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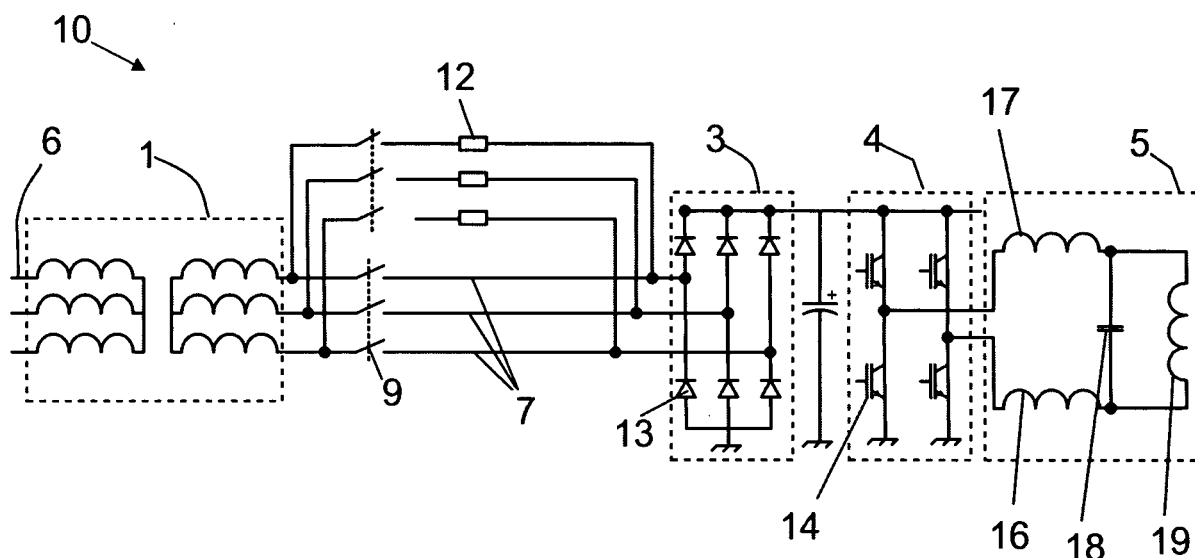
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(54) **Electrical power supply circuit**

(57) There is described a power circuit (10) to supply and control at least one heating element (5), having a single-phase resistive load in alternating voltage, the circuit (10) having a three-phase alternating voltage source (6) comprising: a rectifier (3) suitable to transform the alternating voltage of the three-phase source into a single-phase direct voltage; a frequency converter (4) suit-

able to transform the single-phase direct voltage into single-phase alternating voltage for the heating element (5); a PLC suitable to control said frequency converter (4), according to a periodic sequence of alternating active phases and recirculation phases such that the effective voltage output from said converter (4) can be regulated by varying the duration of said phases.

Fig. 1a



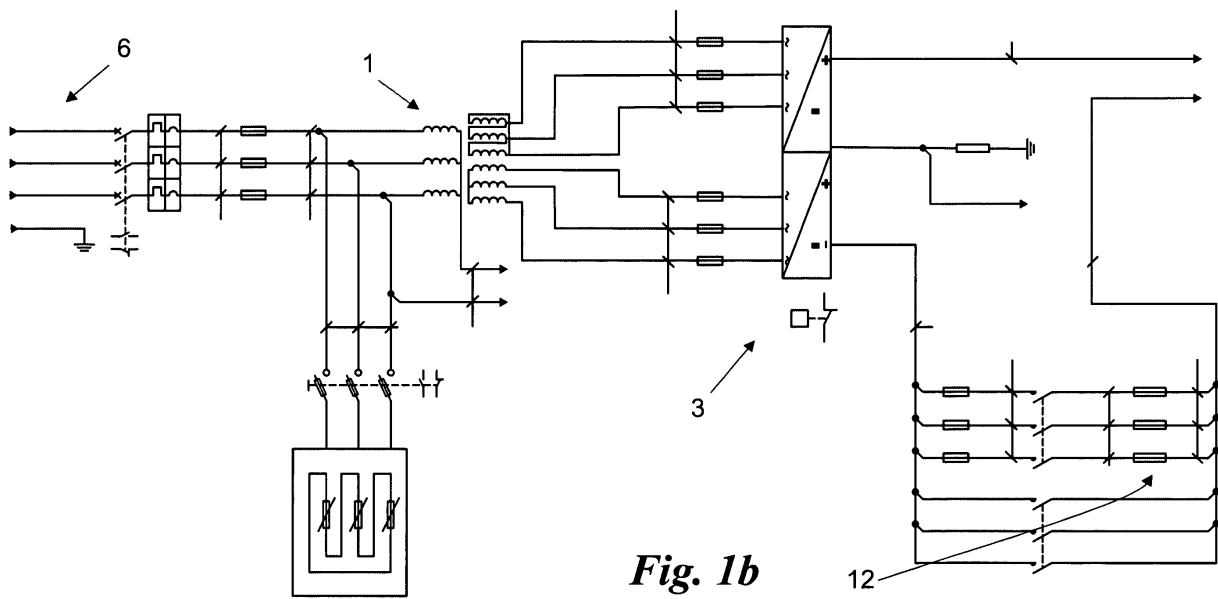


Fig. 1b

Description

[0001] The present invention relates to an electrical power supply circuit to supply and control at least one load, for example an induction heating element for industrial machines for the extrusion of metal section bars.

[0002] In the industrial sector for producing extruded metal section bars, a metal billet is fed longitudinally through an electric induction furnace capable of heating it to increase the plasticity and facilitate deformation thereof during extrusion through a die which defines the final section.

[0003] Among furnaces suitable for the purpose, some are known which are divided longitudinally into subsequent sections controlled with different temperatures dictated by the plastic deformation requirements of the billet material along the extrusion path thereof.

[0004] Due to the high service powers required by these devices, they are supplied by means of an electrical power supply circuit with three-phase voltage. Generally, being supplied with three-phase voltage at fixed frequency, the aforesaid furnaces are divided into sections, each section being supplied with alternating current directly by a respective pair of phases.

[0005] The aforesaid prior art has some important drawbacks.

[0006] In fact, the decision to connect each section to a respective pair of phases means that areas are divided preferably into multiples of three, as by using fewer the system would be unbalanced.

[0007] Moreover, during heating some sections are progressively deactivated, causing unbalance in the system.

[0008] Another drawback of such prior art system is that the prior art three-phase power circuit produces a phase shift between voltage and current and therefore a reduced $\cos\phi$ value, thus requiring the use of a bank of power factor correction capacitors.

[0009] The object of the invention is therefore to provide an electrical power circuit able to substantially overcome the aforesaid drawbacks.

[0010] Another object of the present invention is to provide a power circuit able to regulate the power supplied to each heating element separately.

[0011] A further object of the present invention is to provide a power circuit which is flexible and simple to use for multiple power distribution configurations to more than one furnace.

[0012] Yet another object of the present invention is to provide a power circuit which is able to achieve a high power factor $\cos\phi$, also for low supply powers of the heating elements.

[0013] One more object of the present invention is to provide an electrical power circuit with a configuration suitable to allow cooling of the components of which it is composed, in a simple and inexpensive manner, while ensuring safe electrical insulation.

[0014] A further object of the present invention is to

provide a power circuit which is able to ensure high reliability and duration in time.

[0015] These and other objects are achieved by a power circuit to supply and control at least one heating element as claimed in the attached claim 1.

[0016] Preferred embodiments are highlighted in the dependent claims.

[0017] The invention will now be illustrated with the description below of an embodiment thereof, provided by way of non-limiting example, with reference to the accompanying drawings wherein:

Fig. 1a shows a possible diagram of a power circuit according to the invention, of the type with 6 pulses;

Fig. 1b shows part of a possible diagram of a power circuit according to the invention, of the type with 12 pulses;

Fig. 2 shows the waveform output from the three-phase transformer of the type with 12 pulses;

Fig. 3 shows the voltage and current trend output from the rectifier;

Fig. 4 shows a simplified diagram of a frequency converter according to the invention;

Fig. 5 shows the instantaneous voltage and current trend output from the frequency converter;

Fig. 6 shows the voltage and current trend downstream of the power factor correction reactors;

Fig. 7 shows two possible instantaneous voltage trends at the output of the converter varying the duration of the active phases;

Fig. 8 shows a possible configuration of a circuit according to the invention, in which two furnaces or series of inverters can be controlled through the same rectified voltage; and

Fig. 9 shows a possible embodiment of a sealed container block according to the invention, containing a rectifier and a converter according to the invention. With reference to the figures listed above, a possible embodiment of a power circuit according to the invention is indicated as a whole with the number 10.

[0018] It is suitable to electrically supply an industrial furnace for heating metal billets, for example made of aluminium, to facilitate plastic deformation thereof during feed through a die which defines the final shape of the section of the extruded section bar obtained from said billets.

[0019] Generally, prior art furnaces are provided with heating elements 5 comprising coils 19 wound in the form of solenoid and arranged aligned upstream of the die, inside which the billet is fed to heat it through the known mechanism of electromagnetic induction.

[0020] As shown in Fig. 1, the power circuit 10 comprises an electrical power source 6, of the alternating current three phase type, a rectifier 3 suitable to transform the alternating voltage of the three-phase source 6 into a single-phase direct voltage downstream of the rectifier

3, a frequency converter **4**, arranged downstream of the rectifier **3**, suitable to transform the single-phase direct voltage downstream of the rectifier **3** into single-phase alternating voltage downstream of the converter **4**, suitable to supply the heating element **5**.

[0021] The circuit **10** also comprises a PLC, not shown in the figure, suitable to control the frequency converter **4**, in such a manner as to supply downstream of the converter **4** a desired value of frequency and of single-phase effective voltage to supply the heating element **5**.

[0022] Advantageously, the circuit **10** comprises a three-phase transformer **1** suitable to adapt the power supply voltage of the source **6** to a voltage value suitable to supply the furnace **5**.

[0023] The three-phase transformer **1** also performs the function of galvanic separation between the power supply of the source **6** and the supply circuit **10**.

[0024] In particular, the three-phase transformer **1** has a double secondary and therefore has two separate secondary windings, one of which is star, or "Y", connected, and one delta, or "D", connected, from which a first three-phase line **7** and a second three-phase line **8** extend respectively at the same voltage, which share the line power equally, and which reunite upstream of the rectifier **3**. In this manner, the advantage of limiting line harmonics is achieved.

[0025] In particular each line **7** and **8** has a respective switch **9**. Moreover, each line can have respective pre-charge resistors **12**.

[0026] Advantageously, a three-phase transformer **1** of the rectifiable type with 12 pulses is selected, in order to achieve a substantially sinusoidal waveform downstream of the transformer **1**, as shown in Fig. 2, where the wave **21** output from the transformer is compared with the ideal sinusoidal wave **20**.

[0027] The three-phase voltage output from the two lines **7** and **8**, is thus input to the rectifier **3**.

[0028] This rectifier **3** advantageously comprises uncontrolled diodes **13**, connected as shown in Fig. 1 in order to obtain the maximum angle of flow and minimum harmonic pollution coming from the three-phase voltage upstream. In this manner, a constant direct voltage **22** proportional to the input three-phase line voltage **23** is output from the rectifier **3**, as shown in Fig. 3.

[0029] The frequency converter **4**, shown in Fig. 1, advantageously comprises at least one semiconductor transistor **14** of IGBT type (Insulated Gate Bipolar Transistor), with switch on and switch off controllable through a signal sent by said PLC. These transistors are connected in an H-shaped bridge configuration, in such a manner as to selectively and alternately connect the positive and negative pole of the single-phase direct voltage output from the rectifier **3** to a respective end of the resistive load of the heating element **5**.

[0030] More in detail, each transistor **14** is equivalent to a switch which can be closed or opened through an electrical open/close signal sent by the PLC. In other words, the converter **4** of Fig. 1 can be schematized as

in Fig. 4, in which V_{in} is the direct voltage downstream of the rectifier **8**, V_{out} is the single-phase alternating voltage sent to the heating element **5**, and the switches **15** represent the transistors **14**.

[0031] As shown in Fig. 1, the heating element **5**, besides having a coil **19**, also comprises two reactors **16** and **17** and a capacitor **18**, suitable to adapt the stepped alternating voltage output from the converter to a sinusoidal alternating voltage input to the coil **19**.

[0032] In fact, Fig. 5 shows the voltage **25** and current **24** trend output from the converter **4**, and Fig. 6 shows the corresponding voltage **27** and current **26** trend output from the power factor correction reactors in input to the coil **19**.

[0033] In the case in which the furnace comprises a plurality of heating elements **5** in sequence, the circuit **10** is provided with a plurality of frequency converters **4** connected in parallel downstream of the rectifier **3**, each frequency converter supplying a respective heating element **5**. In this case the PLC is capable of controlling each single converter **4**, and therefore each heating element **5**, separately.

[0034] An example of such configuration is described in Fig. 8, in which twelve heating elements **5** are provided, divided into two groups **42** and **43** of six elements each. Each group **42** and **43** is managed by a respective PLC **40** and **41** capable of controlling the heating groups **5** separately by means of a respective frequency converter **4**. The system is supplied by a single source with three-phase alternating voltage **6**, and comprises a three-phase transformer **1** with double secondary, of which one is star connected and the other delta connected. A respective three-phase line **7** and **8**, at the same voltage, i.e. 520V, extends from each secondary, and reunite in the rectifier **3**. A single-phase direct voltage line, i.e. at 780V, extends downstream of the rectifier **3**, and on which all the frequency converters **4** are connected. The PLC **40** and **41** supplies these converters **4** with a preset sequence of pulses on which the frequency and effective voltage supplied to each heating element **5** depends, according to a function described below.

[0035] The aforesaid two groups of six heating elements can each belong to two separate furnaces, allowing high flexibility in the possibility of multiple distribution of the power, applying it simultaneously to more than one furnace. In practical cases, as high powers are fed through the components of such circuit, they tend to become hot due to power losses, and therefore require a continuous cooling process. In this energy conversion, the largest losses and consequently the most heat are localized in the power transformer **1**, in the rectifier **3**, in the converter or inverter **4** and in the filter reactors **16** and **17**.

[0036] In particular, the transformer **1** must be maintained at a temperature of around 40-45 °C, while the PLC and the regulation electronics must be maintained at a temperature of 30-35°C.

[0037] As shown in Fig. 8, according to the present

invention, this object is achieved by integrating several components in a single block **50** in such a manner as to use a single heat exchanger.

[0038] In particular, in a preferred embodiment of the invention, the rectifier **3** and the frequency converter **4** are contained in a same sealed container **51** electrically insulated and provided on a first face **52** with a electrically insulated and thermally conductive heat sink layer **55** which can face a heat exchanger, not shown. A second face of the sealed container comprises the electrical connections **53**, **54** and **56**.

[0039] More in detail, the layer **55** comprises a thin layer of electrically insulating material interposed between the components contained and the outside, externally coated by a copper or aluminium heat sink substrate. In particular, such configuration allows the components, for example the rectifier and the converter, to be buried directly in an insulating matrix, for example made of plastic or ceramic materials, which forms the container **51**.

[0040] The present invention can also be implemented in other embodiments, in which the sealed container **51** can also include other components therein, selected from the three-phase transformer, filter reactors or yet other components. Operation of a circuit according to the invention and in particular of the frequency converter **4**, the structure of which is described above, is as follows. With reference to Figs. 1 and 4, analyzing the converter **4**, commonly known as "inverter", each of the four transistors **14**, schematized with a switch **15**, has two possible states, ON and OFF, for a total of sixteen theoretical configuration combinations. Of these configurations, four are with only one transistor **14** on and do not involve energy exchanges, seven are to be avoided as they cause a short circuit on the direct current input line, one is the null configuration with all the transistors **14** switched off, while the remaining four configurations are those possible for operation of the inverter **4**. Of these four possible configurations, two are active in which there is an energy exchange between input and output of the converter **4** and two configurations are of recirculation in which the instantaneous voltage output from the converter **4** is null. In the two active configurations two transistors positioned on one of the two diagonals of the H-shaped bridge are switched on, so that the positive pole **23** and the negative pole **29** in input are alternately inverted onto the output voltage V_{out} according to the active diagonal. An inversion of the output voltage corresponds to each alternation of the two active configurations, so as to achieve an alternating voltage, but in steps. In this manner, if the two configurations are cyclically altered with the same duration a null, or alternating, mean output voltage is achieved, the frequency of which is variable simply by varying the period of the cycle and therefore the duration of the configurations.

[0041] A similar trend of voltages output from the inverter **4** is described in Fig. 7, which shows, in a first graph, an instantaneous voltage trend **29** corresponding

to active phases **31** and **32** of maximum duration and recirculation phase **33** of null duration, and, in the second graph, an instantaneous voltage trend **30** with active phases **31** and **32** of lesser duration and recirculation phase of greater duration, of the same period **28** with respect to the first graph. The first graph corresponds to a maximum power supplied to the heating element, while the second corresponds to an intermediate power.

[0042] In particular, switching from one active configuration **31** to the other **32** passes through a recirculation configuration **33** which introduces a null level on the instantaneous output voltage **29**, **30**, which has a total of three levels: the null level **33**, where the instantaneous voltage is equal to zero and two active levels **31** and **32** of an amplitude equal to the output voltage of the rectifier **3** and with opposite polarity.

[0043] During operation, the four possible configurations of the transistors are alternated with the operating frequency of the furnace, which is thus established unequivocally through the cycle period **28**. After establishing the period **28**, it is possible to modulate the effective voltage V_e output from the converter **4** varying the duration of the recirculation configurations **33** and therefore of the active levels **31** and **32**. For example, by increasing the duration of the recirculation configurations **33** and consequently reducing the duration of the active configurations **31** and **32**, the effective output voltage is reduced. In this way, it is possible to vary the effective voltage output from the inverter **4** from zero to a maximum equal to the rectified input voltage. Therefore, the inverter **4** performs the two effective frequency and voltage regulations of the system.

[0044] The invention achieves important advantages.

[0045] In fact, the power circuit according to the invention allows all the heating elements of a furnace for extrusion machines to be controlled separately, in such a manner as to optimize the temperatures in the different subsequent sections in complete freedom, without causing unbalances in the system. Another important advantage of the present invention is that of being able to use any number of heating elements and not necessarily multiples of three.

[0046] An important advantage of the present invention is to allow high flexibility and simple implementation for configurations of multiple distribution of the power generated, applying it simultaneously to more than one furnace.

[0047] A further advantage of the present invention is that of allowing simple and inexpensive cooling of the components through an air/water heat exchanger which does not require high qualities of the water used, due to a large surface of the heat sink layer.

[0048] One more advantage of the present invention is the fact that it achieves a high power factor $\cos\phi$, between 0.98 and 1, which makes the use of a bank of power factor correction capacitors unnecessary.

[0049] Another advantage of the present invention is that of reaching the nominal $\cos\phi$ value already at 20%

of the power regulation.

[0050] Moreover, an advantage of the present invention is reduced harmonic distortion.

[0051] As a consequence of said advantages, it is possible, as mentioned previously, to connect the circuit 10 to an even number, in particular to two, induction furnaces for heating billets.

[0052] These furnaces can be synchronized so that each one, or each group, has a high power heating period and a temperature maintenance period at a lower power, in particular around one fifth of the high power.

[0053] Said heating and maintenance periods are preferably alternated, so that while one group of furnaces, or a single furnace, is in heating mode, a second group of furnaces, or single furnace, is in maintenance mode.

[0054] In fact, induction furnaces for billets require a first heating period at maximum power, during which the whole billet is heated homogeneously, and a second maintenance period, during which only some areas of the billets are heated, while other areas are maintained at a constant temperature.

[0055] Consequently, this process allows 100% of the energy available always to be used and makes it possible to heat a greater number of billets in the unit of time, with the same available power.

[0056] The description above of a specific embodiment is able to show the invention from a conceptual perspective so that others, using prior art, may modify and/or adapt this specific embodiment in various applications, without further research and without departing from the inventive concept and, therefore, it is intended that these adaptations and modifications may be considered as equivalents of the specific embodiment. The means and the materials to implement the various functions described may be of different types without however departing from the scope of the invention. The expressions or the terminology used are intended as purely descriptive and therefore non limiting.

Claims

1. A power circuit (10) to supply and control at least one heating element (5) having a single-phase resistive load with alternating voltage, said circuit (10) having a three-phase alternating voltage source (6) and being **characterized in that** it comprises: a rectifier (3) suitable to transform the alternating voltage of said three-phase source into single-phase direct voltage; a frequency converter (4), suitable to transform said single-phase direct voltage into single-phase alternating voltage for said heating element (5) a PLC suitable to control said frequency converter (4), according to a periodic sequence of alternating active phases and recirculation phases such that the effective voltage output from said converter (4) can be regulated by varying the duration of said phases .

2. The power circuit according to claim 1, wherein said frequency converter (4) comprises at least one semiconductor transistor (14) of IGBT type (insulated Gate Bipolar Transistor), with switch on and switch off controllable through a signal sent by said PLC.
3. The power circuit according to claim 2, wherein said frequency converter comprises four transistors of IGBT type (14) in an H-shaped bridge configuration, in such a manner as to selectively and alternately connect the positive and negative pole of said single-phase direct voltage to a respective end of said resistive load.
4. The power circuit according to one or more of the preceding claims, wherein said rectifier (3) comprises uncontrolled diodes.
5. The power circuit according to one or more of the preceding claims, wherein said three-phase source (6) comprises a three-phase transformer (1).
6. The power circuit according to claim 5, wherein said three-phase transformer (1) is of the type with double secondary, having a first secondary star, or "Y", connected, and a second secondary delta, or "D", connected, suitable to give rise to a first three-phase line (7) and a second three-phase line (8), which reunite upstream of said rectifier (3).
7. The power circuit according to claim 6, wherein at least one between said first and second three-phase lines (7, 8) comprises a switch (9,11).
8. The power circuit according to claim 5, wherein said three-phase transformer (18) is of the type suitable to supply a rectifier with twelve pulses or with twenty-four pulses.
9. The power circuit according to one or more of the preceding claims, comprising at least one filter reactor (16, 17) arranged downstream of said frequency converter (4) and upstream of said resistive load (8), suitable to transform said single-phase alternating voltage output from said frequency converter to a sinusoidal single-phase alternating voltage for said resistive load.
10. The power circuit according to one or more of the preceding claims, wherein at least one between said rectifier (3) and said frequency converter (4) is contained in an insulated sealed container (51) provided on a first face (52) with an electrically insulating (55) and thermally conductive layer which can face a heat exchanger, and on a second face with electrical connections (53, 54, 56).
11. The power circuit according to claim 10, wherein both

said rectifier (3) and said frequency converter (4) are contained in the same said sealed container (51).

12. The power circuit according to claim 10 or 11, where-
in said insulated sealed container (51) contains
therein at least one between: said three-phase trans-
former (4); said at least one filter reactor (16, 17). 5
13. An induction furnace for heating billets comprising
at least one heating element (5) having a single-
phase resistive load in alternating voltage and a pow-
er circuit (10) to supply and control said at least one
heating element according to one or more of the pre-
ceding claims. 10
14. A process to supply and control a plurality of induc-
tion furnaces, comprising at least one heating ele-
ment (5) having a single-phase resistive load with
alternating voltage and connected to a power circuit
(10) to supply and control said at least one heating
element (5), said process comprising a high power
heating period and a temperature maintenance pe-
riod at lower power to said high power and being
characterized in that said furnaces are divided into
two groups of furnaces, each including at least one
furnace, **in that** said furnaces are activated simulta-
neously and **in that** one of said groups is activated
in said heating period and the other of said groups
is activated in said maintenance period. 15
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Fig. 1a

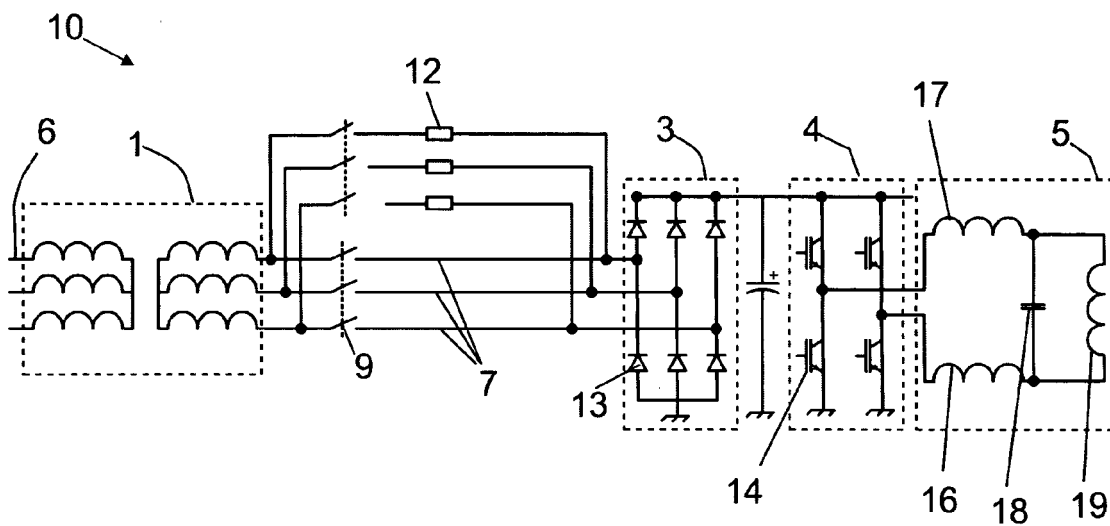
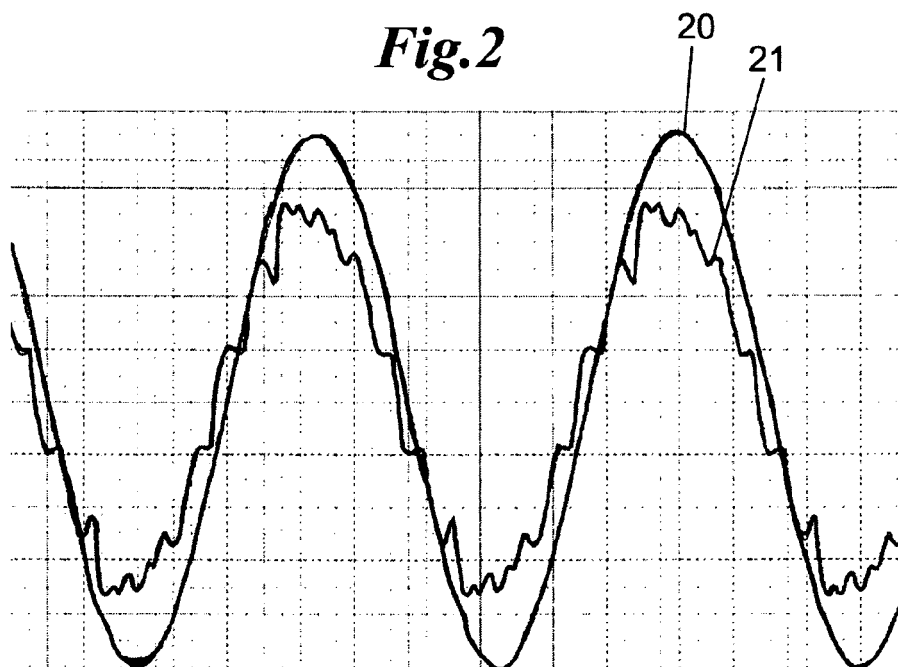


Fig. 2



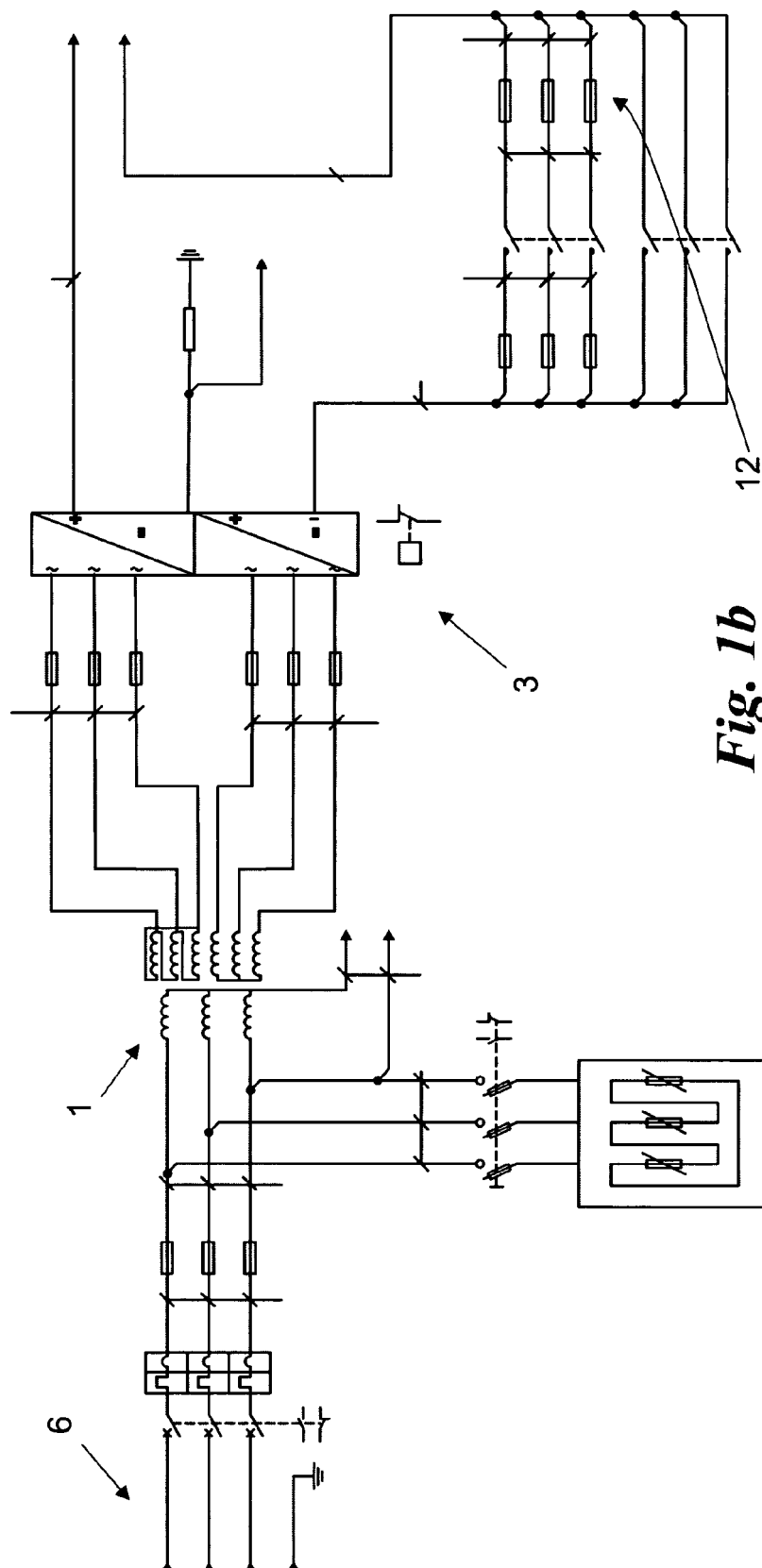


Fig. 1b

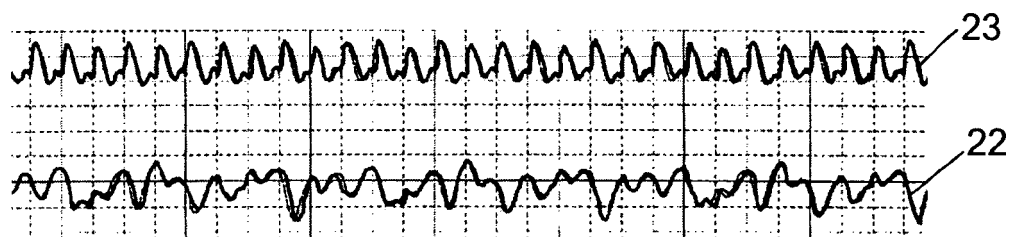


Fig.3

Fig.4

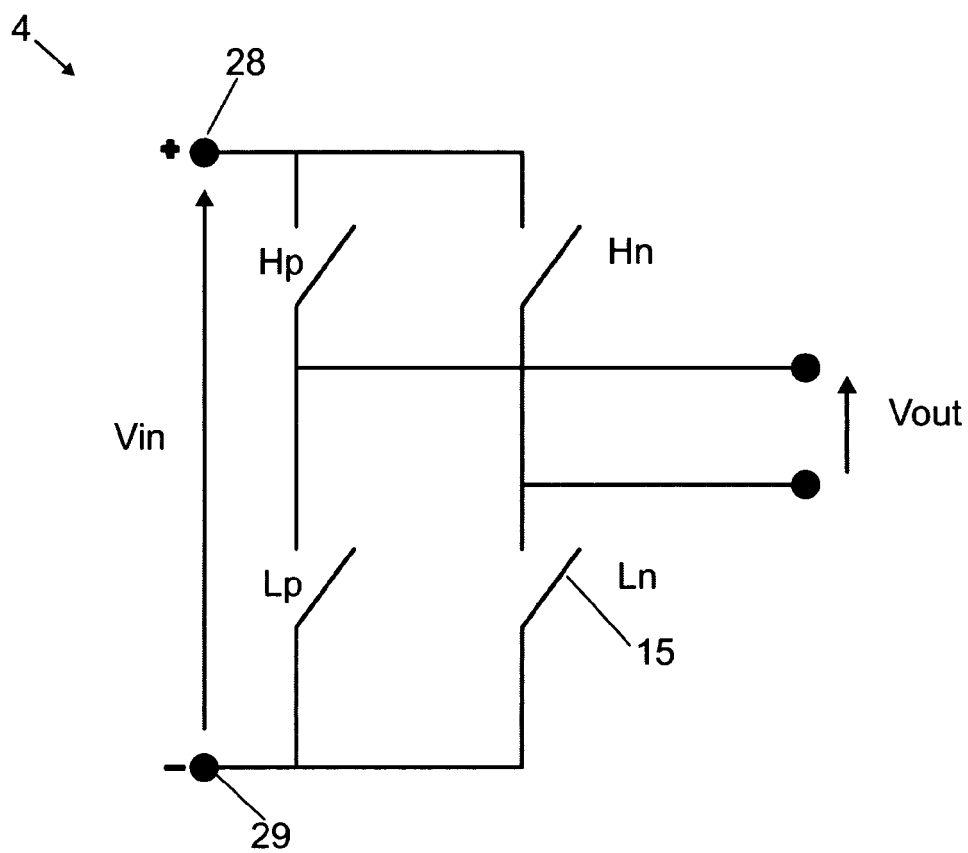


Fig.5

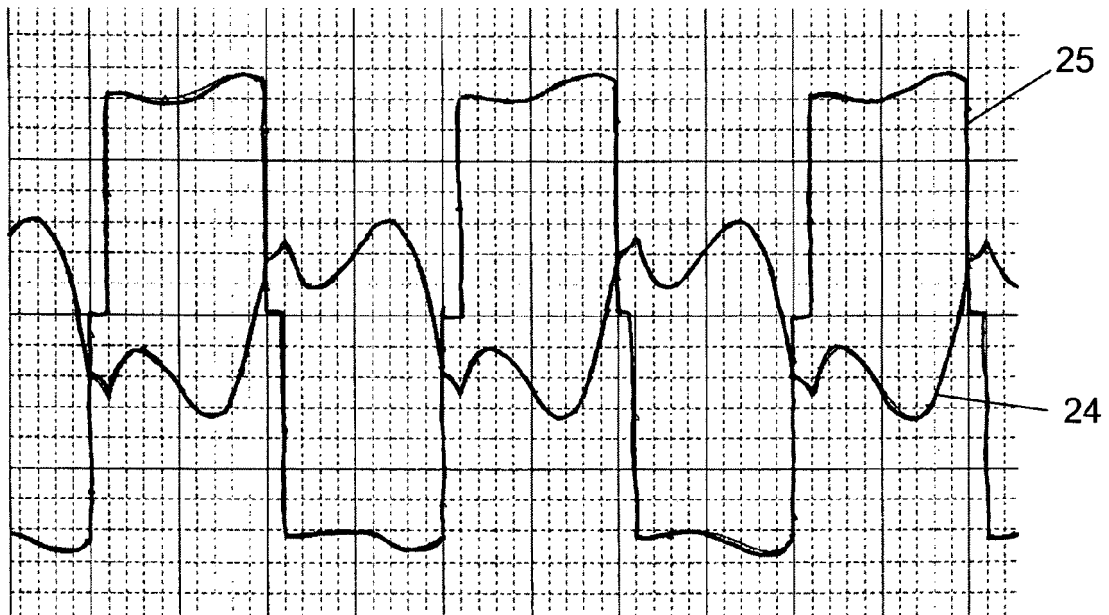
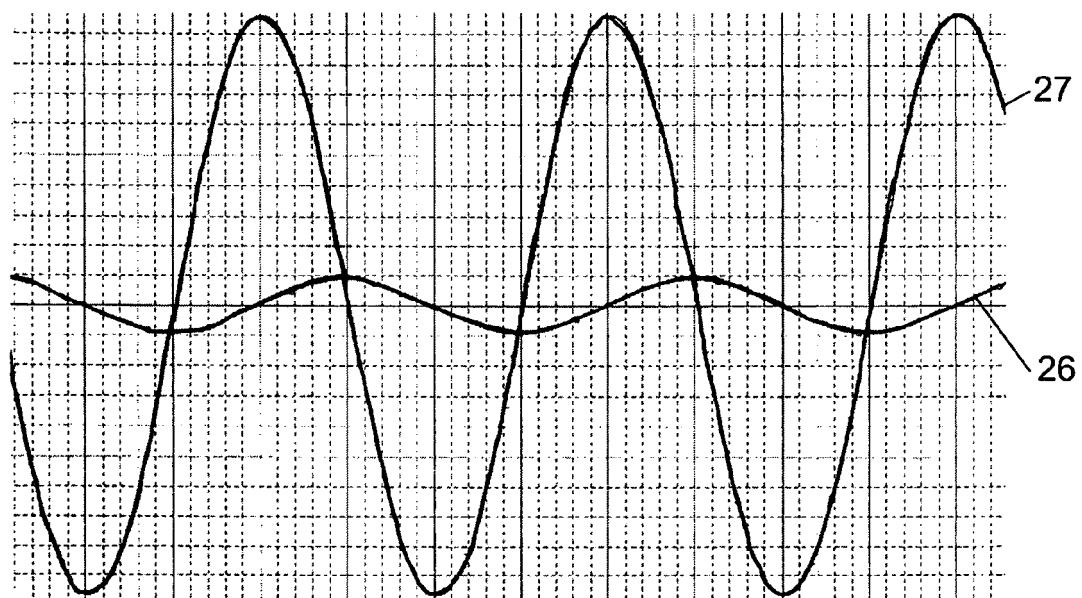


Fig.6



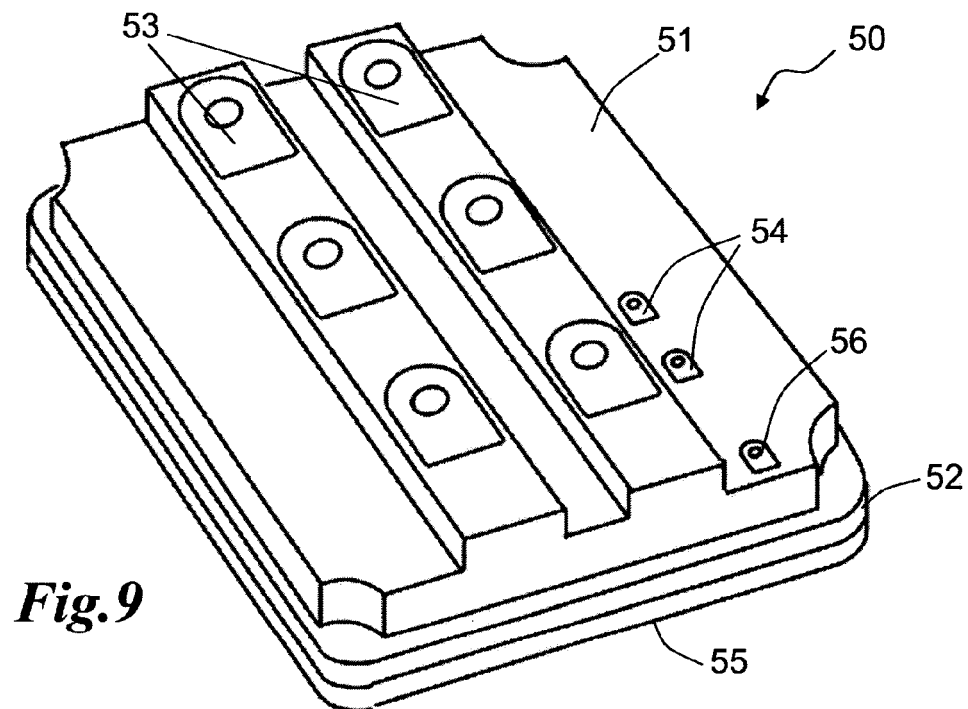
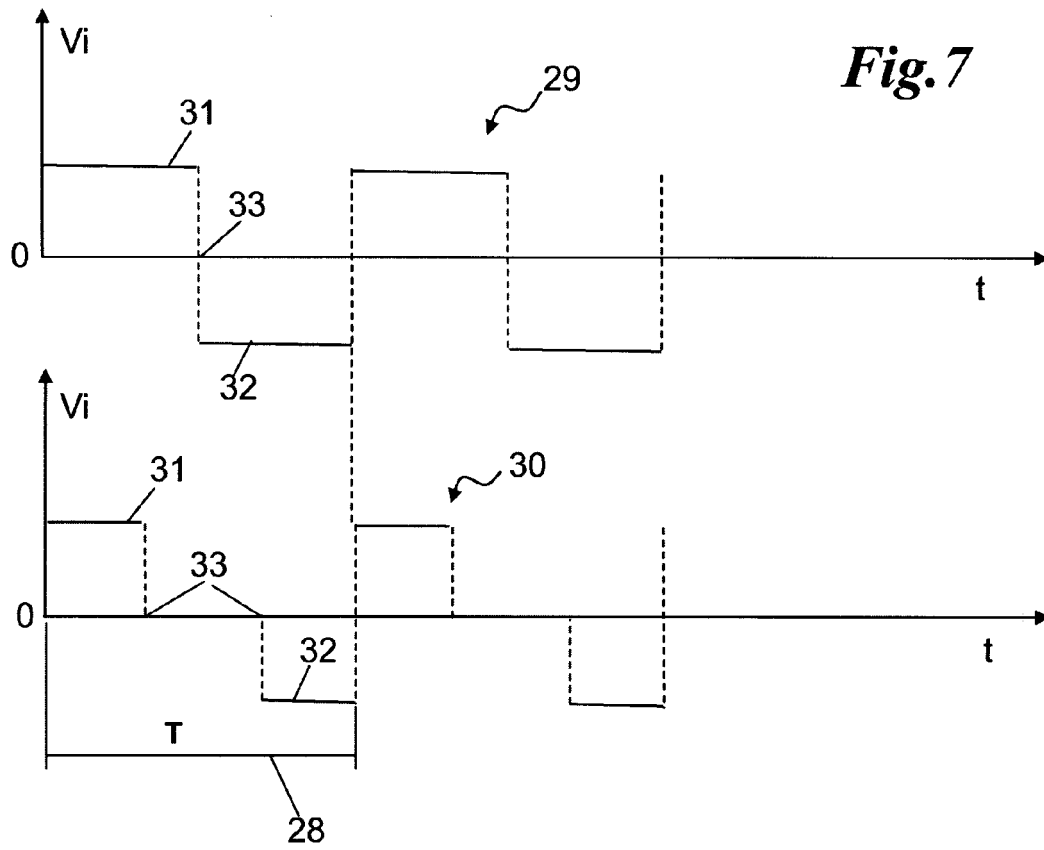
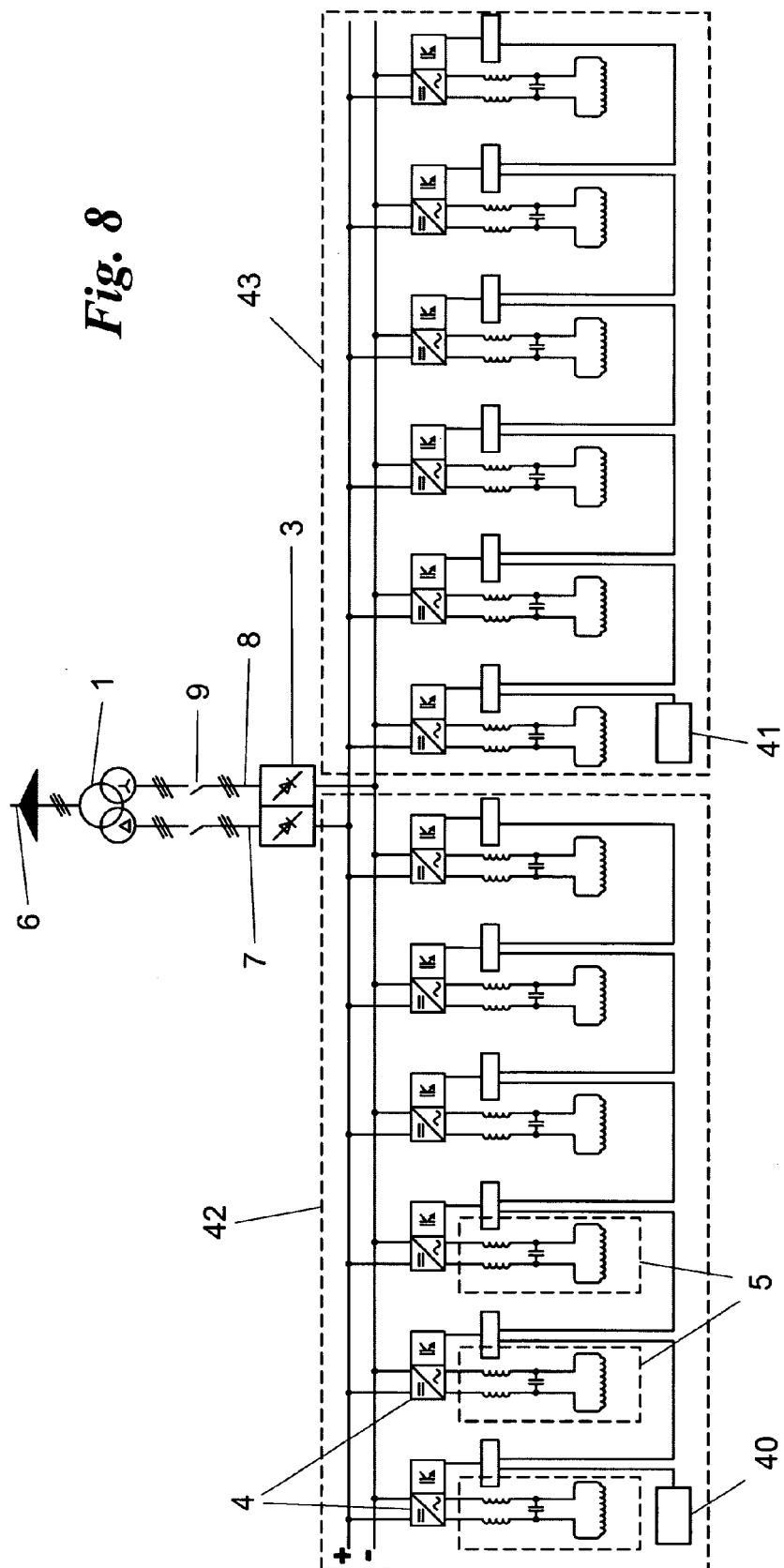


Fig. 8





EUROPEAN SEARCH REPORT

Application Number
EP 09 42 5287

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2006/118549 A1 (FISHMAN OLEG S [US] ET AL FISHMAN OLEG S [US] ET AL) 8 June 2006 (2006-06-08) * paragraphs [0004], [0039], [0044], [0046], [0038], [0034]; figure 5 *	1-13	INV. H05B6/06
A	WO 00/51410 A2 (ABB METALLURG [US]) 8 September 2000 (2000-09-08)	1-13	
A	FR 1 511 457 A (HERAEUS HOCHVAKUUM GMBH) 8 April 1968 (1968-04-08)	1,14	
The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (IPC) H05B
Place of search		Date of completion of the search	Examiner
The Hague		19 April 2010	Taccoen, J
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

1
EPO FORM 1503 03.82 (P04C01)



Application Number

EP 09 42 5287

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing claims for which payment was due.

☐ Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due and for those claims for which claims fees have been paid, namely claim(s):

☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

☐ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

☐ As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.

☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:

☒ None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:

1-13

☐ The present supplementary European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims (Rule 164 (1) EPC).



LACK OF UNITY OF INVENTION
SHEET B

Application Number
EP 09 42 5287

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. claims: 1-13

Power supply controlling

2. claim: 14

Manging of tasks inside induction furnaces.

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 09 42 5287

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

19-04-2010

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