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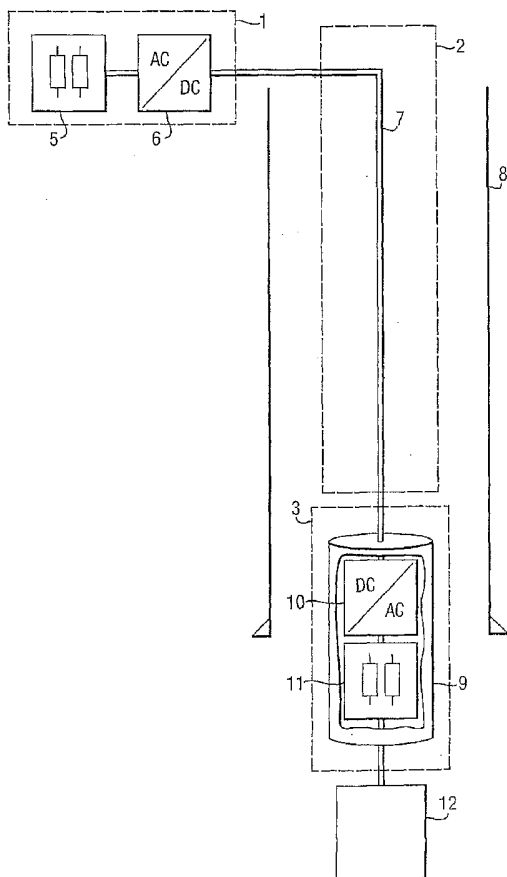
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(54) Title: SYSTEM AND METHOD FOR TRANSMITTING ELECTRIC POWER INTO A BORE



(57) Abstract: A system for transmitting electric power into a bore hole, the system comprising an electric transmission line (7) extending through the bore hole between an electric power source (1) and a receiving station (3), wherein the receiving station includes frequency increasing means (10) for increasing the frequency of the electric current supplied through the electric transmission line, voltage converter means (11) for changing the voltage of the electric current supplied to it via the frequency increasing means, connecting means for supplying the frequency-increased electric current to the voltage converter means, and means for connecting an electric load to the receiving station.



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SYSTEM AND METHOD FOR TRANSMITTING ELECTRIC POWER INTO A BORE HOLE

The present invention relates to a system for transmitting electric power into a bore hole, the system comprising an electric transmission line extending through bore hole between an electric power source and a receiving station.

Such a system is known and described in paper SPE/IADC 52791 of the Society of Petroleum Engineers, entitled "Electric coiled tubing drilling: a smarter CT drilling system" by D. R. Turner *et.al.*. In the known system, an electrically powered bottom hole assembly is connected to an electric coiled tubing that reaches into a bore hole. The electric coiled tubing holds an electric transmission line, for powering a down hole electric DC motor. The peak power output of this motor is 28 HP, corresponding to some 21 kW.

This system is not considered suitable of transmitting much higher electric power at the motor voltage, for instance as high as 100 to 400 kW, since that would require very large cross section cable which would not fit in the coiled tubing. Moreover, such a cable would become so heavy that it would not be able to pull its own weight if it reaches into a typical bore hole suitable for production of hydrocarbons.

It is an object of the invention to provide a system and a method for transmitting electric power into a bore hole capable of transmitting several hundreds of kW, and to provide a bore hole with such a system.

According to the invention, this object is achieved in a system for transmitting electric power into a bore hole, the system comprising an electric transmission line

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extending through the bore hole between an electric power source and a receiving station, wherein the receiving station includes frequency increasing means for increasing the frequency of the electric current supplied through the electric transmission line, and voltage converter means for changing the voltage of the electric current supplied to it via the frequency increasing means, and first connecting means for supplying the frequency-increased electric current to the voltage converter means, and means for connecting an electric load.

The load can be a desired tool operating at a specified voltage. The presence of the voltage converter means in the receiving station allows for the voltage in the electric transmission line to be relatively high compared to the voltage desired for operating the load, which is beneficial for achieving the high power transmission through a suitable transmission line. Due to the presence of the frequency increasing means in the receiving station, this system makes it possible to combine a relatively low frequency electric current, preferably direct current, in the electric transmission line with a relatively high frequency electric current in the voltage converter means.

Herewith, both the electric power transmission through the electric transmission line and the efficiency in the voltage converter means can be optimised. The electric power transmission is optimised because at relatively low frequency the reactive power loading in the transmission line is relatively low resulting in a high efficiency of power transmission. The size of typical transformers is inversely proportional to the current frequency, thus increasing the frequency allows for the use of a relatively small sized voltage converter

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means, such that it can fit in a typical bore hole suitable for production of hydrocarbons.

Preferably the voltage converter means comprises contactless transformer means. Such a contactless
5 transformer can typically comprise inductively coupled primary and secondary coil windings, preferably coupled via a magnetisable core such as an iron core. Such a transformer is ideally suited for high frequency voltage transformation, because the efficiency increases with
10 frequency such that its size can decrease with increasing frequency.

Optionally, the system further comprises frequency decreasing means, preferably including a current rectifier, for reducing the frequency of electric current
15 supplied to it via the voltage converter means, and second connecting means for supplying the voltage-changed electric current to the frequency decreasing means. A number of loads require a relatively low frequency, or a direct current, for their operation, and for this reason
20 the frequency decreasing means can be provided.

In an advantageous embodiment of the invention, the frequency increasing means is arranged to convert the electric current into three subsignals of increased frequency, each of which is 120° phase-shifted with
25 respect to the other two, and whereby the voltage converter means is arranged to change the voltage in each said subsignals. Most power can be transmitted using such three-phase electric current.

An additional advantage of converting to a three-
30 phase electric current is that the ripple frequency caused by switching the electric current to achieve the frequency increase is three or six times higher than the switching frequency. Therefore the ripple amplitude is reduced and the filtering requirements and relatively
35 small.

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Preferably, if the receiving station comprises frequency decreasing means, the frequency decreasing means is then also arranged to combine three subsignals, each of which is 120° phase-shifted with respect to the other two, into one electric current of reduced frequency.

In a particularly advantageous embodiment, bypassing means are provided to feed to or extract from the electric transmission a data signal parallel to the receiving station. This enables to utilise the electric transmission line for carrying a data signal in addition to the high power transmission. Since such data signal does not have to be of high power, it does not need to pass through the receiving station.

One or more of the objects of the invention are also achieved in a bore hole extending into an earth formation, which bore hole is provided with the system in accordance with one of the above described embodiments, and wherein an electric load in the form of a tool is connected to the receiving station for receiving voltage changed electric current. The tool may include one or more of: an electric welding tool, oil-water separator, an induction coil or heating device in general, a perforating tool, a valve system, an electric sparking tool such as an electric spark drilling tool, a motor-driven tool such as a traction device or a drilling assembly, preferably including a drill bit, or an electric submersible pump.

One or more of the objects of the invention are also achieved in a method of transmitting electric power into a bore hole, wherein electric current is transmitted from an electric power source to a receiving station via an electric transmission line, in which receiving station the frequency of the electric current supplied through the electric transmission line is increased in frequency

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increasing means and the voltage of the electric current supplied to it via the first frequency converter is changed in voltage converter means.

5 The invention will now be illustrated by way of example, with reference to the accompanying drawings wherein

Fig. 1 schematically shows a wire line down hole power system for an AC load;

10 Fig. 2 schematically shows a wire line down hole power system for a DC load;

Fig. 3 schematically shows an electrical drill pipe and a down hole power system for a DC load;

Fig. 4 schematically shows a bore hole with an electric powered motorised expander cone.

15 In the figures, like parts carry identical reference numerals.

In Fig. 1 a system for transmitting electric power into a bore hole is schematically shown. Elements of the system are grouped in groups (1), (2) and (3), whereby
20 group (1) corresponds to elements associated with the power source, group (2) corresponds to the electric transmission line (2), and group (3) corresponds to elements in the receiver station. The electric power source is connected to the receiving station via an
25 electric transmission cable 7. The bore hole is schematically represented by casing 8.

The electric power source in Fig. 1, which may typically be located on surface in the case that the bore hole reaches into an earth formation, comprises
30 transformer means 5 for bringing the voltage of the electric current to be transmitted into the bore hole to a desired value, and a converter means 6, here shown in the form of a current rectifier, for lowering the frequency of the electric current. A current rectifier
35 has a DC current as output. A primary advantage of a DC

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current is that the reactive power loading in the electric transmission line is.

5 The receiving station 9 comprises frequency increasing means 10, which is electrically connected to voltage converter means 11, here in the form of a coil transformer. The output of the voltage converter means 11 is connected to a load 12.

10 In practical operation, the system of Fig. 1 is typically fed with single phase or three-phase AC current having a 50 Hz or 60 Hz frequency and a relatively low voltage of less than approximately 1 kV. This is transformed in transformer 5 to a medium or voltage, of between 5 and 30 kV and rectified in rectifier 6 to a high DC voltage.

15 The electric transmission line 7 brings the DC electric power into the bore hole. In bore holes for production of hydrocarbon, the distance over which the electric transmission line 7 reaches can be between several hundreds of meters and 10 km. At the destination
20 in the bottom of the bore hole, the electric current reaches the receiving station 9, where it its frequency is increased in frequency increasing means 10, and its voltage is brought back in voltage converter means 11 to typically between 100 and 800 V, preferably between 400
25 and 800 V, depending on what is required by the nature of load 12.

The frequency preferably lies in a range of between 10 and 100 kHz, in which range there is an optimum compromise between the quality of the frequency increased
30 current and the miniaturisation of the voltage converter means. With a frequency of approximately 25 kHz, the voltage converter means in the form of a coil transformer can comfortably fit in a tube having a diameter of approximately 15 cm. This makes the frequency
35 specifically suitable for application in a bore hole,

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particularly in a bore hole for production of hydrocarbons.

In the case of Fig. 1, the load 12 is supplied with electric power of the same frequency as the voltage converter means 11. For some applications this is
5 appropriate, such as for electric power arc welding inside the bore hole.

In some other applications, however, the frequency must be decreased to several Hz or several tens of Hz, in particular 50 Hz or 60 Hz. An example is powering an AC
10 powered electric motor.

In still some other applications, the frequency must even be decreased to zero resulting in a DC current. A system for transmitting high power DC current in the bore
15 hole is shown in Fig. 2. This system largely corresponds to the system described above and depicted in Fig. 1. The only difference is in the receiving station 13, where a current rectifier 14 is provided in series with the voltage converter means 11. Details of the current
20 rectifier will be discussed further below.

Functionally, the receiving station 13 equates to a DC to DC power converter. Examples of suitable DC to DC power converters are shown and described in, for instance, US patent 5,027,264, an article an article
25 entitled "A three-phase soft-switched high-power-density dc/dc converter for high-power applications" published in IEEE transactions on Industrial Applications, Vol. 27 No. 1 (January/February 1991) by R. W. A. A. De Doncker, D. M. Divan, and M. H. Kheraluwala, and an article
30 entitled "A three-phase series-parallel resonant converter - analysis, design, simulation, and experimental results" published in IEEE transactions on Industrial Applications, Vol. 32 no. 4 (July/August 1999) by A. K. S. Bhat and R. L. Zheng. These DC to DC
35 converters are incorporated by reference.

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The DC to DC converters generally have frequency increasing means composed of full or half bridges with active gate controlled switching devices which can be based on thyristor valves such as metal on semiconductor controlled thyristors (MCT's), or transistor valves such as insulated gate bipolar transistors (IGBT's), metal on semiconductor field effect transistors (MOSFET's). The DC to DC converters further have transformer means for changing the voltage of the increased frequency current, and a current rectifier.

The current rectifier can be based on a bridge of diodes, or active gate controlled switching devices comprising diodes. In the latter case, the DC to DC converter can be operated in two directions, since a bridge based on active gate controlled switching devices function as frequency increasing means in one direction and as current rectifier in the other direction. The advantage of a rectifier based on active gate controlled switching devices is therefore that the down hole power system can also function to transmit electric power out of the bore hole.

Fig. 3 schematically shows a down hole power system in accordance with the invention incorporated in an electrical drill pipe 19. The receiving station is suitable for a DC load as in Fig. 2, but in the case of Fig. 3 it is connectable to the drill pipe via connector 21. The electric transmission line 17 is brought into the drill pipe 19 via side entry sub 20. In other aspects and in its operation, the electric power transmission system of Fig. 3 is the same as described above for Fig. 2.

As an alternative to Fig. 3, the electric power transmission system can be combined with coiled tubing technology analogous to the transmission line described in paper SPE/IADC 52791 of the Society of Petroleum

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Engineers, entitled "Electric coiled tubing drilling: a smarter CT drilling system" by D. R. Turner *et.al.*.

Fig. 4 shows schematically an advantageous type of load in the form of a tool depicted in group (4) and comprising an expansion cone 17 driven by an electrically DC powered traction device 16. This tool is moved upward through a casing tubing having a section 28 with a relatively narrow diameter in order to expand the casing tubing to a larger diameter to form expanded section 18. Such a traction device requires more than 200 kW, or even between 300 and 500 kW, in order to expand a typical casing tubing at an industrially acceptable rate. The receiving station 13 functions in the same way as described above with reference to Fig. 2.

For some applications the power transmitted via the system to the destination inside the bore hole lies in a range of 50 to 500 kW, preferably 200 to 500 kW, depending on the type of operation or application. Such high electric power can be transmitted in a cable having only 1.5 mm² cross sectional area, provided that the voltage is sufficiently high. Preferably, the Ohmic resistance of the cable is less than 14 Ω /km, determined for DC at 20 °C.

A suitable cable is a commercially available HNOK cable from the firm Draka, which is a 8-mm diameter steel shielded coaxial power cable with a 1.5 mm² tin-plated copper central conductor that can conduct a current of 17 A DC. The insulation between the conductor and the steel shielding can support a potential difference of up to 20 kV between the conductor and the shielding. Thus a theoretical maximum power of 340 kW is transmittable using this cable. In practice the power is preferably limited to around 280 kW. A larger diameter core conductor and/or a thicker insulation layer will enable higher powers up to 500 kW.

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C L A I M S

1. A system for transmitting electric power into a bore hole, the system comprising an electric transmission line extending through the bore hole between an electric power source and a receiving station, wherein the receiving station includes frequency increasing means for increasing the frequency of the electric current supplied through the electric transmission line, voltage converter means for changing the voltage of the electric current supplied to it via the frequency increasing means, connecting means for supplying the frequency-increased electric current to the voltage converter means, and means for connecting an electric load to the receiving station.
2. The system of claim 1, wherein the voltage converter means comprises contactless transformer means.
3. The system of claim 1 or 2, comprising frequency decreasing means arranged to reduce the frequency of electric current supplied to it via the voltage converter means.
4. The system of claim 3, wherein the frequency decreasing means includes a current rectifier.
5. The system of any one of the previous claims, wherein the frequency increasing means is arranged to convert the electric current into three subsignals of increased frequency, each of which is 120° phase-shifted with respect to the other two, and whereby the voltage converter means is arranged to change the voltage in each said subsignals.
6. The system of claims 3 and 4 or claims 3 and 5, wherein the frequency decreasing means is arranged to combine three subsignals, each of which is 120° phase-

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shifted with respect to the other two, into one electric current of reduced frequency.

7. The system of any one of the previous claims, wherein frequency increasing means is arranged to bring the
5 frequency of the electric current to a value in a range of between 10 and 100 kHz.

8. The system of any one of the previous claims, wherein bypassing means are provided to feed to or extract from the electric transmission a data signal parallel to the
10 receiving station.

9. A bore hole extending into an earth formation, the bore hole being provided with the system in accordance with any one of claims 1 to 8, wherein an electric load in the form of a tool is connected to the receiving
15 station for receiving voltage changed electric current.

10. The bore hole of claim 9, wherein the tool includes one of an electric welding tool, an electric spark drilling tool, a motor-driven tool such as a traction device or a drill bit.

20 11. Method of transmitting electric power into a bore hole, wherein electric current is transmitted from an electric power source to a receiving station via an electric transmission line, in which receiving station the frequency of the electric current supplied through
25 the electric transmission line is increased in frequency increasing means and the voltage of the electric current supplied to it via the first frequency converter is changed in voltage converter means.

12. The method of claim 11, wherein the voltage reduced
30 electric current is supplied to frequency decreasing means where the frequency of electric current supplied to it via the voltage converter means is reduced.

13. The system substantially as described hereinbefore with reference to the drawings.

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14. The method substantially as described hereinbefore with reference to the drawings.

Fig.1.

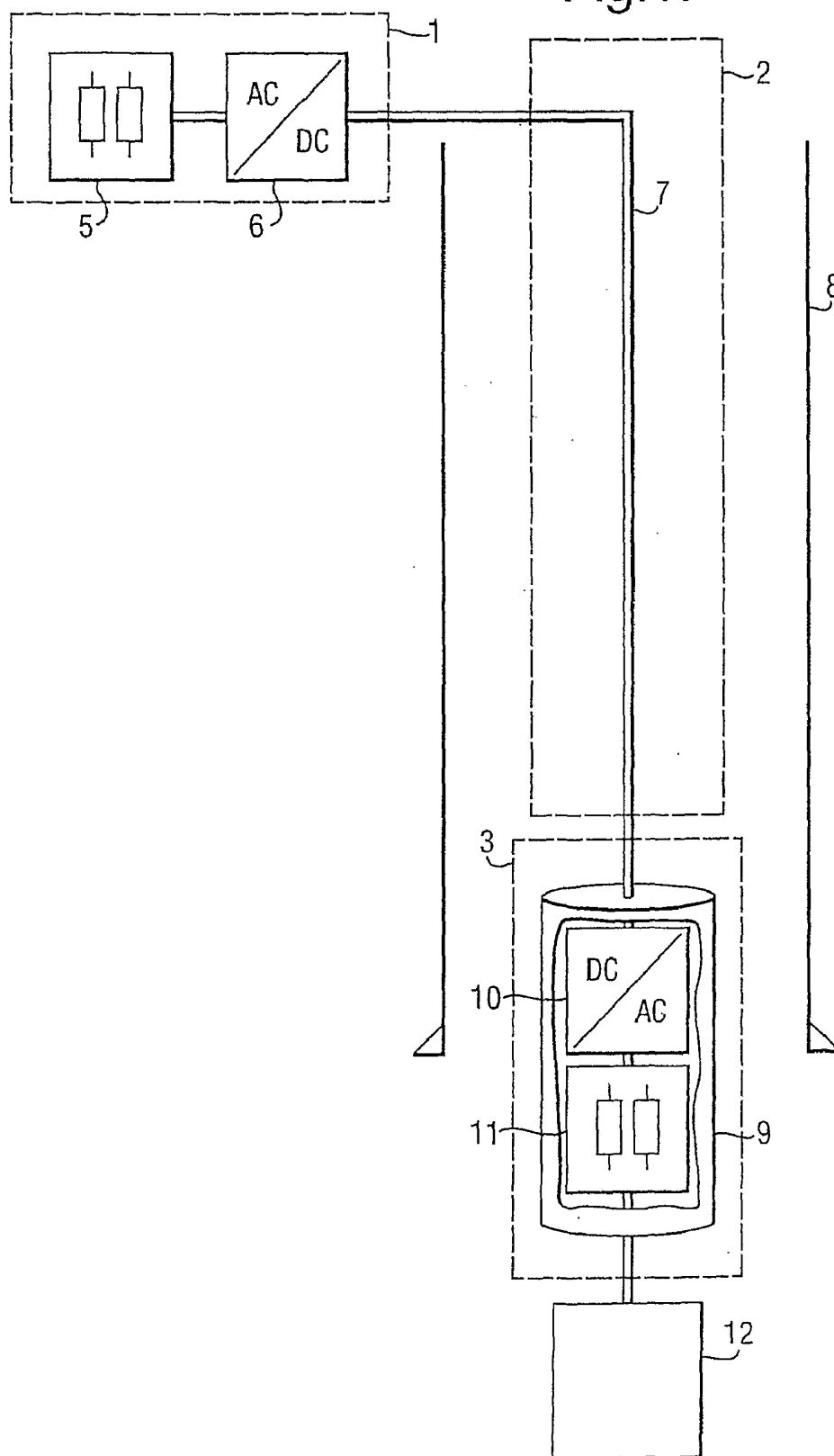


Fig.2.

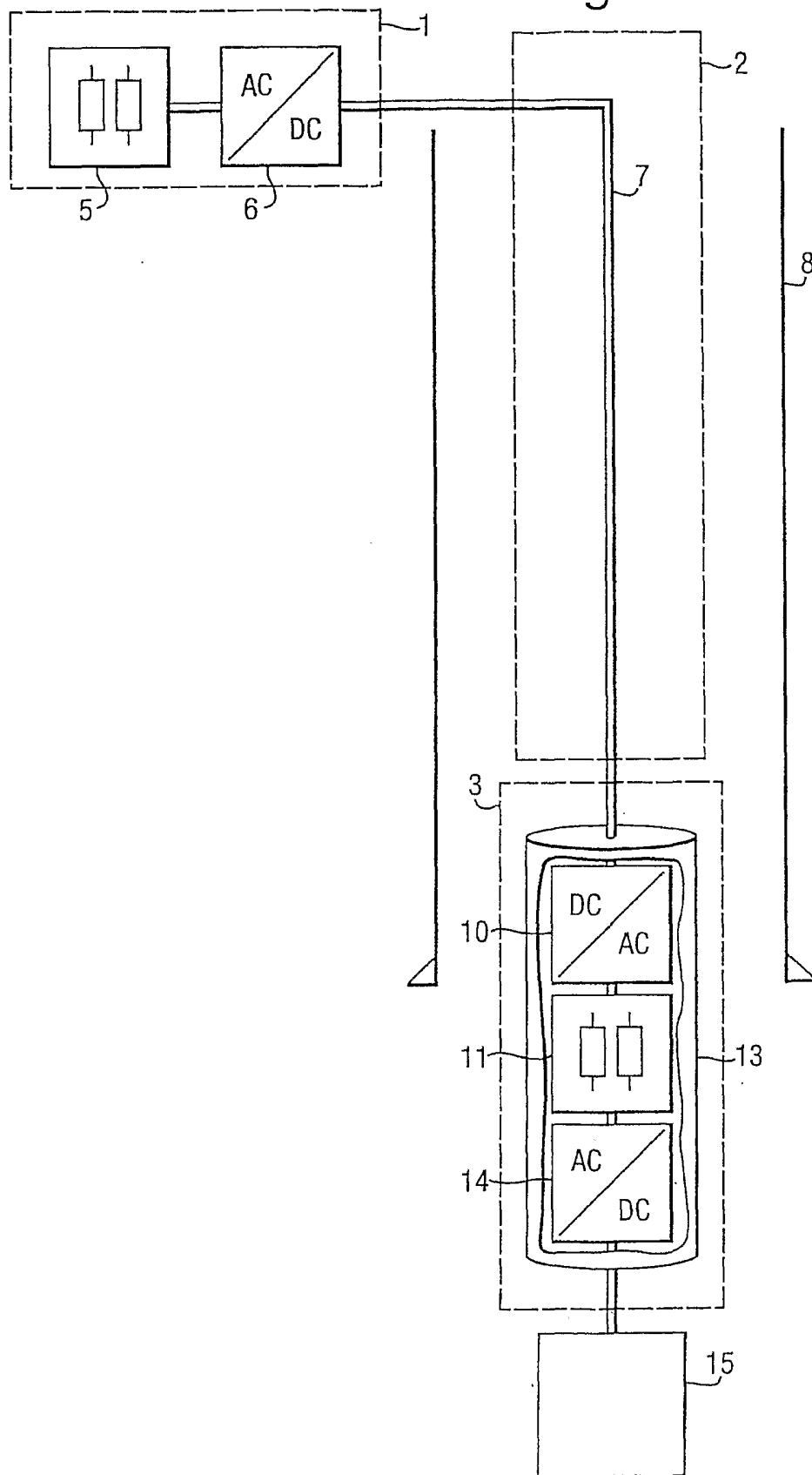


Fig.3.

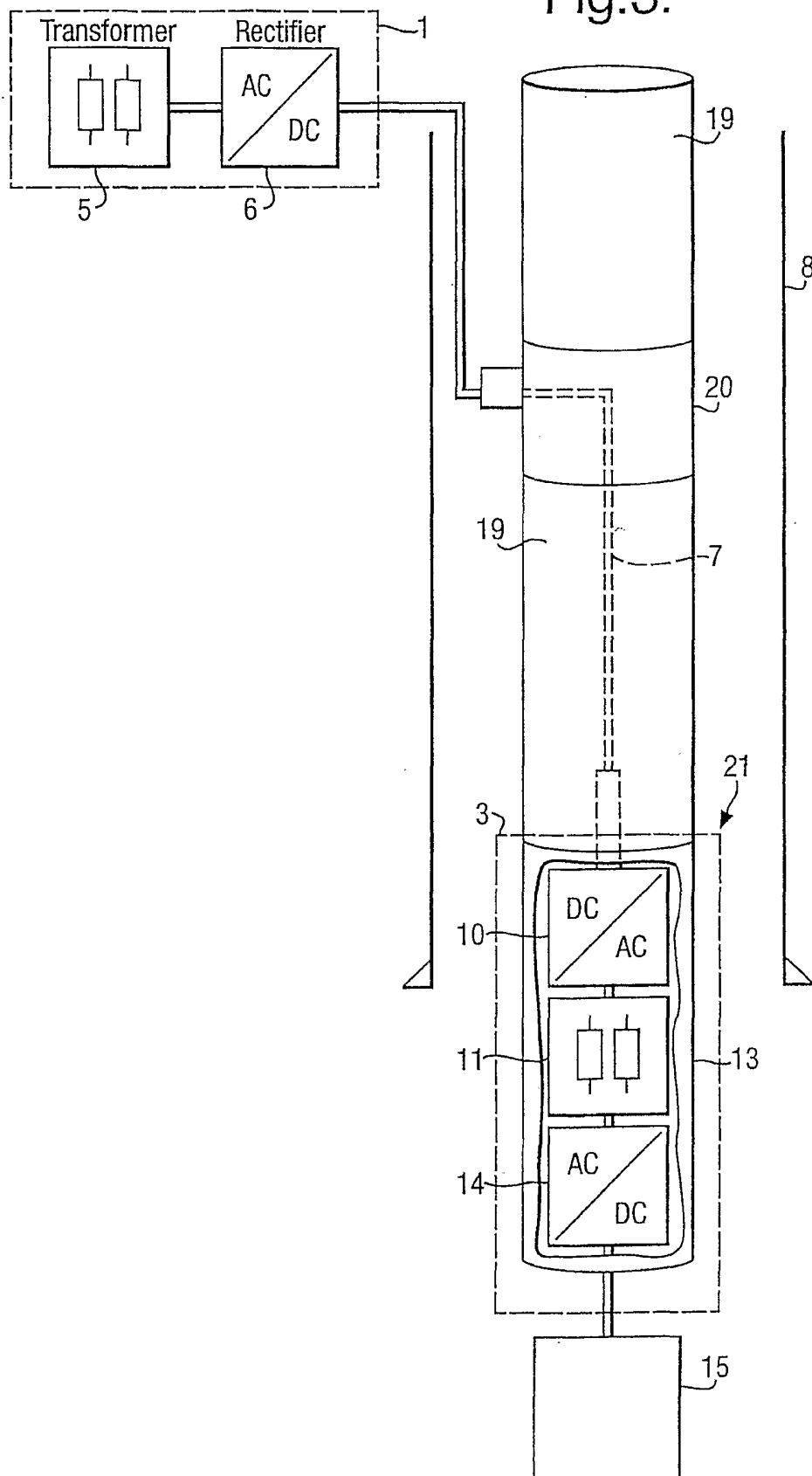
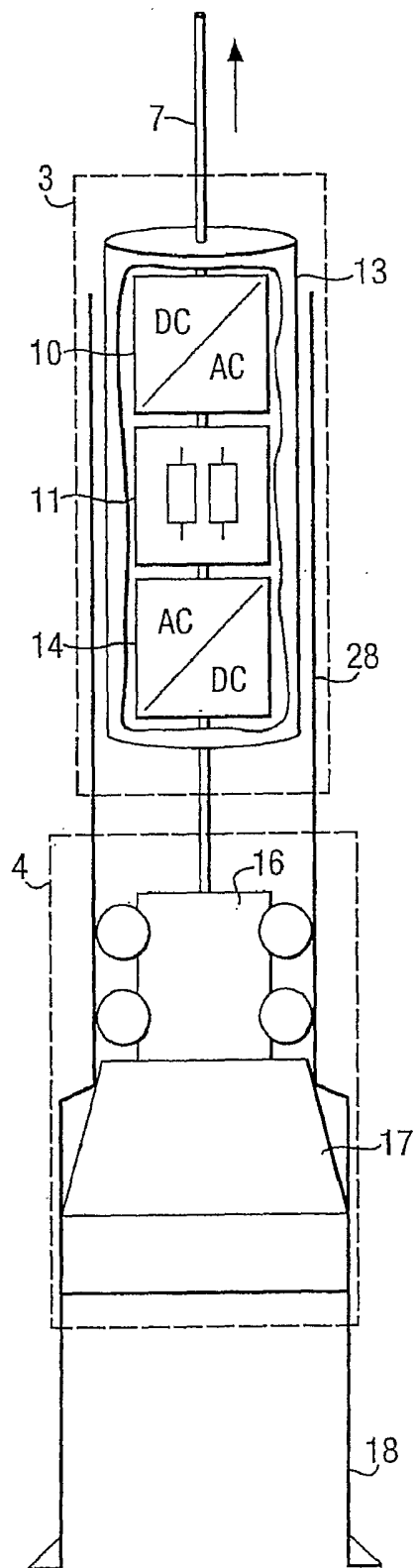


Fig.4.



INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 E21B47/12

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 E21B H02J H02M

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

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

EPO-Internal

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Y	US 5 847 550 A (SCHIE DAVID ET AL) 8 December 1998 (1998-12-08) See abstract column 1, line 13 - column 2, line 14 -----	1-12
Y	US 5 027 264 A (DEDONCKER RIK W ET AL) 25 June 1991 (1991-06-25) cited in the application See whole documentfigure 17 ----- -/--	3-7,12



Further documents are listed in the continuation of box C.



Patent family members are listed in annex.

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INTERNATIONAL SEARCH REPORT

International Application No

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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