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(54) Benævnelse: **IMPEDANS FOR AC-FEJLSTRØMSBEHANDLING TIL HVDC-OMFORMER**

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EP-A1- 1 151 324
EP-B1- 1 151 324
WO-A1-2009/149744
CN-A- 104 578 130
CN-B- 103 066 582
CN-U- 206 790 085
GB-A- 2 397 445
SCHETTLER F ET AL: "HVDC transmission systems using voltage sourced converters design and applications", POWER ENGINEERING SOCIETY SUMMER MEETING, 2000. IEEE 16 - 20 JULY 2000, PISCATAWAY, NJ, USA,IEEE, PISCATAWAY, NJ, USA, Bd. 2, 16. Juli 2000 (2000-07-16), Seiten 715-720, XP010510729, DOI: 10.1109/PESS.2000.867439 ISBN: 978-0-7803-6420-2
XUE YINGLIN ET AL: "On the Bipolar MMC-HVDC Topology Suitable for Bulk Power Overhead Line Transmission: Configuration, Control, and DC Fault Analysis", IEEE TRANSACTIONS ON POWER DELIVERY, IEEE SERVICE CENTER, NEW YORK, NY, US, Bd. 29, Nr. 6, 1. Dezember 2014 (2014-12-01), Seiten 2420-2429, XP011564727, ISSN: 0885-8977, DOI: 10.1109/TPWRD.2014.2352313 [gefunden am 2014-11-18]
BUCHER MATTHIAS K ET AL: "Comparison of fault currents in multiterminal HVDC grids with different grounding schemes", 2014 IEEE PES GENERAL MEETING | CONFERENCE & EXPOSITION, IEEE, 27 July 2014 (2014-07-27), pages 1-5, XP032670771, DOI: 10.1109/PESGM.2014.6938990 [retrieved on 2014-10-29]

Fortsættes ...

IMPEDANCE FOR AC FAULT CURRENT HANDLING FOR HVDC CONVERTER

Description

[0001] The invention relates to a converter unit for high-voltage DC transmission. This converter unit has at least one converter.

[0002] Faults occurring in converters can be resolved by opening an AC circuit breaker (which connects an AC voltage connection of the converter to an AC voltage system). This fault resolution (fault handling) by means of an AC circuit breaker can also be used in particular in modular multilevel converters with half-bridge modules.

[0003] However, the occurrence of so-called unbalanced faults (especially inside the converter) is problematic. These are faults that affect only one pole or two poles of the three-pole (three-phase) AC voltage. It is particularly problematic if the AC circuit breaker is connected to the AC voltage connection of the converter by means of a transformer, the unbalanced fault occurs on the secondary side of the transformer (i.e. on the side facing the converter), and the AC circuit breaker is arranged on the primary side of the transformer (i.e. on the side of the transformer facing away from the converter). Such unbalanced faults result in an unbalanced current load on the secondary side of the transformer, which is transferred to the primary side of the transformer and causes the AC current flowing through the AC circuit breaker to no longer have any current zero crossings (missing zero crossings of the AC current). These missing zero crossings of the AC current prevent the AC circuit breaker from opening quickly after a fault has been detected, since arcs that occur during opening of the AC circuit breaker will not extinguish reliably until there are zero crossings in the AC current.

[0004] However, quick fault resolution is required, especially in the case of modular multilevel converters with half-bridge submodules, since otherwise the free-wheeling diodes of the half-bridge submodules that conduct in the event of a fault can

be thermally overloaded and, in addition to the AC circuit breaker, the converter can also suffer irreversible damage.

[0005] In order to solve this problem, it was proposed in patent application WO 2011/150963 A1 to use a short-circuiting unit which, in the event of an unbalanced fault, short-circuits all three phases of the AC voltage network to earth. This converts the unbalanced fault into a balanced fault (that is to say a fault that affects all three phases), causing zero crossings of the AC current to occur on the primary side of the transformer.

[0006] Furthermore, it was proposed in patent application WO 2016/055106 A1 to short-circuit a tertiary winding of the transformer by means of a short-circuiting unit in the event of an unbalanced fault. This is done in such a way that the three phases of the tertiary winding are short-circuited to each other.

[0007] In the case of the two solutions mentioned above, it is necessary to close short-circuiting switches in the event of a fault. In the first solution mentioned, the resulting short circuit places a heavy load on the AC voltage network and components connected to it. In the second solution mentioned, a tertiary winding of the transformer that is designed for high powers is required in order to be able to influence the currents flowing on the primary side of the transformer quickly enough. Such a tertiary winding is complex and expensive.

[0008] A modular multilevel converter is known from patent specification CN 103 066 582 B, in which the two DC voltage connections are each connected to earth potential by means of a protective circuit. The protective circuit includes resistors, capacitors, a spark gap, a surge arrester and two antiparallel-connected thyristors.

[0009] Published patent application GB 2 397 445 A discloses a converter station with two converters connected in series, in which the connection point between the two converters is connected to earth potential by means of an earthing circuit. The earthing circuit has an inductor or a parallel resonant circuit consisting of at least one inductor and one capacitor.

[0010] Document EP 1 151 324 A discloses a similar converter station in which the connection point between the two converters is connected to earth potential by means of an inductor or by means of a series resonant circuit having an inductor and a capacitor.

[0011] The article "HVDC Transmission Systems using Voltage Sourced Converters - Design and Applications" by F. Schettler et al, Power Engineering Society Summer Meeting, IEEE, 16 July 2000, pages 715-720, discloses a converter station for bipolar high-voltage DC transmission, in which the connection point between the two converters is connected to earth potential by means of an impedance and a surge arrester connected in parallel.

[0012] The invention is based on the object of specifying a converter unit and a method for handling a fault in a converter unit, with which current zero crossings can be achieved even if an unbalanced fault occurs.

[0013] This object is achieved according to the invention by a converter unit and by a method according to the independent patent claims. Advantageous embodiments of the converter unit and the method are specified in the dependent patent claims.

[0014] There is disclosed a converter unit for high-voltage DC transmission

- comprising a first converter,
- wherein a first DC voltage connection of the first converter is connected to a first conductor connection point for a first high-voltage DC transmission conductor,
- wherein a second DC voltage connection of the first converter is connected to an impedance unit having an electrical impedance, forming a connection point, and
- the impedance unit connects the connection point to earth potential.

[0015] In other words, the connection point is connected to earth potential by means of the impedance unit. This converter unit advantageously comprises the impedance unit which connects the connection point to the earth potential. The impedance unit has a non-zero impedance. In contrast to a converter unit in which

the connection point is directly earthed (that is, in which the connection point is connected to earth potential with almost no impedance by means of an electrical conductor), an impedance unit is provided here for the purpose of connecting the connection point to earth potential. This impedance unit damps the fault current flowing from the earth potential to the connection point when an unbalanced fault occurs. This ensures that the primary-side AC currents have current zero crossings even if an unbalanced fault occurs.

[0016] The converter unit is designed in such a way that the second DC voltage connection of the first converter is electrically connected to a first DC voltage connection of a second converter, wherein a second DC voltage connection of the second converter is connected to a second conductor connection point for a second high-voltage DC transmission conductor.

[0017] The converter unit therefore has a second converter. Such a converter unit can be used, for example, to implement a bipolar HVDC transmission system. This converter unit has two converters, both of which are influenced by the impedance unit. This results in a converter unit for high-voltage DC transmission

- comprising a first converter and a second converter,
- wherein a first DC voltage connection of the first converter is connected to a first conductor connection point for a first high-voltage DC transmission conductor,
- wherein a second DC voltage connection of the first converter is electrically connected to a first DC voltage connection of the second converter, forming a connection point,
- wherein a second DC voltage connection of the second converter is connected to a second conductor connection point for a second high-voltage DC transmission conductor, and
- wherein the connection point is connected to earth potential by means of an impedance unit having an electrical impedance.

[0018] The converter unit is also designed in such a way that the impedance unit has an (ohmic) resistor component. Advantageously, a simple ohmic resistor component ("resistor")

can already be used to achieve the situation in which, in the event of an unbalanced fault, the primary-side AC currents have zero crossings.

[0019] The converter unit is designed such that the resistor component has an ohmic resistance of between 5 ohms and 5000 ohms. It has been shown that current zero crossings in the primary-side AC current can already be achieved with relatively small ohmic resistances, especially with ohmic resistances of greater than 5 ohms. However, even with larger resistance values of up to 5000 ohms, the desired effect can be advantageously achieved. A well-suited resistance value of the resistor component can simply be determined by tests, by selecting different resistance values during test operation of the converter unit and monitoring the primary-side AC current to see whether (in the case of unbalanced faults) the desired current zero crossings reliably occur.

[0020] The converter unit is designed in such a way that the resistor component is connected in series with an inductor component. The inductor component connected in series reduces the fault currents flowing through the impedance unit.

[0021] The converter unit can also be designed such that the connection point is additionally connected to earth potential by means of a surge arrester. This surge arrester is used to advantageously protect the resistor component and possibly the optional inductor component from overvoltage. In addition, the power loss occurring in the impedance unit can be advantageously distributed to the resistor component and to the surge arrester.

[0022] The converter unit can be designed such that the surge arrester is connected in parallel with the impedance unit.

[0023] The converter unit may also be designed such that the first converter and/or the second converter have/has a series connection comprising modules, wherein the modules each have at least two electronic switching elements and an electrical energy store. Such modules can be in particular in the form of so-called half-bridge modules.

[0024] The converter unit can also be designed such that the first converter and/or the second converter is/are each a modular multilevel converter. Especially in a modular multilevel converter with half-bridge modules, the impedance unit can be advantageously used to ensure current zero crossings in the primary-side AC current through the AC circuit breaker.

[0025] A high-voltage DC transmission system comprising a converter unit according to one of the variants described above is also disclosed.

[0026] A method for handling a fault in a converter unit for high-voltage DC transmission is also disclosed,

- wherein the converter unit has a first converter,
- wherein a first DC voltage connection of the first converter is connected to a first conductor connection point for a first high-voltage DC transmission conductor,
- wherein a second DC voltage connection of the first converter is connected to an impedance unit (having an electrical impedance), forming a connection point, and
- wherein the impedance unit connects the connection point to earth potential,
- wherein an AC voltage connection of the first converter is connected to a secondary winding of a first transformer, and a primary winding of the first transformer is connected to a first AC circuit breaker, wherein in the method
- a fault current begins to flow from the earth potential through the impedance unit to the connection point (and through free-wheeling paths of the first converter) in response to an (unbalanced, converter-internal) fault at the AC voltage connection of the first converter, in particular in response to a single-pole or two-pole fault at the AC voltage connection of the first converter,
- the fault current is damped by virtue of the impedance of the impedance unit and a voltage is built up at the impedance unit, as a result of which an AC current flowing through the primary winding of the first transformer (despite the unbalanced

fault) has zero crossings such that this AC current is able to be switched off by means of the first AC circuit breaker.

[0027] The method can also take place in such a way that the second DC voltage connection of the first converter is electrically connected to a first DC voltage connection of a second converter, wherein a second DC voltage connection of the second converter is connected to a second conductor connection point for a second high-voltage DC transmission conductor, wherein an AC voltage connection of the second converter is connected to a secondary winding of a second transformer, and a primary winding of the second transformer is connected to a second AC circuit breaker, wherein in the method, in response to an (unbalanced, converter-internal) fault at the AC voltage connection of the second converter, in particular in response to a single-pole or two-pole fault at the AC voltage connection of the first converter or at the AC voltage connection of the second converter, the

fault current begins to flow from the earth potential through the impedance unit to the connection point (and through the free-wheeling paths of the first converter),

- the fault current is damped by virtue of the impedance of the impedance unit and a voltage is built up at the impedance unit, as a result of which an AC current flowing through the primary winding of the first transformer or an AC current flowing through the primary winding of the second transformer (despite the unbalanced fault) has zero crossings such that this AC current is able to be switched off by means of the first AC circuit breaker or by means of the second AC circuit breaker.

[0028] The method has the same advantages as those described above in connection with the converter unit.

[0029] The invention is explained in more detail below on the basis of exemplary embodiments. Identical reference signs in this case refer to identical or functionally identical elements. In this regard,

Figure 1

illustrates an exemplary embodiment of a converter having a multiplicity of modules,

Figure 2

illustrates an exemplary embodiment of a module of the converter,

Figure 3

illustrates an exemplary embodiment of a high-voltage DC transmission system with two converter units, and

Figure 4

illustrates a further exemplary embodiment of a high-voltage DC transmission system with two converter units

[0030] Figure 1 illustrates a converter 1 in the form of a modular multilevel converter 1 (MMC). This multilevel converter 1 has a first AC voltage connection 5, a second AC voltage connection 7 and a third AC voltage connection 9. The first AC voltage connection 5 is electrically connected to a first phase module branch 11 and a second phase module branch 13. The first phase module branch 11 and the second phase module branch 13 form a first phase module 15 of the converter 1. That end of the first phase module branch 11 which is remote from the first AC voltage connection 5 is electrically connected to a first DC voltage connection 16; that end of the second phase module branch 13 which is remote from the first AC voltage connection 5 is electrically connected to a second DC voltage connection 17.

[0031] The second AC voltage connection 7 is electrically connected to one end of a third phase module branch 18 and to one end of a fourth phase module branch 21. The third phase module branch 18 and the fourth phase module branch 21 form a second phase module 24. The third AC voltage connection 9 is electrically connected to one end of a fifth phase module branch 27 and to one end of a sixth phase module branch 29. The fifth phase module branch 27 and the sixth phase module branch 29 form a third phase module 31.

[0032] That end of the third phase module branch 18 which is remote from the second AC voltage connection 7 and that end of the fifth phase module branch 27 which is remote from the third AC voltage connection 9 are electrically connected to the first

DC voltage connection 16. That end of the fourth phase module branch 21 which is remote from the second AC voltage connection 7 and that end of the sixth phase module branch 29 which is remote from the third AC voltage connection 9 are electrically connected to the second DC voltage connection 17. The first phase module branch 11, the third phase module branch 18 and the fifth phase module branch 27 form a converter part 32; the second phase module branch 13, the fourth phase module branch 21 and the sixth phase module branch 29 form a converter part 33.

[0033] Each phase module branch has a plurality of modules (1_1, 1_2, 1_3, 1_4 ... 1_n; 2_1 ... 2_n; etc.) which are electrically connected in series (by means of their DC-electrical power connections). Such modules are also referred to as submodules. In the exemplary embodiment in Figure 1, each phase module branch has n modules. The number of modules electrically connected in series by means of their DC-electrical power connections may be very different; there are at least three modules connected in series but there may also be 50, 100 or more modules, for example, electrically connected in series. In the exemplary embodiment, n = 36: the first phase module branch 11 thus has 36 modules 1_1, 1_2, 1_3, ... 1_36. The other phase module branches 13, 18, 21, 27 and 29 are constructed in the same fashion.

[0034] The modules 1_1 to 6_n are controlled by a control device that is not illustrated. Optical messages or optical signals are transmitted from this central control device to the individual modules via an optical communication link 37 (for example via an optical waveguide). The message transmission between the control device and a module is illustrated symbolically by an arrow 37 in each case; the direction of the message transmission is symbolized by the arrow head. This is illustrated using the example of the modules 1_1, 1_4 and 4_5; messages are sent to the other modules in the same way. For example, the control device sends, to each of the individual modules, a target value for the level of the output voltage that is to be provided by the respective module.

[0035] The first AC voltage connection 5, the second AC voltage connection 7 and the third AC voltage connection 9 are electrically connected to secondary windings 50 of a three-phase transformer 53. Primary windings 56 of the transformer 53 are electrically connected to an AC voltage system 62 via a three-pole AC circuit breaker 59. The AC voltage system 62 may be, for example, an AC voltage network 62 (in particular an AC voltage energy supply network). The secondary windings 50 and the primary windings 56 can each be interconnected in any way, for example in star connection or in delta connection.

[0036] By way of example, Figure 1 illustrates a single-pole (single-phase) fault 65 which occurs at the third AC voltage connection 9 of the converter 1. In the exemplary embodiment, this is an earth fault 65 of that phase of the AC voltage which is assigned to the third AC voltage connection 9. Such a fault occurring from a phase of the AC voltage of the converter 1 to earth potential 68 leads to an unbalanced current load on the secondary side of the transformer (i.e. the side facing the converter 1), which is transferred to the primary side of the transformer (i.e. to the side facing away from the converter 1) and causes the AC current flowing through the AC circuit breaker 59 to no longer have any current zero crossings. Such "missing current zero crossings" of the AC current flowing through the AC circuit breaker 59 will impair (after the fault 65 has been detected) the rapid opening of the AC circuit breaker. This is due to the fact that, if there are no zero crossings of the current, an arc (created when the mechanical contacts of the AC circuit breaker 59 are opened) will not be reliably extinguished. Therefore, it is desirable for the current flowing through the AC circuit breaker 59 to continue to have current zero crossings even in the event of an unbalanced fault 65. This is achieved by means of an impedance unit, as explained further below.

[0037] Figure 2 illustrates an exemplary embodiment of a module 200 of the converter 1. This can be, for example, one of the modules 1_1 ... 6_n illustrated in Figure 1.

[0038] The module 200 is configured as a half-bridge module 200. The module 200 has a first (deactivatable) electronic switching element 202 (first deactivatable semiconductor valve 202) with a first antiparallel-connected diode 204. Furthermore, the module 200 has a second (deactivatable) electronic switching element 206 (second deactivatable semiconductor valve 206) with a second antiparallel-connected diode 208, and also an electrical energy store 210 in the form of a capacitor 210. The first electronic switching element 202 and the second electronic switching element 206 are configured in each case as an IGBT (insulated-gate bipolar transistor). The first electronic switching element 202 is electrically connected in series with the second electronic switching element 206. A first DC-electrical module connection 212 is arranged at the connection point between the two electronic switching elements 202 and 206. A second DC-electrical module connection 215 is arranged at that connection of the second electronic switching element 206 which is opposite the connection point. The second module connection 215 is furthermore electrically connected to a first connection of the energy store 210; a second connection of the energy store 210 is electrically connected to that connection of the first electronic switching element 202 which is opposite the connection point.

[0039] The energy store 210 is thus electrically connected in parallel with the series circuit formed by the first electronic switching element 202 and the second electronic switching element 206. What can be achieved by appropriate control of the first electronic switching element 202 and the second electronic switching element 206 by means of an electronic control device (not illustrated) of the converter is that between the first module connection 212 and the second module connection 215 either the voltage of the energy store 210 is output or no voltage is output (i.e. a zero voltage is output). Interaction of the modules of the individual phase module branches thus enables the respectively desired output voltage of the converter to be generated.

[0040] Figure 3 illustrates an exemplary embodiment of a high-voltage DC transmission system 300 (HVDC transmission system 300). This HVDC transmission system has a first converter unit 303 and a second converter unit 306. The first converter unit 303 and a second converter unit 306 are electrically connected to each other by means of a first high-voltage DC transmission conductor 309 (HVDC transmission conductor 309) and by means of a second HVDC transmission conductor 312. The first converter unit 303 forms a first converter station 303 of the HVDC transmission system 300; the second converter unit 306 forms a second converter station 306 of the HVDC transmission system 300.

[0041] The first converter unit 303 has a first converter 315 and a second converter 318. The second converter unit 306 has a first converter 321 and a second converter 324. A first DC voltage connection 327 of the first converter 315 is electrically connected to a first conductor connection point 330 for the first high-voltage DC transmission conductor 309. A second DC voltage connection 333 of the first converter 315 is electrically connected to an impedance unit 339, forming a connection point 336. The impedance unit 339 has a non-zero electrical impedance. The impedance unit 339 connects the connection point 336 to earth potential 342. In other words, the connection point 336 is electrically connected to earth potential 342 by means of the impedance unit 339. The connection point 336 is electrically connected to a first DC voltage connection 345 of the second converter 318. A second DC voltage connection 348 of the second converter 318 is electrically connected to a second conductor connection point 352 for the second high-voltage DC transmission conductor 312.

[0042] Electrical switches S1 to S19 are arranged in the HVDC transmission system 300. These switches S1 to S19 can be used to electrically isolate or bridge various system parts if required. These switches can thus be used to configure the HVDC transmission system 300, for example by bridging individual converters or by isolating individual converters from the rest

of the system. The switch S7 is a first AC circuit breaker S7; the switch S8 is a second AC circuit breaker S8. The switch S15 is a third AC circuit breaker S15 and the switch S16 is a fourth AC circuit breaker S16. The remaining switches S1-S6, S9-S14 and S17-S19 are optional switches, i.e. the HVDC transmission system 300 also generally works without these optional switches.

[0043] The impedance unit 339 has a first (ohmic) resistor component 355. An inductor component 358 is connected in series with the resistor component 355. A surge arrester 361 is optionally connected in parallel with the resistor component 355 or in parallel with the series circuit formed by the resistor component 355 and the inductor component 358. The connection point 336 can thus also be additionally connected to earth potential 342 by means of the surge arrester 361. The surge arrester 361 is connected in parallel with the impedance unit 339. It is sufficient if the connection point 336 is connected to earth potential 342 by means of the resistor component 355 and the inductor component 358. The other elements (surge arrester 361, switch S17) are optional and can also be omitted in other exemplary embodiments.

[0044] The resistor component 355 has an ohmic resistance of between 5 ohms and 5000 ohms. The resistor component 355 thus has a non-zero ohmic resistance; the impedance unit has a non-zero impedance. It has been found that even small ohmic resistances, such as 5 ohms, can be sufficient to ensure current zero crossings in the AC current flowing through the circuit breaker. However, the resistor component 355 must of course be adapted to the respective technical conditions. A person skilled in the art can use a simple series of tests to determine a well-suited resistance value of the resistor component by experimentally generating an unbalanced fault at various resistance values and by examining the primary-side AC current for the presence of current zero crossings. If, after a simulated unbalanced fault, there are current zero crossings of the AC current, the respective resistance value is suitable.

[0045] An AC voltage connection 364 of the first converter 315 is electrically connected to secondary windings 367 of a three-phase transformer 370. Primary windings 373 of the transformer 370 are electrically connected to a first AC voltage system 379 (in particular to an AC voltage network 379) via the three-phase AC circuit breaker S7.

[0046] In the same manner, an AC voltage connection 385 of the second converter 318 is electrically connected to secondary windings 388 of a second transformer 391. Primary windings 394 of the second transformer 391 are connected to the AC voltage system 379 via a second AC circuit breaker S8.

[0047] For the AC current flowing through the AC circuit breaker S7, the impedance unit 339 ensures that there are current zero crossings even in the event of an unbalanced fault. The AC current flowing through this AC circuit breaker S7 thus forms the current that flows on the primary side of the first transformer 370. The AC circuit breaker S7 is closed during normal operation, with the result that the operating current of the converter flows through the AC circuit breaker S7. When a fault is detected, especially when an unbalanced fault is detected, the AC circuit breaker S7 is opened. This also analogously applies to the second AC circuit breaker S8. Also for the AC current flowing through the second AC current circuit breaker S8, the impedance unit 339 ensures that there are current zero crossings in the event of an unbalanced fault.

[0048] The second converter unit 306 is constructed in the same way as the first converter unit 303. The first converter 321 and the second converter 324 of the second converter unit 306 are electrically connected in series, forming a second connection point 336'. The second converter unit 306 is likewise connected to a second AC voltage system 398 (in particular to a second AC voltage network 398) in the same manner via transformers and AC circuit breakers. The second converter unit 306 may optionally also have a second impedance unit 399 with a second surge arrester 400 connected in parallel. The switch S19 can be used to isolate the impedance unit 399 from the connection point

between the first converter 321 and the second converter 324; the switch S18 can be used to bridge the impedance unit 399. For the transmission of power, it is sufficient if one of the two converter units 303 and 306 is equipped with an impedance unit.

[0049] When an unbalanced fault occurs, a fault current I begins to flow to the earth potential 342 and flows through the impedance unit 339 to the connection point 336 through the free-wheeling paths (free-wheeling diodes) of the converter 315. The fault current I is damped by the impedance unit 339, in particular by the resistor component 355, and a voltage is built up at the impedance unit 339. This ensures that the AC current flowing through the primary winding 373 of the first transformer 370 has zero crossings. This AC current can then be switched off by means of the first AC current circuit breaker S7.

[0050] Figure 4 illustrates a further HVDC transmission system 400. This further HVDC transmission system 400 differs from the HVDC transmission system 300 illustrated in Figure 3 only in that the first converter unit 303 is additionally electrically connected to the second converter unit 306 by means of a third HVDC transmission conductor 430. In this case, the second DC voltage connection 333 of the first converter 315 (and thus also the first connection point 336) is (switchably) electrically connected to a third conductor connection point 433 for the third HVDC transmission conductor 430 via the switch S20. In the same manner, the second DC voltage connection 436 of the first converter 321 is (switchably) electrically connected to a further conductor connection point 439 for the third HVDC transmission conductor 430 via the switch S21. This further HVDC transmission system 400 has the advantage over the HVDC transmission system 300 illustrated in Figure 3 that, even in the event of failure of the first HVDC transmission conductor 309 or the second HVDC transmission conductor 312, the HVDC transmission system 400 can continue to be operated in a single-pole manner by means of the third HVDC transmission conductor 430 (without interruption).

[0051] A description has been given of a converter unit and a method in which an impedance unit is used to ensure zero crossings of the AC current at the primary-side AC voltage connections of the transformer, even if there is an unbalanced (converter-internal) fault. An electrical impedance is introduced into the earthing path of the converter unit by means of the impedance unit. It is particularly advantageous that unbalanced faults can be resolved by means of the impedance unit without the need for short-circuiting switches on a primary, secondary or tertiary side of the transformer. In comparison with a primary-side or secondary-side short-circuiting switch, it is particularly advantageous that no additional load on the AC voltage network (AC voltage system) occurs. Furthermore, a conventional AC circuit breaker can advantageously be used, since zero crossings of the current (flowing through the AC circuit breaker) are ensured. No novel control of the AC circuit breaker is necessary (conventional control and protection software can be used) and no novel coordination of the AC circuit breaker is necessary either.

[0052] In comparison with a tertiary-side short-circuiter, the following advantages result:

- a cost-effective transformer design is possible (no heavy-duty tertiary winding is required)
- there is no dependence on network parameters
- no novel adaptations of the control and protection software are necessary because a conventional AC circuit breaker can be used.

[0053] Advantageously, passive fault resolution is made possible by means of the impedance unit. This means that no components (for example short-circuiting switches) need to be closed or opened. This allows for a simple and cost-effective way of resolving the fault. Furthermore, the disclosed solution with the impedance unit is loss-neutral because the impedance unit is installed outside the main current path of the converter unit. In other words, a current generally only flows through the impedance unit when a fault occurs.

[0054] Advantageously, therefore, in particular, it is possible to resolve converter-internal unbalanced faults (for example single-pole faults to earth) without the use of short-circuiters. The impedance unit in the earthing path damps the fault current I (which flows from the secondary side of the transformer to the earth potential through the impedance unit). A counter-voltage is built up across the impedance unit 339 by the fault current I. This results in natural current zero crossings of the AC current on the primary side of the transformer and thus in the AC circuit breaker.

[0055] The described solution can be used particularly advantageously in bipolar voltage source converters based on half-bridge technology.

Patentkrav

1. Fremgangsmåde til behandling af en fejl i en omformerenhed (303) til højspændingsjævnstrømstransmission,

- hvor omformerenheden (303) har en første omformer (315),
- hvor en første jævnstrømsspændingsforbindelse (327) af den første omformer (315) er forbundet til et første lederforbindelsespunkt (330) for en første højspændingsjævnstrømstransmissionsleder (309),
- hvor en anden jævnstrømsspændingsforbindelse (333) af den første omformer (315) er forbundet til en impedansenhed (339) med en elektrisk impedans, der danner et forbindelsespunkt (336),
- hvor impedansenheden (339) forbinder forbindelsespunktet (336) til jordpotential (342),
- hvor impedansenheden (339) har en ohmisk modstandskomponent (355) der er forbundet i serie med en induktorkomponent (358), hvor modstandskomponenten (355) har en ohmisk modstand på mellem 5 ohm og 5000 ohm, og
- hvor en vekselstrømsspændingsforbindelse (364) af den første omformer (315) er forbundet til en sekundær vikling (367) af en første transformer (370), og en primær vikling (373) af den første transformer (370) er forbundet til en første vekselstrømsafbryder (S7), hvor i fremgangsmåden
- en fejlstrøm (I) begynder at strømme fra jordpotentialet (342) igennem impedansenheden (339) til forbindelsespunktet (336) i respons på en enkeltpols- eller topolsfejl ved trepolsvekselstrømsspændingsforbindelsen (364) af den første omformer (315),
- fejlstrømmen (I) dæmpes i kraft af impedansen af impedansenheden (339) og en spænding bygges op ved impedansenheden (339), som et resultat af hvilket en vekselstrøm der strømmer igennem den primære vikling (373) af den første transformer (370) har nul krydsninger således at denne vekselstrøm er i stand til at blive afbrudt ved hjælp af den første vekselstrømsafbryder (S7), og
- hvorved vekselstrømmen afbrydes ved hjælp af den første vekselstrømsafbryder (S7).

2. Fremgangsmåde ifølge krav 1,

- hvor den anden jævnstrømsspændingsforbindelse (333) af den første omformer (315) er elektrisk forbundet til en første jævnstrømsspændingsforbindelse (345) af en anden omformer (318),
- hvor en anden jævnstrømsspændingsforbindelse (348) af den anden omformer (318) er forbundet til et andet lederforbindelsespunkt (352) for en anden højspændingsjævnstrømstransmissionsleder (312),
- hvor en vekselstrømsspændingsforbindelse (385) af den anden omformer (318) er forbundet til en sekundær vikling (388) af en anden transformer (391), og en primær vikling (394) af den anden transformer (391) er forbundet til en anden vekselstrømsafbryder (S8), hvor i fremgangsmåden
- fejlstrømmen (I) begynder at strømme fra jordpotentialet (342) igennem impedansenheden (339) til forbindelsespunktet (336) i respons på en enkeltpols- eller topolsfejl ved trepolsvekselstrømsspændingsforbindelsen (364) af den første omformer (315) eller ved trepolsvekselstrømsspændingsforbindelsen (385) af den anden omformer (318),
- fejlstrømmen (I) dæmpes i kraft af impedansen af impedansenheden (339) og en spænding bygges op ved impedansenheden (339), som et resultat af hvilket en vekselstrøm der strømmer igennem den primære vikling (373) af den første transformer (370) eller den primære vikling (394) af den anden transformer (391) har nul krydsninger således at denne vekselstrøm er i stand til at blive afbrudt ved hjælp af den første vekselstrømsafbryder (S7) eller ved hjælp af den anden vekselstrømsafbryder (S8), og
- hvorved denne vekselstrøm afbrydes ved hjælp af den første vekselstrømsafbryder (S7) eller ved hjælp af den anden vekselstrømsafbryder (S8).

3. Omformerenhed (303) til højspændingsjævnstrømstransmission

- omfattende en første transformer (370) og en anden transformer (391),

- omfattende en impedansenhed (339) med en elektrisk impedans, og
- omfattende en første omformer (315) og omfattende en anden omformer (318),
- hvor en første jævnstrømsspændingsforbindelse (327) af den første omformer (315) er i stand til at blive forbundet til et første lederforbindelsespunkt (330) for en første højspændingsjævnstrømstransmissionsleder (309),
- hvor en anden jævnstrømsspændingsforbindelse (333) af den første omformer (315) er forbundet til impedansenheden (339), der danner et forbindelsespunkt (336),
- impedansenheden (339) forbinder forbindelsespunktet (336) til jordpotential (342), og
- den anden jævnstrømsspændingsforbindelse (333) af den første omformer (315) er elektrisk forbundet til en første jævnstrømsspændingsforbindelse (345) af den anden omformer (318),
- hvor en anden jævnstrømsspændingsforbindelse (348) af den anden omformer (318) er i stand til at blive forbundet til et andet lederforbindelsespunkt (352) for en anden højspændingsjævnstrømstransmissionsleder (312),
- impedansenheden (339) har en ohmisk modstandskomponent (355) og en induktorkomponent (358), og
- den ohmiske modstandskomponent (355) er forbundet i serie med induktorkomponenten (358),
- hvor en vekselstrømsspændingsforbindelse (364) af den første omformer (315) er forbundet til en sekundær vikling (367) af den første transformer (370), og
- hvor en vekselstrømsspændingsforbindelse (385) af den anden omformer (318) er forbundet til en sekundær vikling (388) af den anden transformer (391),

kendetegnet ved, at

- omformerenheden har en første vekselstrømsafbryder (S7) og en anden vekselstrømsafbryder (S8),

- en primær vikling (373) af den første transformer (370) er forbundet til den første vekselstrømsafbryder (S7),
- en primær vikling (394) af den anden transformer (391) er forbundet til den anden vekselstrømsafbryder (S8),
- modstandskomponenten (355) har en ohmisk modstand på mellem 5 ohm og 5000 ohm, og
- omformerenheden (303) er konfigureret til at udføre fremgangsmåden ifølge krav 1 eller 2.

4. Omformerenhed ifølge krav 3, som har en overspændingsafleder (361), hvor
- forbindelsespunktet (336) er endvidere forbundet til jordpotential (342) ved hjælp af overspændingsaflederen (361).

5. Omformerenhed ifølge krav 4, hvor
- overspændingsaflederen (361) er forbundet parallelt med impedansenheden (339).

6. Omformerenhed ifølge kravene 3 til 5, hvor
- den første omformer (315) og/eller den anden omformer (318) har en serieforbindelse omfattende moduler (200), hvor modulerne (200) hver har i det mindste to elektroniske omskifterelementer (202, 206) og et elektrisk energilager (210).

7. Omformerenhed ifølge kravene 3 til 6, hvor
- den første omformer (315) og/eller den anden omformer (318) er en modulær multiniveauomformer.

8. Højspændingsjævnstrømstransmissionssystem (300) omfattende en omformerenhed (303) ifølge et af kravene 3 til 7.

FIG 1

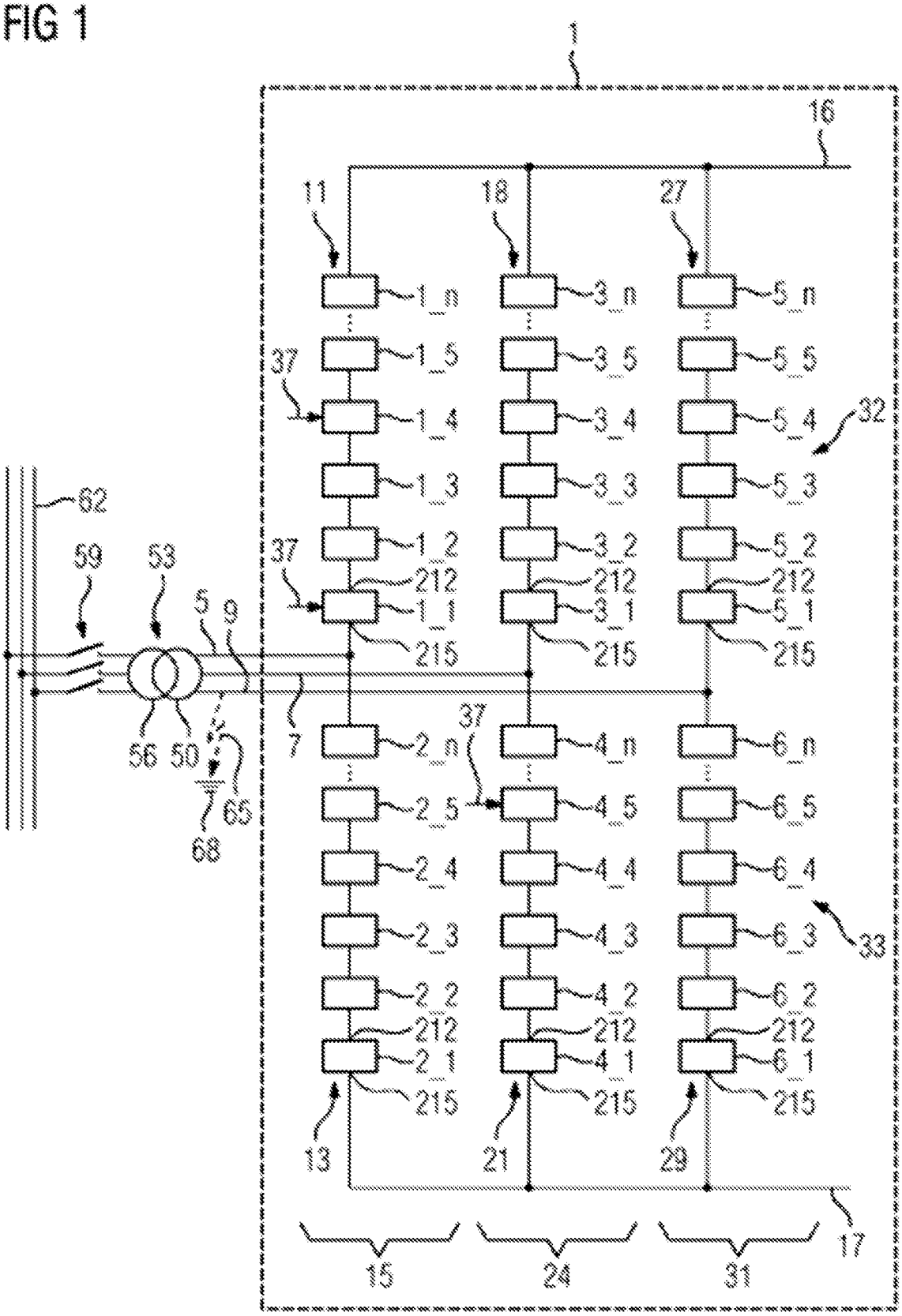
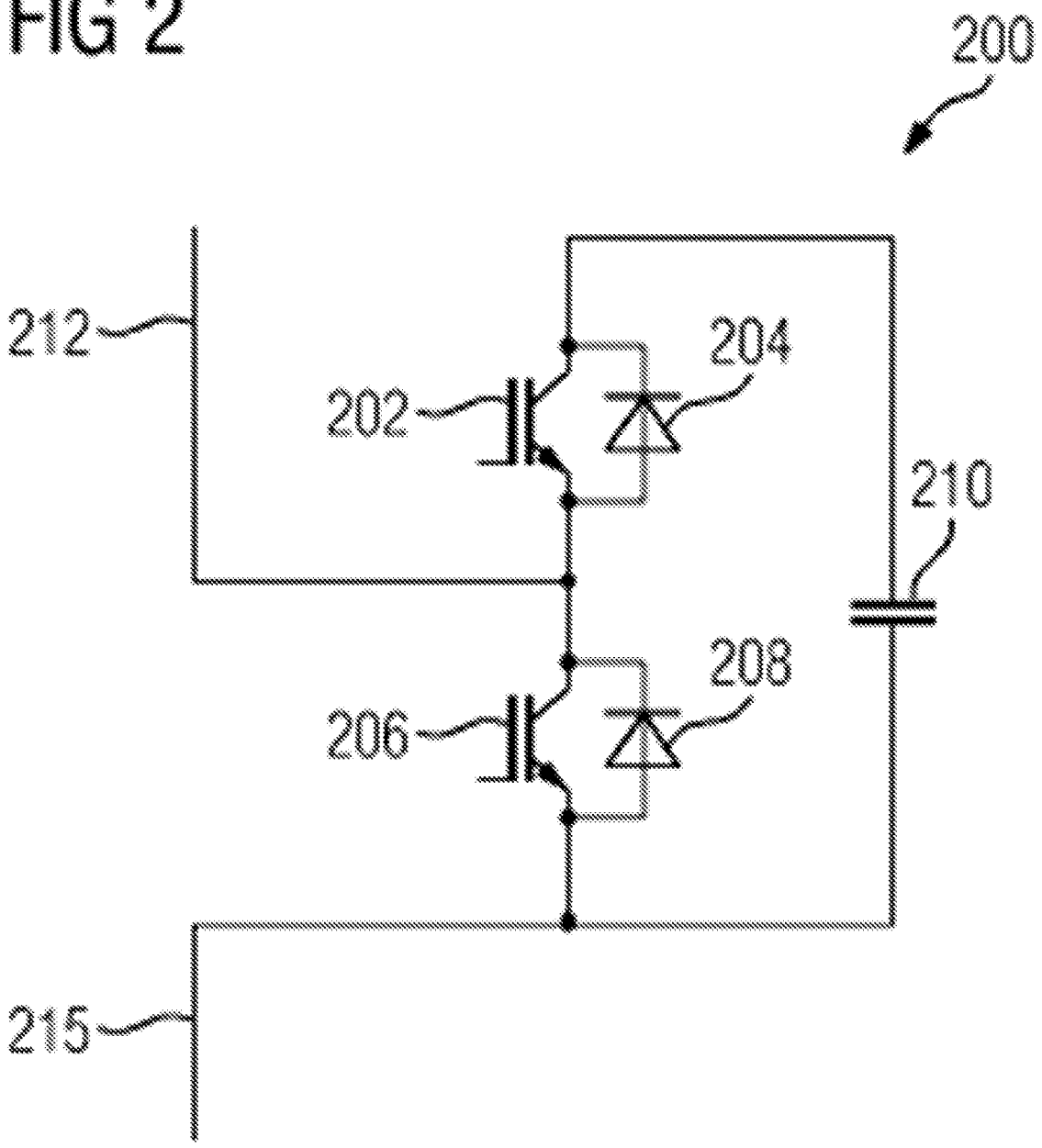

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FIG 2



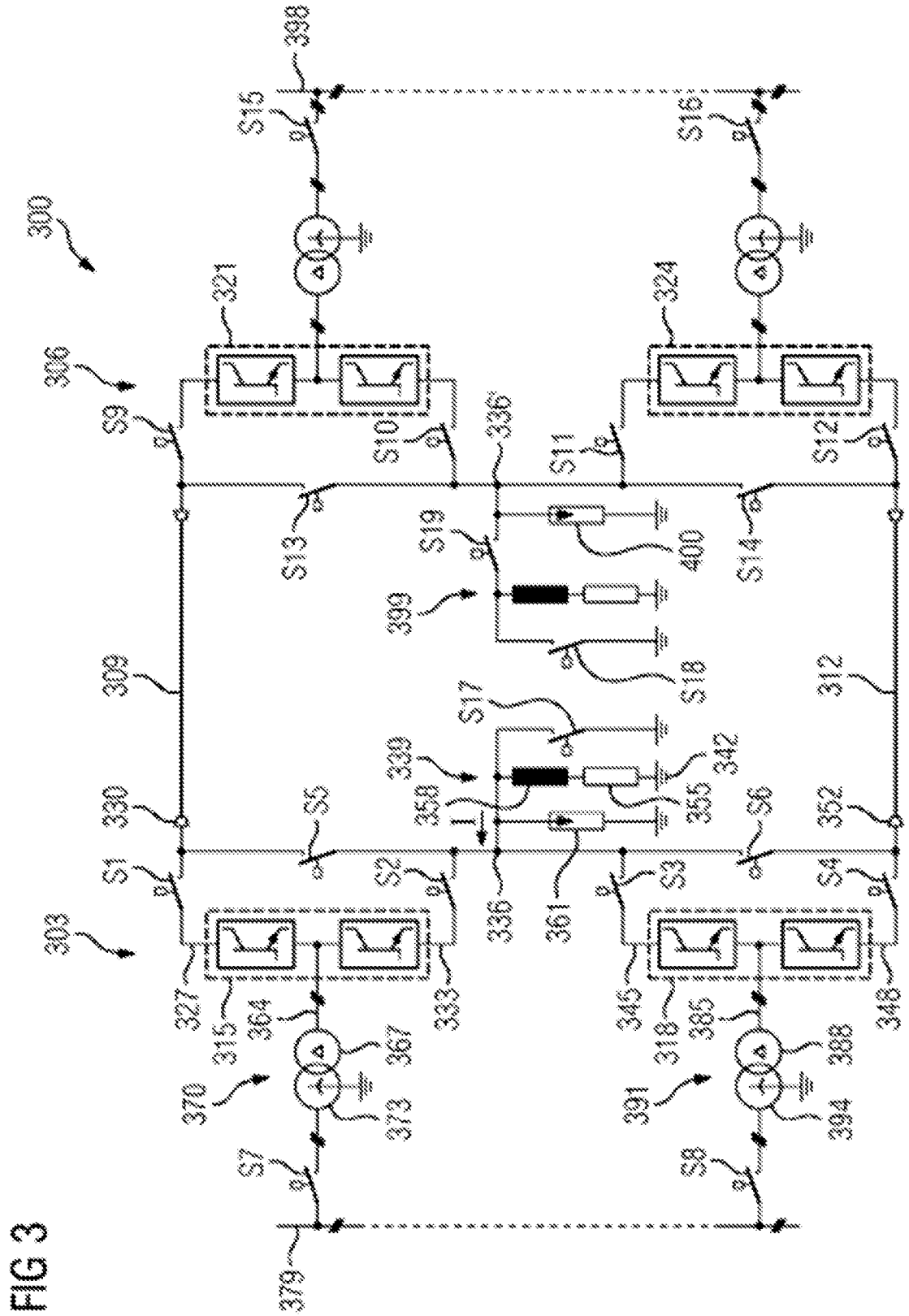

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FIG 3

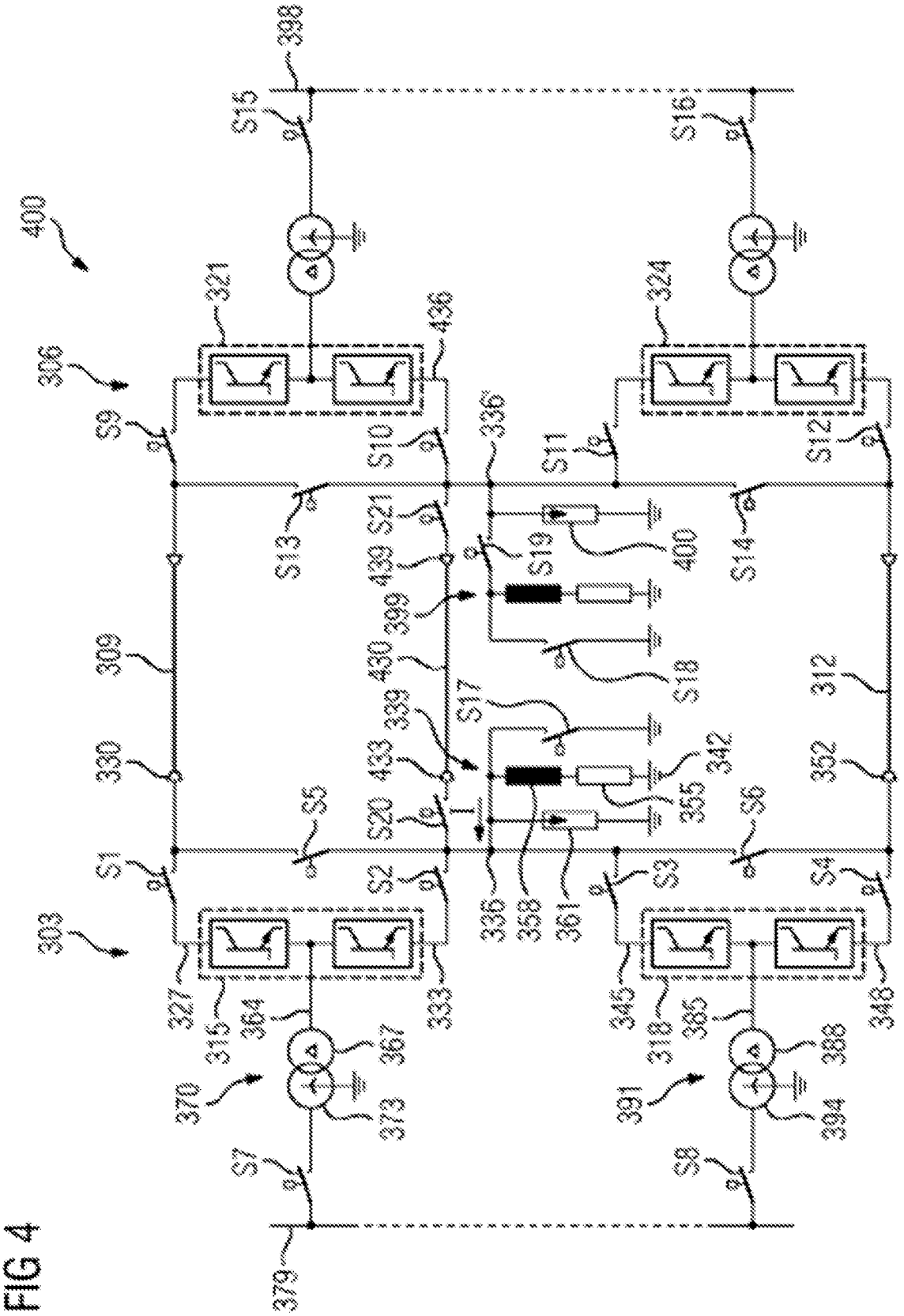

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FIG 4