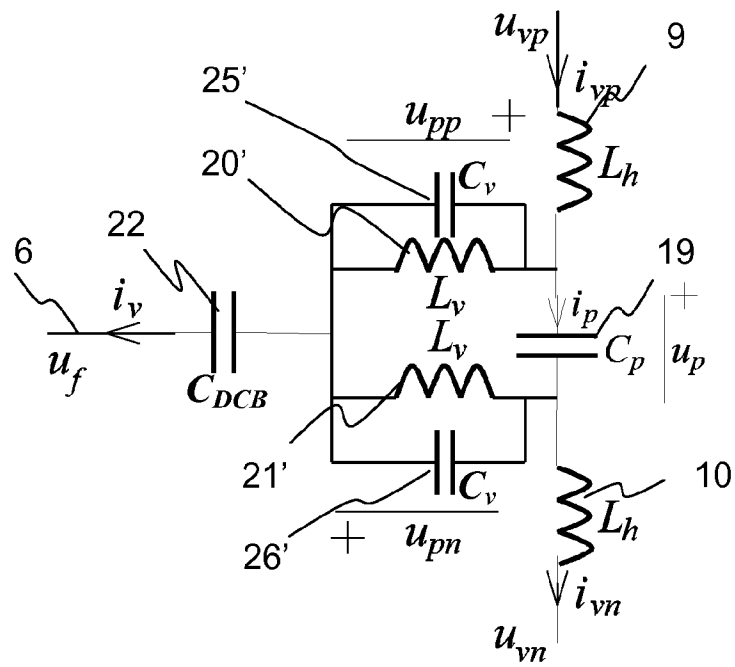


Fig. 13

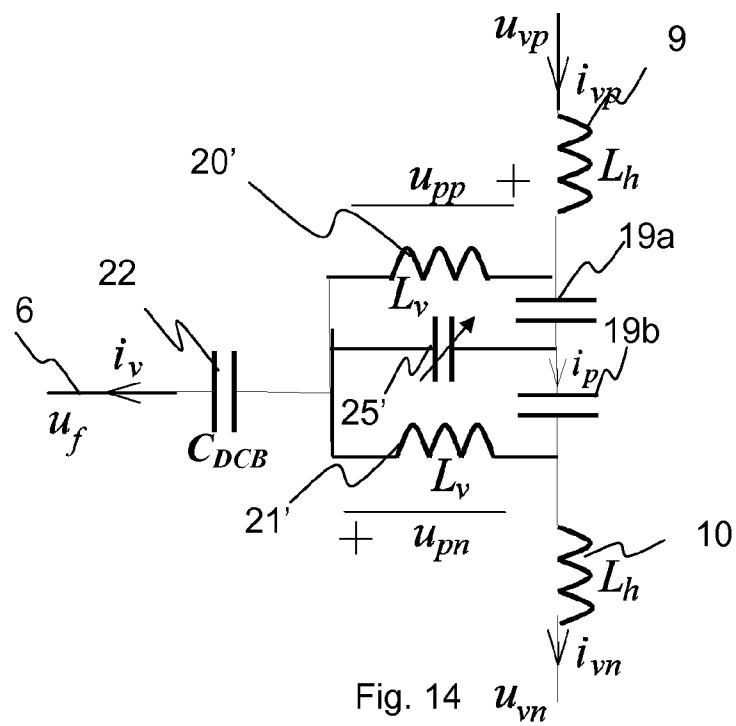


Fig. 14

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2010/054998

A. CLASSIFICATION OF SUBJECT MATTER
INV. H02M1/12 H02M1/14
ADD. H02M7/49

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

B. FIELDS SEARCHED

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

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

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

EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2009/149755 A1 (ABB TECHNOLOGY AG [CH]; ASPLUND GUNNAR [SE]) 17 December 2009 (2009-12-17) figures 7,8 page 4 page 6, lines 27-32 page 10, line 31 - page 11, line 32 -----	1-20
A	GB 2 397 445 A (ALSTOM [FR]) 21 July 2004 (2004-07-21) figures 2,4,5 page 5, line 1 - page 6, line 11 page 6, line 24 - page 7, line 4 -----	1-20
A	GB 2 459 764 A (SIEMENS AG [DE]) 11 November 2009 (2009-11-11) abstract; figures 1-5 page 1 ----- -/-	1-20



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

11 March 2011

Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2010/054998

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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International application No

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