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(72) **Inventeurs/Inventors:**
DOMMASCHK, MIKE, DE;
DORN, JOERG, DE;
EULER, INGO, DE;
LANG, JOERG, DE;
SOERANGR, DAG, DE;
TU, QUOC-BUU, DE;
WUERFLINGER, KLAUS, DE

(73) **Propriétaire/Owner:**
SIEMENS AKTIENGESELLSCHAFT, DE

(74) **Agent:** SMART & BIGGAR

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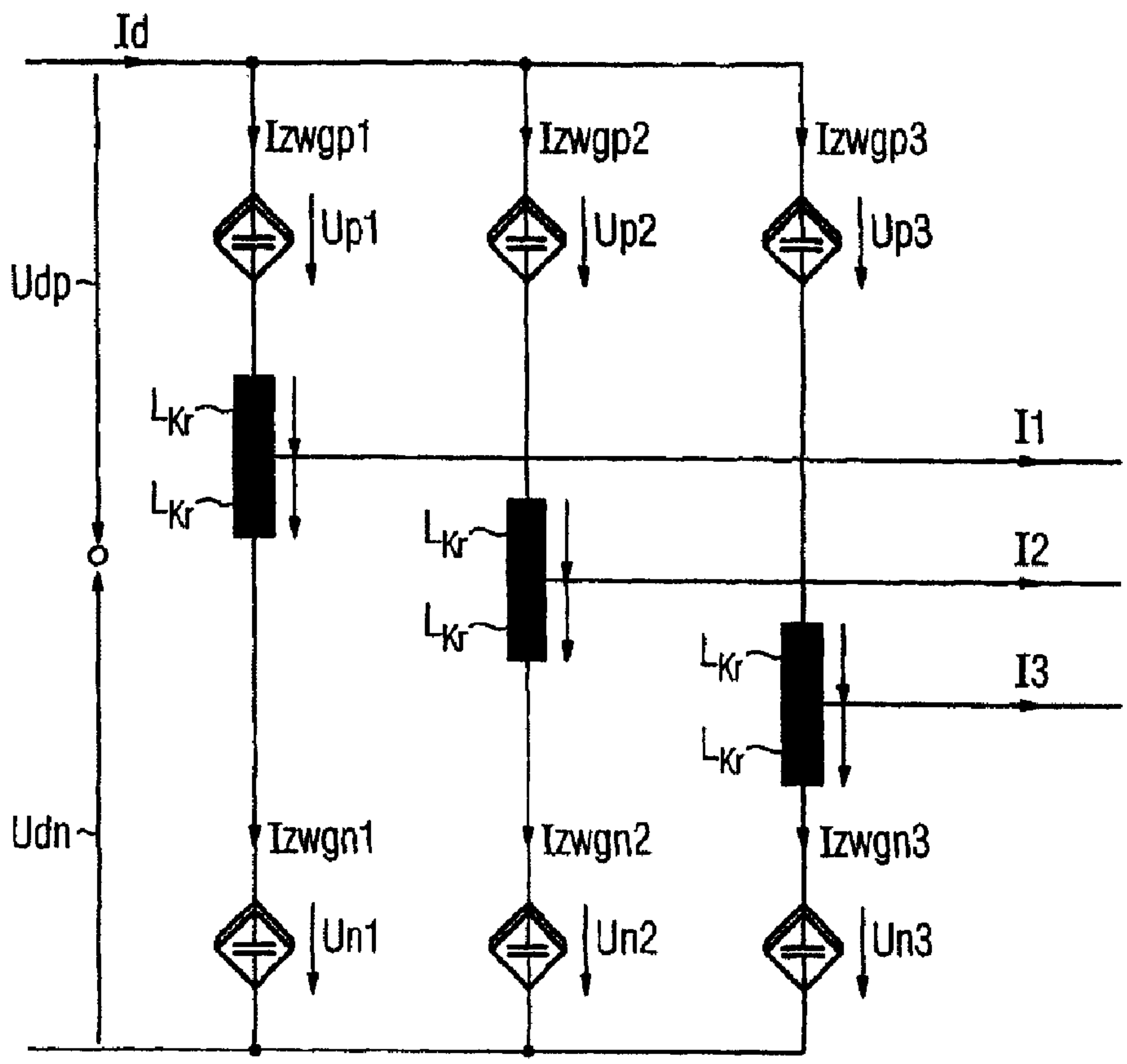
(54) **Title: DEVICE FOR CONVERTING AN ELECTRIC CURRENT**



(57) **Abrégé/Abstract:**
The invention relates to a device (1) comprising: at least one phase module (2a, 2b, 2c) with an a.c. voltage connection (3_1,3_2,3_3) and at least one d.c. voltage connection (p,n), a phase module branch (6p1, 6p2, 6p3, 6n1, 6n2, 6n3) being arranged between

(57) **Abrégé(suite)/Abstract(continued):**
each d.c. voltage connection (p,n) and the a.c. voltage connection (3_1,3_2,3_3) and each phase module branch (6p1, 6p2, 6p3, 6n1, 6n2, 6n3) having a series circuit of sub-modules (7), each of which has an energy accumulator (8) and at least one power semiconductor (T_1,T_2); and regulating means for regulating the device. The aim of the invention is to provide a device that can regulate circulating currents in a targeted manner. To achieve this, each phase module (2a, 2b, 2c) has at least one inductance (L_{kr}) and the regulating means are designed to regulate a circulating current that flows through the phase modules (2a, 2b, 2c).

Abstract

The invention relates to a device (1) comprising: at least one phase module (2a, 2b, 2c) with an a.c. voltage connection (3_1,3_2,3_3) and at least one d.c. voltage connection (p,n), a phase module branch (6p1, 6p2, 6p3, 6n1, 6n2, 6n3) being arranged between each d.c. voltage connection (p,n) and the a.c. voltage connection (3_1,3_2,3_3) and each phase module branch (6p1, 6p2, 6p3, 6n1, 6n2, 6n3) having a series circuit of sub-modules (7), each of which has an energy accumulator (8) and at least one power semiconductor (T_1,T_2); and regulating means for regulating the device. The aim of the invention is to provide a device that can regulate circulating currents in a targeted manner. To achieve this, each phase module (2a, 2b, 2c) has at least one inductance (L_{kr}) and the regulating means are designed to regulate a circulating current that flows through the phase modules (2a, 2b, 2c).

Device for converting an electric current

The invention relates to a device for converting an electrical current with at least one phase module, which has an AC voltage connection and at least one DC voltage connection, a phase module branch being formed between each DC voltage connection and the AC voltage connection, and each phase module branch having a series circuit comprising submodules, which each have an energy store and at least one power semiconductor and with regulating means for regulating the device.

Such a device is already known, for example, from the work by A. Lesnicar and R. Marquardt "An Innovative Modular Multilevel Converter Topology Suitable for a Wide Power Range", which appeared on Powertech 2003. This paper discloses a power converter, which is intended to be connected to an AC voltage system. The power converter has a phase module for each phase of the AC voltage system to be connected to it, each phase module having an AC voltage connection and two DC voltage connections. Phase module branches extend between each DC voltage connection and the AC voltage connection such that a so-called 6-pulse bridge circuit is provided. The module branches comprise a series circuit of submodules, which each comprise two disconnectable power semiconductors, with which in each case inverse freewheeling diodes are connected in parallel. The disconnectable power semiconductors and the freewheeling diodes are connected in series, with a capacitor being provided in parallel with said series circuit. Said components of the submodules are wired to one another such that either the capacitor voltage or the voltage zero drops across the two-pole output of each submodule.

The disconnectable power semiconductors are controlled by means of so-called pulse width modulation. The regulating means for controlling the power semiconductors have measuring sensors for detecting currents whilst obtaining current values. The current values are supplied to a central control unit, which has an input interface and an output interface. A modulator, i.e. a software routine, is provided between the input interface and the output interface. The modulator has, inter alia, a selector unit and a pulse width generator. The pulse width generator generates the control signals for the individual submodules. The disconnectable power semiconductors are changed over from an on setting, in which a current flow via the disconnectable power semiconductors is made possible, to an off setting, in which a current flow via the disconnectable power semiconductors is interrupted, by means of the control signals generated by the pulse width generator. In this case, each submodule has a submodule sensor for detecting a voltage drop across the capacitor.

Further papers relating to the control method for a so-called multi-level power converter topology are those by R. Marquardt, A. Lesnicar, J. Hildinger "Modulares Stromrichterkonzept für Netzkupplungsanwendung bei hohen Spannungen" [Modular power converter concept for power supply system coupling application in the case of high voltages], presented at the ETG technical conference in Bad Nauenheim, Germany 2002, by A. Lesnicar, R. Marquardt, "A new modular voltage source inverter topology", EPE' 03 Toulouse, France 2003 and by R. Marquardt, A. Lesnicar "New Concept for High Voltage Modular

Multilevel Converter", PESC 2004 Conference in Aachen, Germany.

The German patent application 10 2005 045 090.3, published as DE 10 2005 059 652 A1 on 28 June 2007, which is as yet unpublished, has disclosed a method for controlling a polyphase power converter with distributed energy stores. The disclosed device likewise has a multi-level power converter topology with phase modules, which have an AC voltage connection arranged symmetrically in the center of each phase module and two DC voltage connections. Each phase module comprises two phase module branches, which extend between the AC voltage connection and one of the DC voltage connections. In turn, each phase module branch comprises a series circuit of submodules, each submodule comprising disconnectable power semiconductors and freewheeling diodes connected back-to-back in parallel therewith. In addition, each submodule has a unipolar capacitor. Regulating means are used for regulating the power semiconductors, which regulating means are also designed to set branch currents which flow between the phase modules. By controlling the branch currents, current oscillations, for example, can be actively damped and operating points at lower output frequencies can be avoided. Furthermore, uniform loading of all of the disconnectable semiconductor switches and symmetrization of very asymmetrical voltages can be brought about.

The submodules of the phase modules generate in each case discrete output voltages, with the result that, given unequal voltage ratios between the phase modules, circulating currents can be brought about between the individual phase modules. These circulating currents are dependent on the ratio of the voltages applied to the inductances within the current path, in addition to the switching frequency at which the power semiconductors are switched. At low switching frequencies of below 200 Hz, the circulating currents can barely be managed in terms of regulation technology in the case of small inductances and cannot be avoided.

An object of some embodiments of the invention is therefore to provide a device of the type mentioned at the outset with which circulating currents can be controlled and possibly reduced in a targeted manner.

In some embodiments, each phase module has at least one inductance, and the regulating means is designed to regulate a circulating current, which flows via the phase modules.

According to the invention, each phase module has at least one inductance. The inductances are designed such that targeted regulation of the circulating currents is made possible by means of the regulating means. In other words, the inductances are matched to the respectively present conditions, such as the DC voltage applied, the AC voltage applied or the like. The regulation predetermines desired circulating voltage setpoint values, which are applied during the regulation of the associated phase module branch as the setpoint value, for example other setpoint voltages of the phase module branch affected, and thus ensure a desired circulating current. In this case, the regulation advantageously has a current regulating unit and an associated drive unit for each phase module branch. The current regulating unit is connected to the submodules of the respective phase module branch only via the drive unit, but not directly. In this case, the current regulating unit generates, for example, a branch voltage setpoint value, which is made available to the drive unit. The drive unit provides control signals, which are supplied to the disconnectable power semiconductors of the submodules, with the result that a total voltage drop across the submodules of the associated phase module branch corresponds to the branch setpoint voltage as precisely as possible. The application of the circulating voltage setpoint values to other setpoint voltages of the respective phase module branch takes place by means of the current regulating unit, which combines said setpoint values with one another in linear fashion, i.e. by means of summation and/or subtraction. The result of this linear combination is branch voltage setpoint values, which are each associated with a phase module branch.

Since each phase module branch has an identical inductance, the required symmetry in terms of regulation technology is provided.

Advantageously, each phase module branch is connected to the AC voltage connection via an inductance. According to this expedient development, the AC voltage connection is arranged between two inductances.

In accordance with a development which is expedient in this regard, the inductances of the phase module are coupled to one another. The coupling increases the total inductance, with the result that the individual inductances in terms of their values, i.e. their inductance, can be correspondingly lowered. In this way, costs are saved. In other words, smaller inductors or coils can be used in the phase module. The total inductance achieved by the coupling in addition affects only the circulating currents and at best the DC components of the phase module branch currents. The inductance for AC-side phase currents is reduced by the coupling of the inductances, however.

The coupling of the inductances can take place via air, via an iron core or the like.

In accordance with this invention, there is provided a device for converting an electrical current with at least one phase module, which has an AC voltage connection and at least one DC voltage connection (p,n), a phase module branch with at least one inductance being formed between each DC voltage connection (p,n) and the AC voltage connection, and each phase module branch having a series circuit comprising submodules, which each have an energy store and at least one power semiconductor (T_1,T_2) and with regulating means for regulating the device, wherein the at least one inductance is selected to be so high that a regulation of circulating currents is made possible by means of the regulating means, which circulating currents, given unequal voltages between the phase modules, flow via the phase modules and between the phase modules.

Further advantages and configurations are the subject matter of the description below relating to exemplary embodiments of the invention with reference to the figures in the drawing, in which identical reference symbols relate to functionally identical component parts and in which:

figure 1 shows an exemplary embodiment of a device according to the invention in a schematic illustration,

figure 2 shows an equivalent circuit diagram of a submodule of a device as shown in figure 1,

figure 3 shows the device shown in figure 1 with coupled inductances,

figure 4 shows an enlarged illustration of the coupling of the inductances,

figure 5 shows the structure of the regulating means of the device shown in figure 1, and

figure 6 shows the application of circulating voltage setpoint values to other setpoint values of the regulating means.

Figure 1 shows an exemplary embodiment of the device 1 according to the invention which comprises three phase modules 2a, 2b and 2c. Each phase module 2a, 2b and 2c is connected to a positive DC voltage line p and to a negative DC voltage line n, with the result that each phase module 2a, 2b, 2c has two DC voltage connections. In addition, in each case one AC voltage connection 3_1, 3_2 and 3_3 is provided for each phase module 2a, 2b and 2c. The AC voltage connections 3_1, 3_2 and 3_3 are connected to a three-phase AC voltage system 5 via a transformer

4. The phase voltages U1, U2 and U3 drop across the phases of the AC voltage system 5, with system currents In1, In2 and In3 flowing. The AC-voltage-side phase current of each phase module is denoted by I1, I2 and I3. The DC voltage current is I_d. Phase module branches 6p1, 6p2 and 6p3 extend between each of the AC voltage connections 3_1, 3_2 or 3_3 and the positive DC voltage line p. The phase module branches 6n1, 6n2 and 6n3 are formed between each AC voltage connection 3_1, 3_2, 3_3 and the negative DC voltage line n. Each phase module branch 6p1, 6p2, 6p3, 6n1, 6n2 and 6n3 comprises a series circuit of submodules (not illustrated in detail in figure 1) and an inductance, which is denoted by L_{Kr} in figure 1.

Figure 2 illustrates the series circuit of the submodules 7 and in particular the design of the submodules by means of an electrical equivalent circuit diagram in more detail, with only the phase module branch 6p1 being singled out in figure 2. The rest of the phase module branches have an identical design, however. It can be seen that each submodule 7 has two disconnectable power semiconductors T1 and T2 connected in series. Disconnectable power semiconductors are, for example, so-called IGBTs, GTOs, IGCTs or the like. They are known to a person skilled in the art as such, with the result that a detailed illustration is not required at this juncture. A freewheeling diode D1, D2 is connected back-to-back in parallel with each disconnectable power semiconductor T1, T2. A capacitor 8 is connected as the energy store in parallel with the series circuit of the disconnectable power semiconductors T1, T2 or the freewheeling diodes D1 and D2. Each capacitor 8 is charged in unipolar fashion. Two voltage states can now be generated at the two-pole connection terminals X1 and X2 of each submodule 7. If, for example, a drive signal is generated by a drive unit 9, with which drive signal the disconnectable power semiconductor T2 is changed over into its on setting, in which a current flow via the power semiconductor T2 is made possible, the voltage drop across the terminals X1, X2 of the submodule 7 is zero. In this case, the disconnectable power semiconductor T1 is in its off setting, in which a current flow via the disconnectable power semiconductor T1 is interrupted. This prevents the discharge of the capacitor 8. If, on the other hand, the disconnectable power semiconductor T1 is changed over to its on setting, but the disconnectable power semiconductor T2 is changed over to its off setting, the full capacitor voltage Uc is present at the terminals X1, X2 of the submodule 7.

The exemplary embodiment of the device according to the invention shown in figures 1 and 2 is also referred to as a so-called multi-level power converter. Such a multi-level power converter is suitable, for example, for driving electrical machines, such as motors or the like, for example. Furthermore, such a multi-level power converter is also suitable for use in the sector of energy distribution and transmission. Thus, the device according to the invention is used, for example, as a back-to-back link, which comprises two power converters which are connected to one another on the DC-voltage side, the power converters each being connected to an AC voltage system. Such back-to-back links are used for the exchange of energy between two energy distribution systems, the energy distribution systems having, for example, a different frequency, phase angle, neutral-point connection or the like. Furthermore, applications in the field of wattless power compensation as so-called FACTS (Flexible AC Transmission Systems) come into consideration. High-voltage DC transmission over long distances is also conceivable with such multi-level power converters.

The inductances L_{Kr} are used for limiting the currents flowing via the respective phase module and therefore for protecting the disconnectable power semiconductors T1, T2 and the freewheeling diodes D1 and D2 of the submodules 7 from overcurrents. In the context of the invention, however, the respective inductance is selected to be so high that active regulation of the circulating currents which flow between the phase modules is made possible. In the context of the invention, therefore, inductances are required which are higher than those which are sufficient merely for protecting the power semiconductors. Furthermore, a symmetrical distribution of the inductances over the phase module branches with a view to regulation is advantageous.

Figure 3 shows the device shown in figure 1, but with the inductances L_{Kr} of a phase module being coupled to one another. As a result of this coupling, the inductances may be lower than in the exemplary embodiment shown in figure 1 given the same rated voltages and the same use conditions. In other words, the coupling provides the possibility of reducing the inductors or coils required for construction in terms of their physical size and the rest of their configuration. On the basis of a coupling factor K for the magnetic coupling, the following results for the effective inductance of a phase module branch in the circulating current direction L_K:

$$L_K = L_L\ (1+K),$$

where L_L corresponds to the inductance of the sum of the individual inductances which are not coupled to one another. The phase module branch currents comprise, in addition to the circulating currents, DC current components and phase currents I1, I2 and I3 flowing between the AC voltage connections 3_1, 3_2, 3_3 and the connected AC voltage system. An increased inductance results only for the DC components and the circulating currents. The inductance L_{CONV} for the phase currents I1, I2 and I3 is reduced, however, by the coupling in accordance with

$$L_{CONV} = L_L\ (1-K).$$

In this way, circulating currents can be reduced and can be supplied for active regulation. The coupling can take place via air, but also via an iron core or the like. In the case of air-core inductors, coupling factors of up to 20% can be produced. In addition to the damping of the circulating currents, the coupled inductances also ensure improved splitting of the phase currents into identical components between the phase module branches of the same phase module.

Figure 5 illustrates the structure of the regulating means. The regulating means comprise a current regulating unit 10 and drive units 9p1, 9p2, 9p3 and 9n1 and 9n2 and 9n3. Each of the drive units is associated with a phase module branch 6p1, 6p2, 6p3, 6n1, 6n2 and 6n3, respectively. The drive unit 9p1 is, for example, connected to each submodule 7 of the phase module branch 6p1 and generates the control signals for the disconnectable power semiconductors T1, T2. A submodule voltage sensor (not illustrated in the figures) is provided in each submodule 7. The submodule voltage sensor is used for detecting the capacitor voltage drop across the capacitor 8 as the energy store of the submodule 7 whilst obtaining a capacitor voltage value Uc. The capacitor voltage value Uc is made available to the respective drive unit, in this case 9p1. The drive unit 9p1 therefore obtains the capacitor voltage values of all of the submodules 7 of the phase module branch 6p1 associated with it and summates these values to obtain a branch energy actual value or in this case branch voltage actual value UcΣp1, which likewise is associated with the phase module branch 6p1. This branch voltage actual value $Uc\Sigma p1$ is supplied to the current regulating unit 10.

Moreover, the current regulating unit 10 is connected to various measuring sensors (not illustrated in the figures). Thus, current transformers arranged on the AC-voltage side of the phase modules 2a, 2b, 2c are used to generate and supply phase current measured values I1, I2, I3 and current transformers arranged at each phase module are used to generate and supply phase module branch currents Izwg and a current transformer arranged in the DC voltage circuit of the power converter is used to provide DC current measured values Id. Voltage transformers of the AC system provide system voltage measured values U1, U2, U3 and DC voltage transformers provide positive DC voltage measured values Udp and negative DC voltage measured values Udn, the positive DC voltage values Udp corresponding to a DC voltage drop between the positive DC voltage connection p and ground, and the negative DC voltage values Udn corresponding to a voltage drop between the negative DC voltage connection and ground.

The current regulating unit 10 is also supplied setpoint values. In the exemplary embodiment shown in figure 11, the regulating unit 10 is supplied an active current setpoint value Ipref and a wattless current setpoint value Iqref. In addition, a DC voltage setpoint value Udref is applied to the input of the current regulating unit 10. Instead of a DC voltage setpoint value Udref, the use of a DC setpoint value Idref is also possible in the context of the invention.

The setpoint values Ipref, Iqref and Udref and said measured values interact with one another when using different regulators, with a branch voltage setpoint value

Up1ref, Up2ref, Up3ref, Un1ref, Un2ref, Un3ref being generated for each drive unit 9p1, 9p2, 9p3, 9n1, 9n2 and 9n3. Each drive unit 9 generates control signals for the submodules 7 associated with it, with the result that the voltage drop Up1, Up2, Up3, Un1, Un2, Un3 across the series circuit of the submodules corresponds to the respective branch voltage setpoint value Up1ref, Up2ref, Up3ref, Un1ref, Un2ref, Un3ref as far as possible.

The current regulating unit 10 forms suitable branch voltage setpoint values Up1ref, Up2ref, Up3ref, Un1ref, Un2ref, Un3ref from its input values.

Figure 6 shows that, for example, the branch voltage setpoint value Upref is calculated by linear combination of a system phase voltage setpoint value Unetz1, a branch voltage intermediate setpoint value Uzwgp1, a DC voltage setpoint value Udc, a symmetrizing voltage setpoint value Uasym and a balancing voltage setpoint value Ubalp1. This takes place for each of the phase module branches 6p1, 6p2, 6p3, 6n1, 6n2, 6n3 independently of one another. The circulating currents can be set in a targeted manner using the branch voltage intermediate setpoint values Uzwg in conjunction with the set branch inductances. The balancing voltage setpoint values Ubal are also used for compensating for asymmetries as regards the energies stored in the phase module branches 6p1, 6p2, 6p3, 6n1, 6n2, 6n3.

CLAIMS:

1. A device for converting an electrical current with at least one phase module, which has an AC voltage connection and at least one DC voltage connection (p,n), a phase module branch with at least one inductance being formed between each DC voltage connection (p,n) and the AC voltage connection, and each phase module branch having a series circuit comprising submodules, which each have an energy store and at least one power semiconductor (T_1,T_2) and with regulating means for regulating the device, wherein the at least one inductance is selected to be so high that a regulation of circulating currents is made possible by means of the regulating means, which circulating currents, given unequal voltages between the phase modules, flow via the phase modules and between the phase modules.

2. The device as claimed in claim 1, wherein each phase module branch is connected to the AC voltage connection via an inductance (L_{Kr}).

3. The device as claimed in claim 1 or 2, wherein the inductances (L_{Kr}) of a phase module are coupled to one another.

4. The device as claimed in claim 3, wherein the inductances (L_{Kr}) are coupled to one another via air.

5. The device as claimed in claim 4, wherein the inductances are (L_{Kr}) coupled to one another via an iron core.

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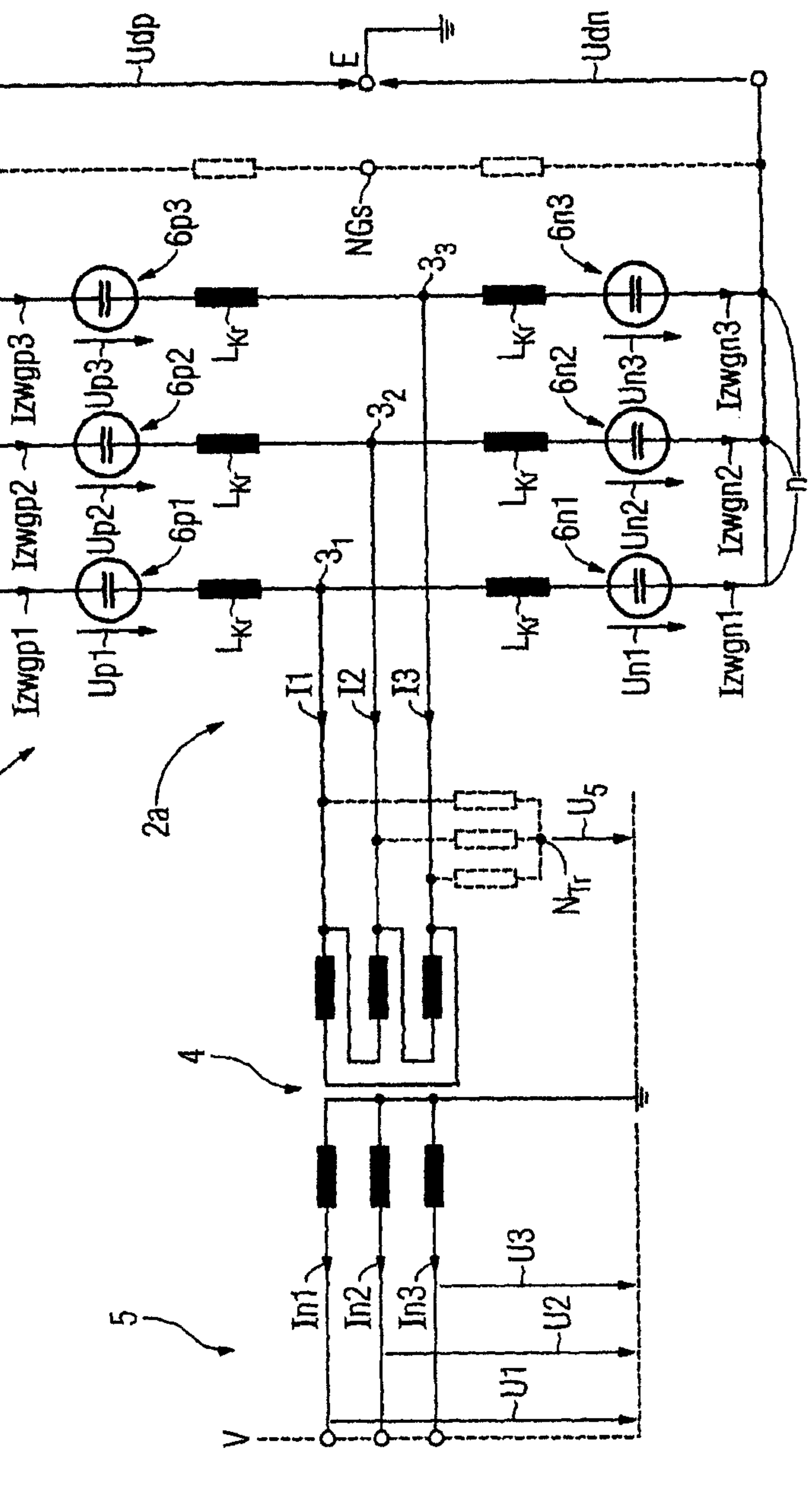

FIG 1

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FIG 2

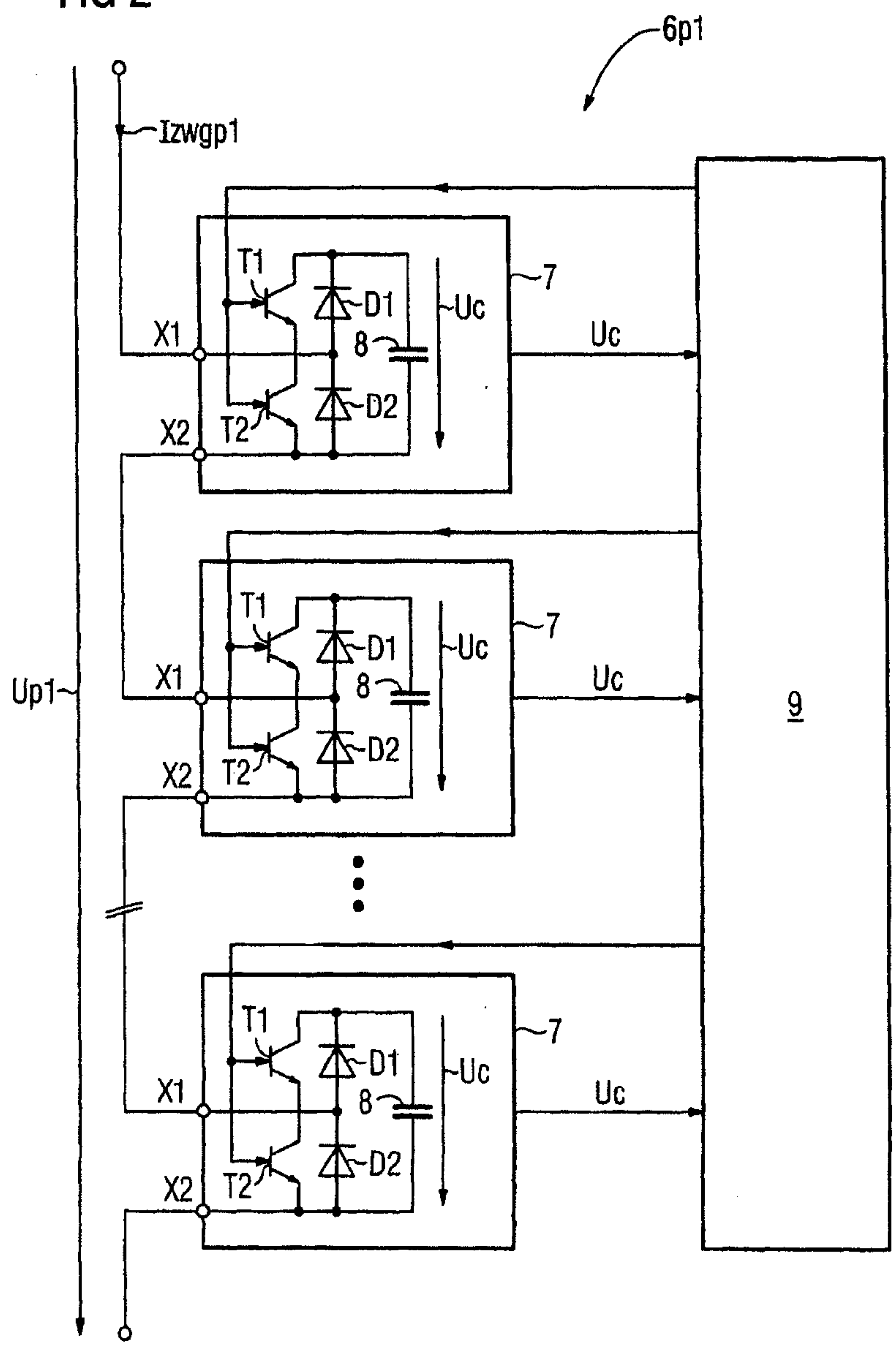

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FIG 3

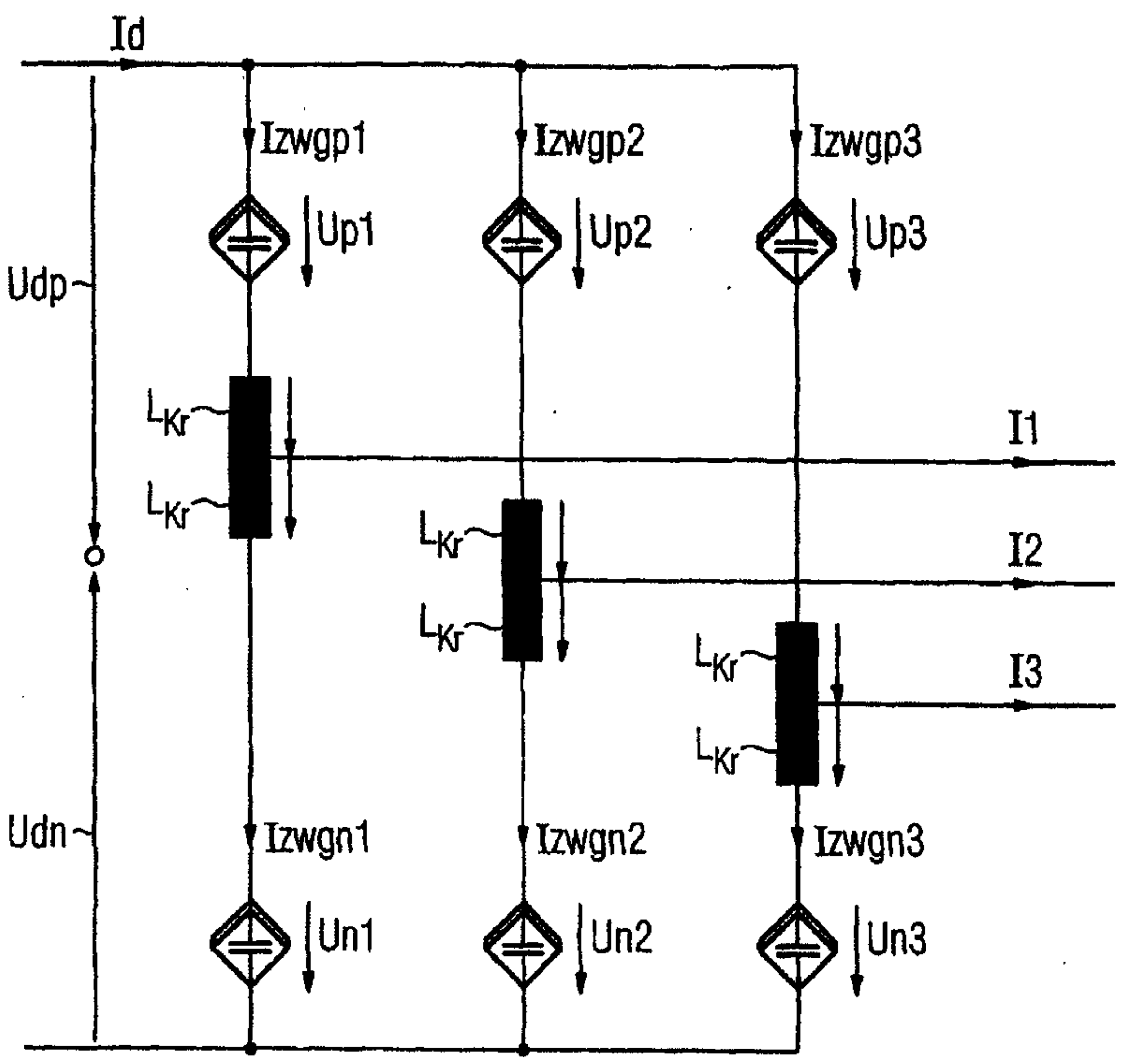

FIG 4

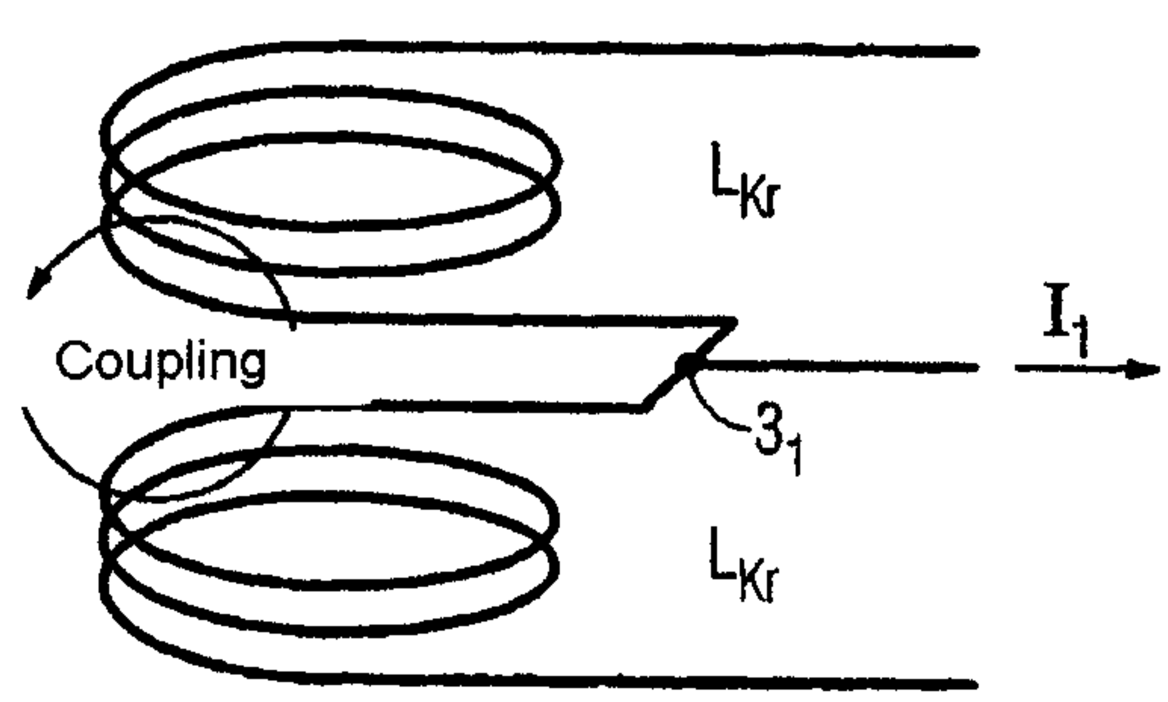

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FIG 5

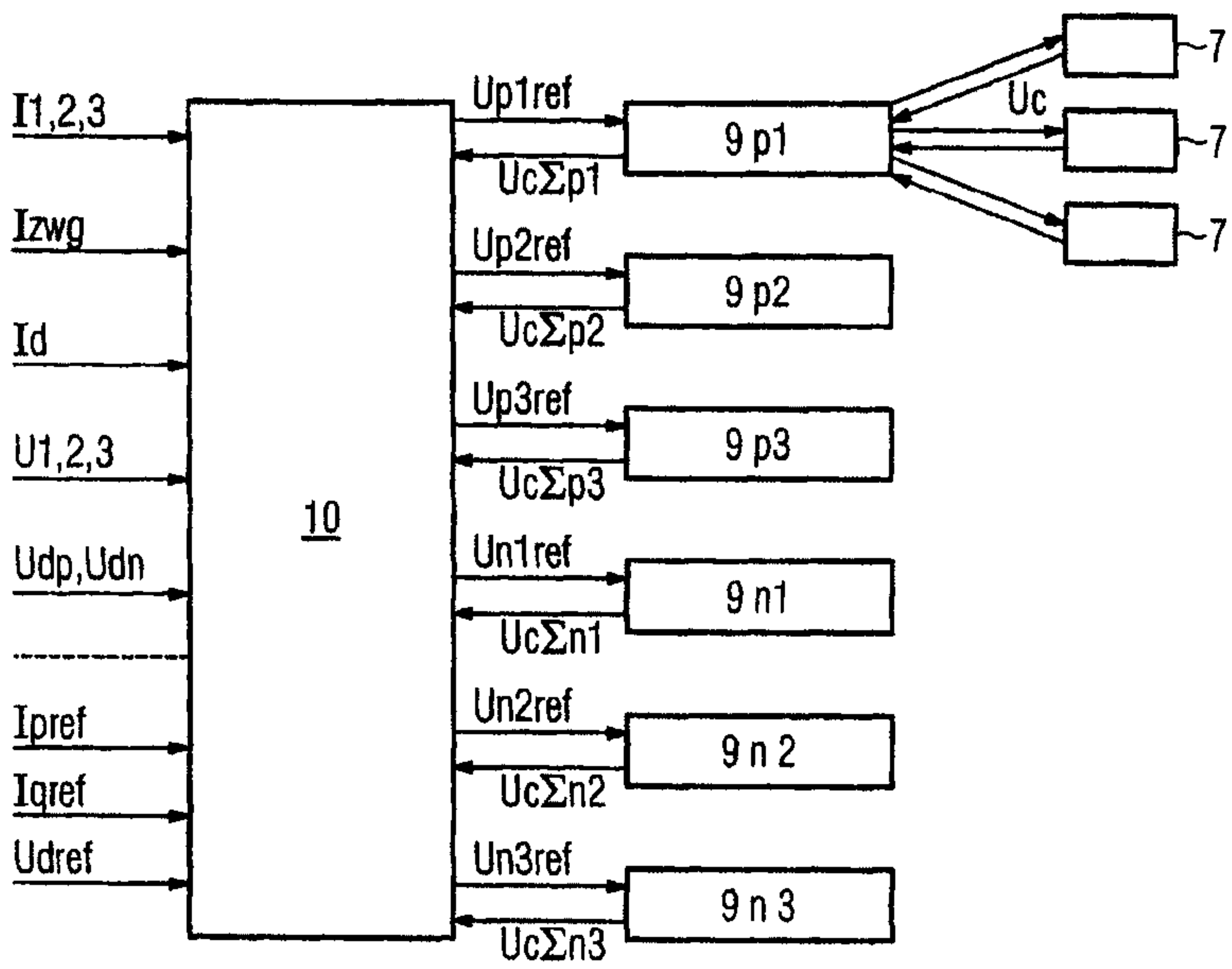

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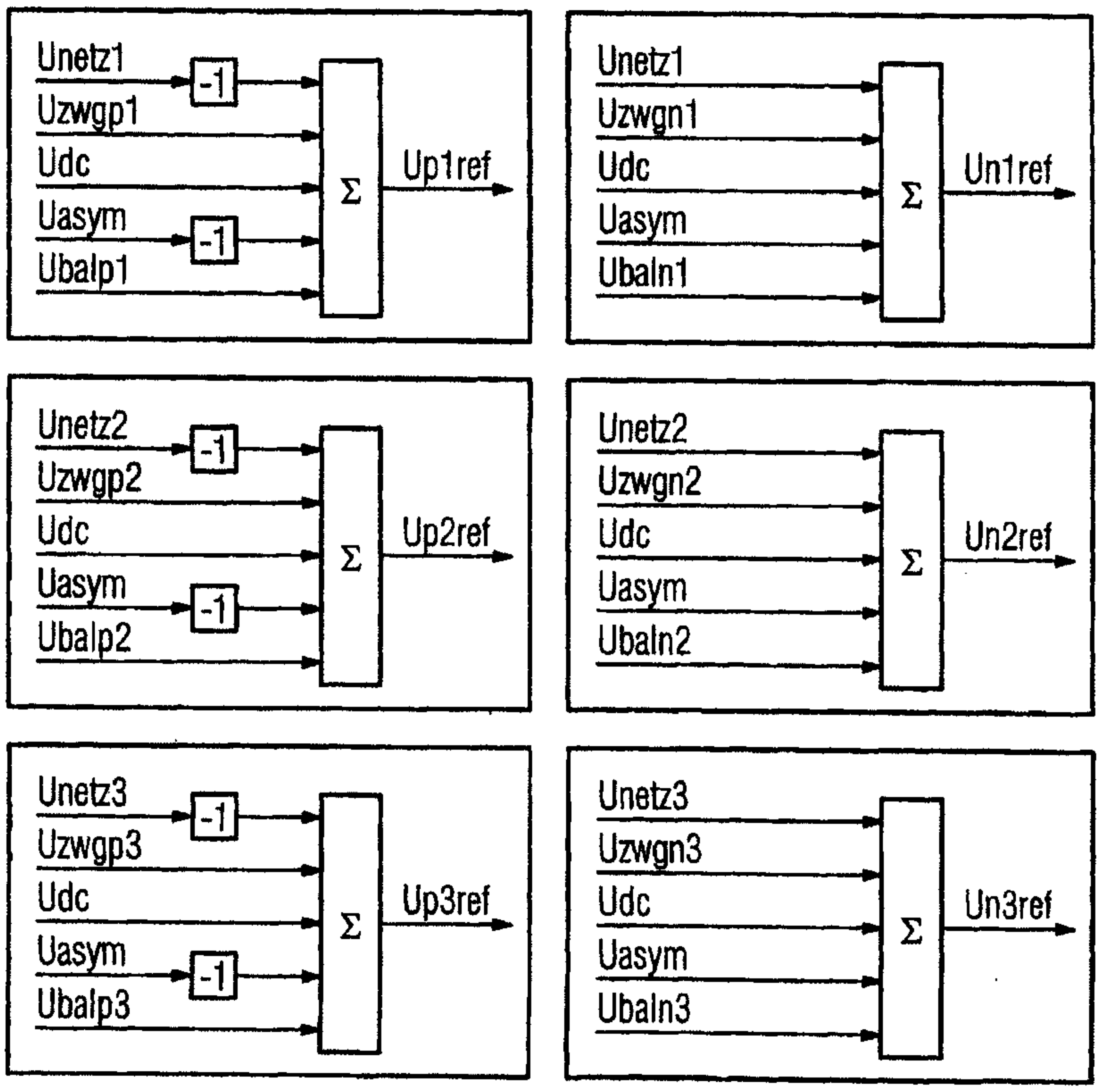
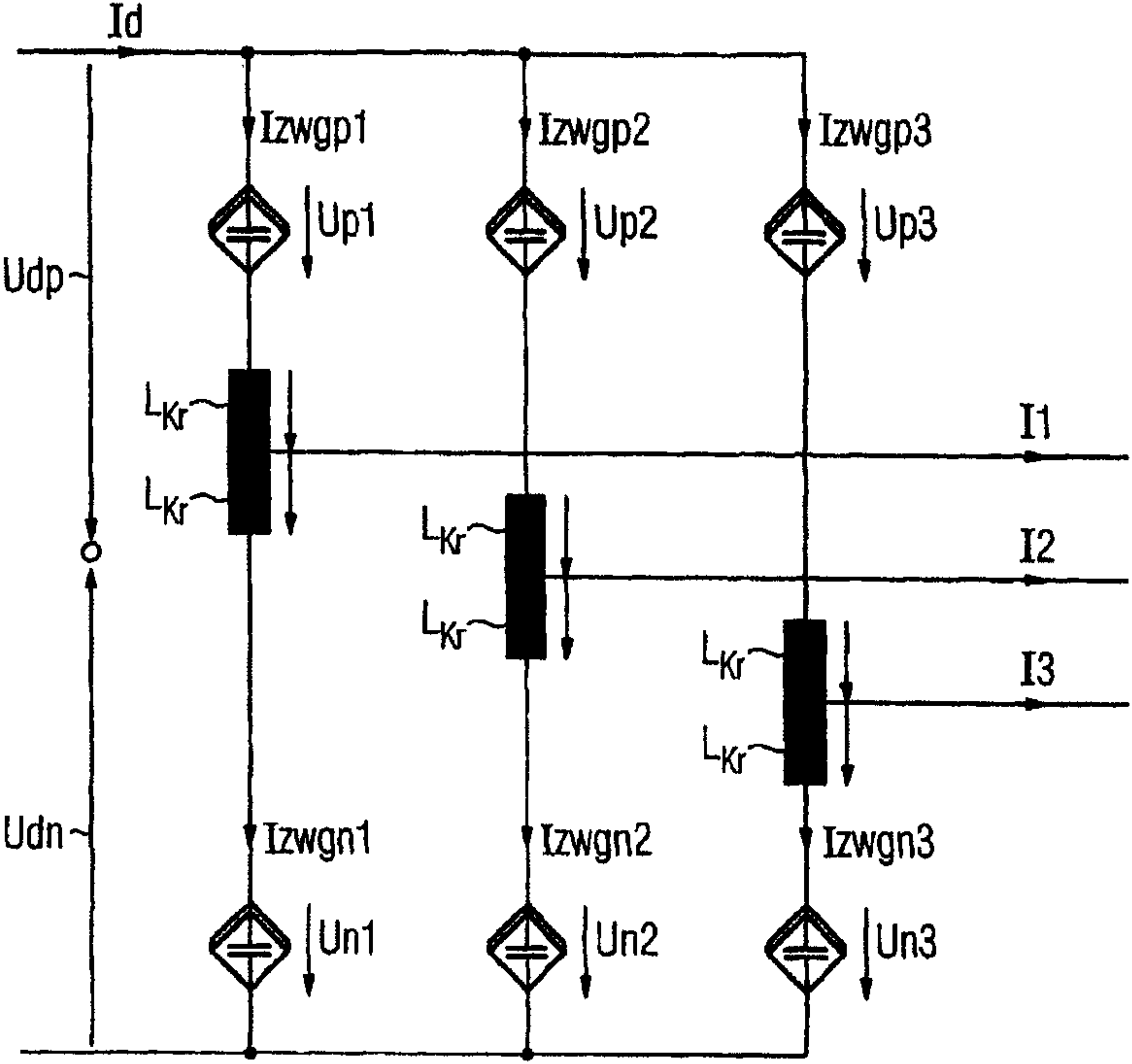
FIG 6




Id
Izwgp1
Izwgp2
Izwgp3
Up1
Up2
Up3
Udp
L_{Kr}
L_{Kr}
L_{Kr}
L_{Kr}
L_{Kr}
L_{Kr}
I1
I2
I3
Udn
Izwgn1
Izwgn2
Izwgn3
Un1
Un2
Un3