



(51) International Patent Classification:

E21B 41/00 (2006.01) *H02P 9/02* (2006.01)
H02J 3/38 (2006.01)

(21) International Application Number:

PCT/US2018/029047

(22) International Filing Date:

24 April 2018 (24.04.2018)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

201710270951.4 24 April 2017 (24.04.2017) CN

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(81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ,
CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO,
DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN,
HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP,
KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME,

(54) Title: DOWNHOLE POWER GENERATION SYSTEM AND METHOD

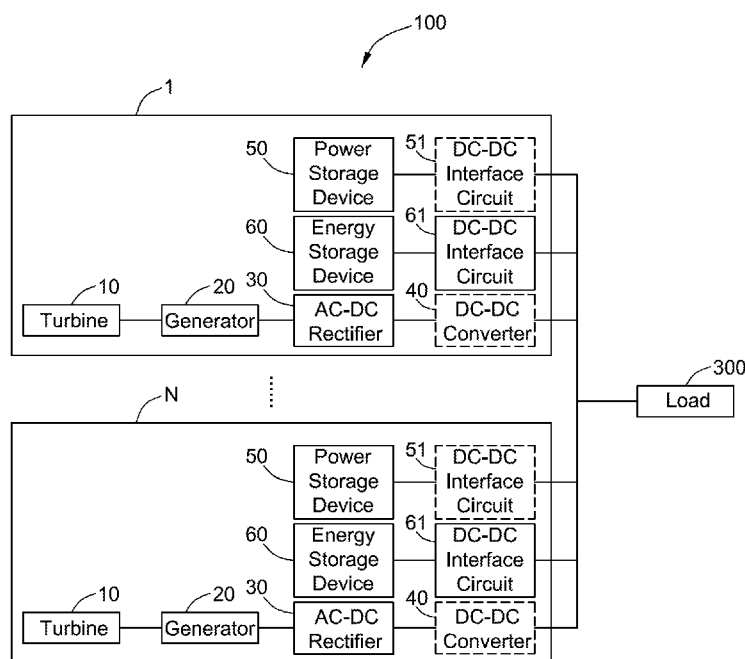


FIG. 1

(57) Abstract: A downhole power generation system is disclosed, which includes a plurality of power generation modules for providing power to a load. Each power generation module includes a turbine, and the plurality of turbines in the plurality of power generation modules are so positioned physically that one or more turbines is exposed to a downhole fluid and flow of the downhole fluid drives the one or more turbines to rotate. Each power generation module further includes a generator coupled with the turbine for converting rotational energy from the turbine to electrical energy, and an AC-DC rectifier coupled with the generator for converting an alternating current voltage from the generator to a direct current voltage, and outputting the direct current voltage to the load. A downhole power generation method is also disclosed.

MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ,
OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA,
SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN,
TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

- (84) Designated States** (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

- with international search report (Art. 21(3))

DOWNHOLE POWER GENERATION SYSTEM AND METHOD

BACKGROUND

[0001] This disclosure relates generally to power generation systems, and more particularly to a downhole power generation system and a downhole power generation method.

[0002] Downhole drilling or sensing systems are used in oil and gas exploration and production wells. Some downhole sensors for fracturing monitoring and long-term production surveillance, downhole data communication module and other downhole loads are often applied to the downhole drilling or sensing systems for performing their respective functions. These downhole loads require power to operate. It is well known in the art to use a turbine to convert mechanical power from a downhole fluid, for example production fluid, into rotational energy to drive an electrical generator. Then, the electrical generator can generate electrical energy and power can be thus provided to these downhole loads.

[0003] However, the downhole has a very harsh environment, for example, high temperature, high pressure and sand buildup. The turbine is exposed in such the harsh downhole environment for a long time, so the turbine may be easily subjected to damage.

[0004] Furthermore, in the early stage installation process of the turbine, it must be ensured that the flow of the downhole fluid can always drive operation of the turbine. Otherwise, the conventional downhole power generation device having the turbine and the electrical generator wouldn't work. Thus, in the conventional downhole power generation device, installation place of the turbine in the downhole plays a role in the whole downhole power generation device.

[0005] However, due to complexity of the downhole fluid and variability of flow of the downhole fluid, the conventional power generation device would no doubt increase difficulty of installation of the turbine.

[0006] Therefore, in the view of the foregoing, a need for a reliable energy source to power these downhole loads is becoming increasingly urgent.

BRIEF DESCRIPTION

[0007] In one aspect of embodiments of the present disclosure, a downhole power generation system is provided. The downhole power generation system comprises a plurality of power generation

modules for providing power to a load. Each power generation module comprises a turbine, and the plurality of turbines in the plurality of power generation modules are so positioned physically that one or more turbines is exposed to a downhole fluid and flow of the downhole fluid drives the one or more turbines to rotate. Each power generation module further comprises a generator coupled with the turbine for converting rotational energy from the turbine to electrical energy, and an AC-DC rectifier coupled with the generator for converting an alternating current voltage from the generator to a direct current voltage, and outputting the direct current voltage to the load.

[0008] In another aspect of embodiments of the present disclosure, a downhole power generation method is provided. The downhole power generation method comprises: driving one or more of a plurality of turbines, by flow of a downhole fluid, to rotate; converting one or more rotational energies from the one or more turbines, by one or more generators, to one or more electrical energies respectively; converting one or more alternating current voltages from the one or more generators, by one or more AC-DC rectifiers, to one or more direct current voltages respectively; and providing the one or more direct current voltages to a load.

DRAWINGS

[0009] These and other features, aspects, and advantages of the present disclosure will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

[0010] FIG. 1 is a schematic diagram of a downhole power generation system in accordance with an embodiment of the present disclosure;

[0011] FIG. 2 is an exemplary example of distribution of turbines in a casing;

[0012] FIG. 3 is a schematic diagram of an example of a downhole power generation system having two power generation modules;

[0013] FIG. 4 is test results of the downhole power generation system of FIG. 3;

[0014] FIG. 5 is a schematic diagram of a downhole power generation system in accordance with another embodiment of the present disclosure; and

[0015] FIG. 6 is a flow chart of an exemplary downhole power generation method in accordance with an embodiment of the present disclosure.

DETAILED DESCRIPTION

[0016] Embodiments of the present disclosure will be described hereinbelow with reference to the accompanying drawings. In the following description, well-known functions or constructions are not described in detail to avoid obscuring the disclosure in unnecessary detail.

[0017] Unless defined otherwise, technical and scientific terms used herein have the same meaning as is commonly understood by one of ordinary skill in the art to which this disclosure belongs. The terms “first”, “second”, and the like, as used herein do not denote any order, quantity, or importance, but rather are used to distinguish one element from another. Also, the terms “a” and “an” do not denote a limitation of quantity, but rather denote the presence of at least one of the referenced items. The term “or” is meant to be inclusive and mean either or all of the listed items. The use of “including,” “comprising” or “having” and variations thereof herein are meant to encompass the items listed thereafter and equivalents thereof as well as additional items. The terms “connected” and “coupled” are not restricted to physical or mechanical connections or couplings, and can include electrical connections or couplings, whether direct or indirect. In addition, Terms indicating specific locations, such as “top”, “bottom”, “left”, and “right”, are descriptions with reference to specific accompanying drawings. Embodiments disclosed in the present disclosure may be placed in a manner different from that shown in the figures. Therefore, the location terms used herein should not be limited to locations described in specific embodiments.

First Embodiment of Downhole Power Generation System

[0018] FIG. 1 illustrates a schematic diagram of a downhole power generation system 100 in accordance with an embodiment of the present disclosure. As shown in FIG. 1, the downhole power generation system 100 includes a plurality of power generation modules 1-N for providing power to a load 300. The load 300 may for example include sensors such as temperature and pressure sensor, flow rate sensor, or a data communication module. Each power generation module 1-N includes a turbine 10, and the plurality of turbines 10 in the plurality of power generation modules 1-N are so positioned physically that one or more turbines 10 is exposed to a downhole fluid. Flow of the downhole fluid may drive the one or more turbines 10 to rotate.

[0019] Each power generation module 1-N further includes a generator 20 coupled with the turbine 10, and an AC-DC (Alternating Current-Direct Current) rectifier 30 coupled with the generator 20. In each power generation module 1-N, the generator 20 can convert rotational energy from the turbine 10

to electrical energy, the AC-DC rectifier 30 can convert an alternating current (AC) voltage from the generator 20 to a direct current (DC) voltage.

[0020] In the downhole power generation system 100 of the present disclosure, because a multiplicity of turbines 10 can ensure that one or more of the plurality of turbines 10 is exposed to the flow of the downhole fluid in a multiphase environment, such the multi-turbine power generation configuration can achieve a reliable and redundant power supply for the load 300.

[0021] Furthermore, because the plurality of turbines 10 are distributed in the multiphase environment, the plurality of turbines 10 may be driven by the downhole fluid having different flow rates due to respective different physical positions and may thus have different rotational speeds. Due to different physical positions of respective turbines 10 of the plurality of power generation modules 1-N, the plurality of power generation modules 1-N may generate different amounts of power. All the different amounts of power can be provided to the load 300. The amounts of power generated from the plurality of power generation modules 1-N depend on physical positions of respective turbines 10. The downhole power generation system 100 of the present disclosure allows each of the plurality of turbines 10 to rotate at the different rotational speed.

[0022] The plurality of turbines 10 in the plurality of power generation modules 1-N may be distributed around a flow path P (as shown in FIG. 2) of the downhole fluid. In one implement, the downhole fluid flows within a casing 400 (as shown in FIG. 2), and the plurality of turbines 10 may be spacedly arranged at an inner circumferential wall of the casing 400 or deployed closer to the center of the casing 400. The plurality of turbines 10 distributed in the multiphase environment can ensure that the flow of the downhole fluid can drive at least one turbine 10 to operate and it may thus provide a redundant and more reliable power supply to the load 300.

[0023] As an example, FIG. 2 illustrates a distribution of four turbines 10 in the casing 400. With reference to FIG. 2, the four turbines 10 may be respectively arranged at a top inner wall, a bottom inner wall, a left inner wall and a right inner wall of the casing 400. When the flow rate of the downhole fluid is sufficient, the downhole fluid may be full of the whole casing 400, in this circumstance, all the four turbines 10 may operate, but the four turbines 10 may be driven by the downhole fluid having different flow rates. For example, because the downhole fluid may include many impurities, the flow of the downhole fluid at the top inner wall of the casing 400 may be dominated by gas and the flow of the downhole fluid at the bottom inner wall of the casing 400 may be blocked by sedimentation. In a word, the flow of the downhole fluid in the multiphase environment may be different. When the flow

rate of the downhole fluid is less, the downhole fluid may not fill the whole casing 400, in this circumstance, only a portion of the four turbines 10 may operate and may be also driven by the downhole fluid having different flow rates.

[0024] However, the distribution of turbines 10 in the casing 400 as shown in FIG. 2 is only as an example. The number of turbines 10 of the present disclosure should be not limited to be four, and the downhole power generation system 100 of the present disclosure may include two, three or more turbines 10. In addition, the distribution of turbines 10 of the present disclosure in the casing 400 should be not limited herein. The turbines 10 of the present disclosure may be evenly or unevenly distributed at the inner circumferential wall of the casing 400 or deployed closer to the center of the casing 400. As a matter of fact, the number and the distribution of turbines 10 of the present disclosure can be suitably selected based on the downhole fluid and its flow condition and in combination of product costs.

[0025] As shown in FIG. 3, the downhole power generation system includes two power generation modules (called as a first power generation module 1 and a second power generation module 2) will be taken as an illustrative example to demonstrate the power sharing for the load 300 thereafter. The turbines 10 in the first and the second power generation modules 1 and 2 are respectively located in different physical positions of the casing 400 and may be driven by the downhole fluid having different flow rates, for example a first flow rate F_1 and a second flow rate F_2 . Thus, the turbines 10 in the first and the second power generation modules 1 and 2 may have a first rotational speed N_1 and a second rotational speed N_2 . The first power generation module 1 may output a first voltage V_1 and a first power P_1 . The second power generation module 2 may output a second voltage V_2 and a second power P_2 . A total voltage output by the downhole power generation system, i.e. a voltage across the load 300 is V_{load} , and a total power output by the downhole power generation system to the load 300 is P_{load} .

[0026] FIG. 4 illustrates test results of the downhole power generation system of FIG. 3. A following conclusion can be obtained clearly from FIG. 4:

$$P_{load} = P_1 + P_2$$

[0027] The total power P_{load} output to the load 300 by the downhole power generation system can be consistent with the sum of the first power P_1 output by the first power generation module 1 and the second power P_2 output by the second power generation module 2. Thus, the power generated by the two turbines 10 having different rotational speeds N_1 and N_2 can be shared to the load 300.

[0028] Although the above validation takes the two power generation modules 1 and 2 as an illustrative example, the above conclusion can be similarly applied to the downhole power generation system having any number of power generation modules.

[0029] In the downhole power generation system 100 of the present disclosure having multiphase-distributed multi-turbines configuration, the amounts of power generated by the plurality of turbines 10 having different rotational speeds can be all provided to the load 300.

[0030] Returning to FIG. 1, each power generation module may further include a DC-DC (Direct Current-Direct Current) converter 40 coupled with the AC-DC rectifier 30 and the load 300. Each DC-DC converter 40 can regulate the DC voltage from the corresponding AC-DC rectifier 30 and provide a regulated voltage to the load 300.

[0031] Furthermore, each DC-DC converter 40 can also have optimized power control (OPC) function because each power generation module is independent of other power generation modules, and can regulate an output power of the corresponding generator 20 so that each power generator module 1-N provides an optimized power to the load 300 at different flow rate of the downhole fluid.

[0032] Therefore, the downhole power generation system 100 of the present disclosure can further maximize the power generated from each of the plurality of turbines 10.

[0033] In the downhole power generation system 100 of the present disclosure, each power generation module 1-N may further include a power storage device 50, and the power storage device 50 is coupled with the AC-DC rectifier 30 and the load 300. In the condition with the DC-DC converter 40, the power storage device 50 is coupled with the DC-DC converter 40 and the load 300. Optionally, the power storage device 50 is coupled with the AC-DC rectifier 30 (the DC-DC converter 40 if have) and the load 300 via a DC-DC interface circuit 51. For example, the power storage device 50 may include a high temperature (HT) super capacitor.

[0034] The plurality of power storage devices 50 may provide additional power to the load 300 when power generating from the one or more turbines 10 is not enough for the load 300. The downhole power generation system 100 of the present disclosure may provide high power density by the plurality of power storage devices 50 in the plurality of power generation modules 1-N.

[0035] With continued reference to FIG. 1, in the downhole power generation system 100 of the present disclosure, each power generation module 1-N may further include an energy storage device

60 coupled with the AC-DC rectifier 30 (the DC-DC converter 40 if have) and the load 300 via a DC-DC interface circuit 61. For example, the energy storage device 60 may include one or more high temperature (HT) primary or rechargeable batteries.

[0036] The plurality of energy storage devices 60 may provide additional electrical energy to the load 300 when energy generating from the one or more turbines 10 is not enough for the load 300. The downhole power generation system 100 of the present disclosure may provide long time operation by the plurality of energy storage devices 60 in the plurality of power generation modules 1-N.

[0037] In the condition that the energy storage device 60 uses one or more HT rechargeable batteries, when the energy generating from the one or more turbines 10 is excessive for the load 300, excessive energy generating from the one or more turbines 10 may be stored in the plurality of energy storage devices 60.

[0038] In addition, when any one turbine 10 in the plurality of power generation modules 1-N is driven by the downhole fluid having a lower flow rate, the energy storage device 60 in the power generation module corresponding to the turbine 10 may provide electrical energy to the turbine 10 so as to help the turbine 10 conquer its breakout torque. Thus, the downhole power generation system 100 of the present disclosure can also provide electrical energy from the energy storage devices 60 to help one or more turbines 10 conquer breakout torque at a lower flow rate of the downhole fluid.

Second Embodiment of Downhole Power Generation System

[0039] FIG. 5 illustrates a schematic diagram of a downhole power generation system 200 in accordance with another embodiment of the present disclosure. As shown in FIG. 5, different from the downhole power generation system 100 of the first embodiment, the downhole power generation system 200 of the second embodiment may include a centralized power storage device 70 coupled with the plurality of the AC-DC rectifier 30 (the DC-DC converters 40 if have) in the plurality of power generation modules 1-N and the load 300. Optionally, the centralized power storage device 70 may be coupled with the plurality of the AC-DC rectifier 30 (the DC-DC converter 40 if have) in the plurality of power generation modules 1-N and the load 300 via a DC-DC interface circuit 71. The downhole power generation system 200 of the second embodiment replaces the plurality of power storage devices 50 in FIG. 1 with the centralized power storage device 70 in FIG. 5. The centralized power storage device 70 may include for example a HT super capacitor.

[0040] With continued reference to FIG. 5, different from the downhole power generation system 100 of the first embodiment, the downhole power generation system 200 of the second embodiment may include a centralized energy storage device 80 coupled with the plurality of the AC-DC rectifier 30 (the DC-DC converters 40 if have) in the plurality of power generation modules 1-N and the load 300 via a DC-DC interface circuit 81. The downhole power generation system 200 of the second embodiment replaces the plurality of energy storage devices 60 in FIG. 1 with the centralized energy storage device 80 in FIG. 5. The centralized energy storage device 80 may include for example one or more high temperature (HT) primary or rechargeable batteries.

[0041] Such the centralized power storage device 70 and/or the centralized energy storage device 80 can reduce volume of the downhole power generation system 200 in a limited space of downhole environment, and can provide a more compact and cost effective design for the downhole power generation system 200 of the present disclosure.

Downhole Power Generation Method

[0042] FIG. 6 illustrates a flow chart of an exemplary downhole power generation method in accordance with an embodiment of the present disclosure. The downhole power generation method in accordance with an embodiment of the present disclosure may include the steps as follows.

[0043] As shown in FIG. 6, in block B61, one or more of a plurality of turbines 10 may be driven to rotate by flow of a downhole fluid, and may thus generate one or more rotational energies. Due to different physical positions of the plurality of turbines 10, the one or more turbines 10 may be driven by the downhole fluid having different flow rates, and thus the one or more rotational energies generated may be different.

[0044] In block B62, the one or more rotational energies from the one or more turbines 10 may be converted to one or more electrical energies respectively by one or more generators 20, and one or more AC voltages may thus be generated. Because the one or more rotational energies generated may be different, the one or more electrical energies converted may also be different and the one or more AC voltages may have different voltage values.

[0045] In block B63, the one or more AC voltages from the one or more generators 20 may be converted to one or more DC voltages respectively by one or more AC-DC rectifiers 30. Because the one or more AC voltages may have different voltage values, the one or more DC voltages converted may also have different voltage values.

[0046] In block B64, the one or more DC voltages which may have different voltage values may be provided to a load 300.

[0047] The downhole power generation method of the present disclosure can ensure that the flow of the downhole fluid can drive one or more of the plurality of turbines distributed in a multiphase environment, and thus the downhole power generation method of the present disclosure can achieve a reliable and redundant power supply for the load 300. The downhole power generation method of the present disclosure allows each of the plurality of turbines 10 to rotate at the different speed.

[0048] With continued reference to FIG. 6, the downhole power generation method may further include block B65 after block B63 and before block B64. In block B65, the one or more direct current voltages output from the one or more AC-DC rectifier 30 may be regulated by one or more DC-DC converters 40. Under this circumstance, in block B64, one or more regulated voltages may be provided to the load 300.

[0049] Thus, the downhole power generation method of the present disclosure can maximize the power generated from each of the plurality of turbines 10.

[0050] The downhole power generation method of the present disclosure may further include providing additional power to the load 300 by a centralized power storage device 70 (as shown in FIG. 5), for example a HT super capacitor when power generating from the one or more turbines 10 is not enough for the load 300.

[0051] The downhole power generation method of the present disclosure may further include providing additional electrical energy to the load 300 by a centralized energy storage device 80 (as shown in FIG. 5), for example one or more HT primary or rechargeable batteries when energy generating from the one or more turbines 10 is not enough for the load 300. The downhole power generation method of the present disclosure may further include storing excessive energy generating from the one or more turbines 10 in the centralized energy storage device 80 when the energy generating from the one or more turbines 10 is excessive for the load 300. Furthermore, the downhole power generation method of the present disclosure may further include providing electrical energy from one or more energy storage devices 60 (as shown in FIG. 1), or a centralized energy storage device 80 (as shown in FIG. 5) to the one or more turbines 10 so as to help the one or more turbines 10 conquer respective breakout torque when the one or more turbines 10 are driven by the downhole fluid having lower flow rates.

[0052] Therefore, the downhole power generation method of the present disclosure may enable high power density and cost effective design with high reliability and long lifetime operation by the centralized power storage device 70 and the centralized energy storage device 80. Furthermore, the downhole power generation method of the present disclosure can provide electrical energy from one or more energy storage devices 60, or the centralized energy storage device 80 to help one or more turbines 10 conquer respective breakout torque at a lower flow rate of the downhole fluid.

[0053] While steps of the downhole power generation method in accordance with embodiments of the present disclosure are illustrated as functional blocks, the order of the blocks and the separation of the steps among the various blocks shown in FIG. 6 are not intended to be limiting. For example, the blocks may be performed in a different order and a step associated with one block may be combined with one or more other blocks or may be sub-divided into a number of blocks.

[0054] While the disclosure has been illustrated and described in typical embodiments, it is not intended to be limited to the details shown, since various modifications and substitutions can be made without departing in any way from the spirit of the present disclosure. As such, further modifications and equivalents of the disclosure herein disclosed may occur to persons skilled in the art using no more than routine experimentation, and all such modifications and equivalents are believed to be within the spirit and scope of the disclosure as defined by the following claims.

WHAT IS CLAIMED IS:

1. A downhole power generation system, comprising:
 - a plurality of power generation modules for providing power to a load, each power generation module comprising:
 - a turbine, wherein the plurality of turbines in the plurality of power generation modules are so positioned physically that one or more turbines is exposed to a downhole fluid and flow of the downhole fluid drives the one or more turbines to rotate;
 - a generator coupled with the turbine for converting rotational energy from the turbine to electrical energy; and
 - an AC-DC rectifier coupled with the generator for converting an alternating current voltage from the generator to a direct current voltage, and outputting the direct current voltage to the load.
2. The downhole power generation system of claim 1, wherein rotational speeds of the one or more turbines and the amounts of power generated from the plurality of power generation modules depend on physical positions of respective turbines.
3. The downhole power generation system of claim 1, wherein the plurality of turbines are distributed around a flow path of the downhole fluid.
4. The downhole power generation system of claim 1, wherein the downhole fluid flows within a casing, and the plurality of turbines are spacedly arranged at an inner circumferential wall of the casing or deployed closer to the center of the casing.
5. The downhole power generation system of any one of claims 1 to 4, wherein each power generation module further comprises:
 - a DC-DC converter coupled with the AC-DC rectifier and the load for regulating the direct current voltage and providing a regulated voltage to the load.
6. The downhole power generation system of claim 5, wherein each DC-DC converter is further configured for regulating an output power of the corresponding generator so that each power generator module provides an optimized power to the load at different flow rate of the downhole fluid.
7. The downhole power generation system of claim 1, wherein each power generation module further comprises:
 - a power storage device coupled with the AC-DC rectifier and the load.

8. The downhole power generation system of claim 1, further comprising:
a centralized power storage device respectively coupled with the plurality of AC-DC rectifiers in the plurality of power generation modules and the load.
9. The downhole power generation system of claim 7 or 8, wherein the power storage device comprises a high temperature super capacitor.
10. The downhole power generation system of claim 1, wherein each power generation module further comprises:
an energy storage device coupled with the AC-DC rectifier and the load via a DC-DC interface circuit.
11. The downhole power generation system of claim 1, further comprising:
a centralized energy storage device coupled with the plurality of AC-DC rectifiers in the plurality of power generation modules and the load via a DC-DC interface circuit.
12. The downhole power generation system of claim 10 or 11, wherein the energy storage device comprises one or more high temperature primary or rechargeable batteries.
13. A downhole power generation method, comprising:
driving one or more of a plurality of turbines, by flow of a downhole fluid, to rotate;
converting one or more rotational energies from the one or more turbines, by one or more generators, to one or more electrical energies respectively;
converting one or more alternating current voltages from the one or more generators, by one or more AC-DC rectifiers, to one or more direct current voltages respectively; and
providing the one or more direct current voltages to a load.
14. The downhole power generation method of claim 13, further comprising:
regulating the one or more direct current voltages by one or more DC-DC converters; and
providing one or more regulated voltages to the load.
15. The downhole power generation method of claim 14, further comprising:
regulating one or more output powers of the one or more generators so as to maximize the power generated from each of the one or more turbines at different flow rate of the downhole fluid; and
providing one or more regulated powers to the load.

16. The downhole power generation method of claim 13, further comprising:
providing additional power, by a centralized power storage device to the load when power generating from the one or more turbines is not enough for the load.

17. The downhole power generation method of claim 13, further comprising:
providing additional electrical energy, by a centralized energy storage device to the load when energy generating from the one or more turbines is not enough for the load.

18. The downhole power generation method of claim 17, further comprising:
storing excessive energy generating from the one or more turbines in a centralized energy storage device when the energy generating from the one or more turbines is excessive for the load.

19. The downhole power generation method of claim 13, further comprising:
providing electrical energy from one or more energy storage devices, or a centralized energy storage device respectively to the one or more turbines so as to help the one or more turbines conquer respective breakout torque when the one or more turbines are driven by the downhole fluid having lower flow rates.

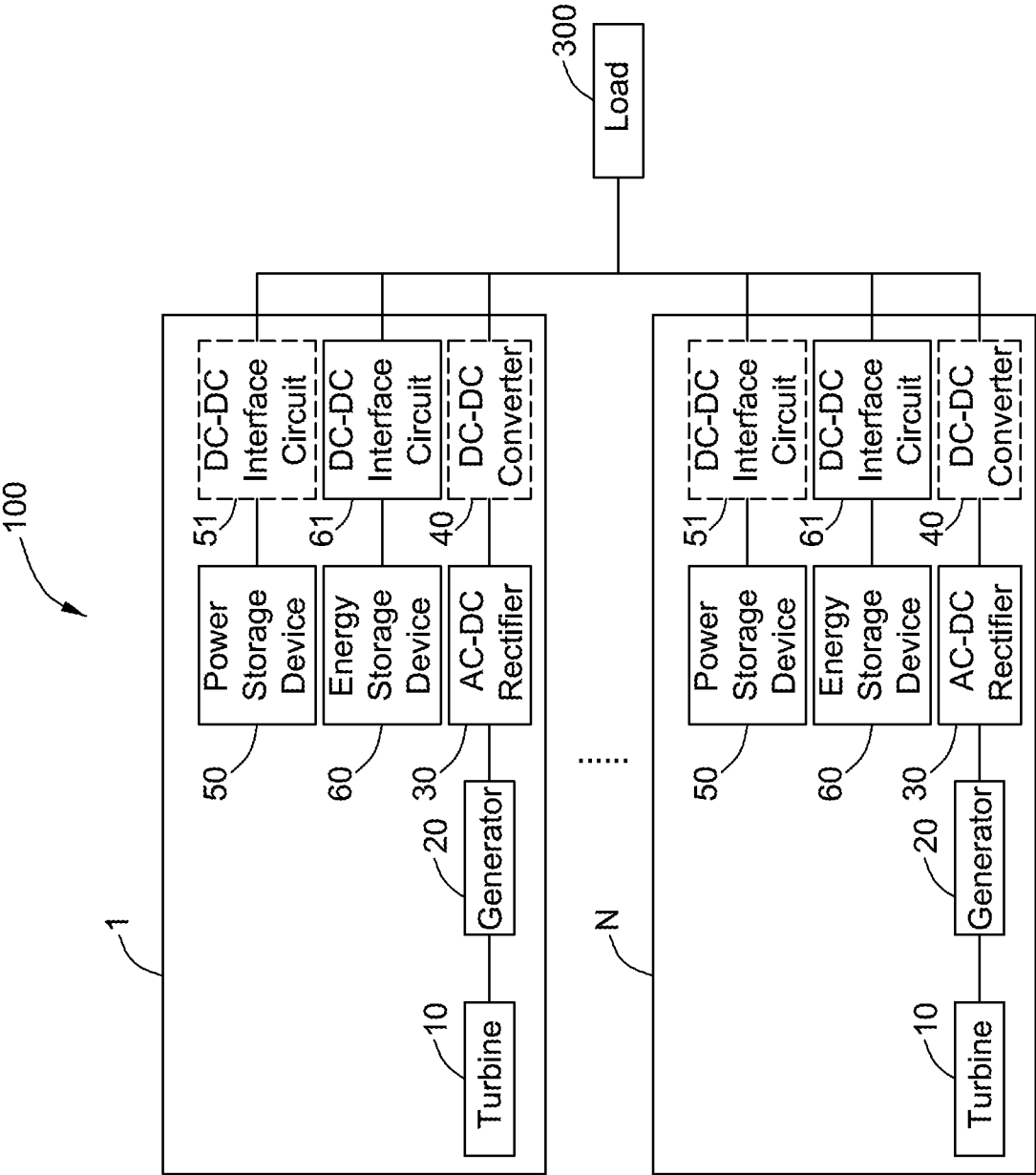


FIG. 1

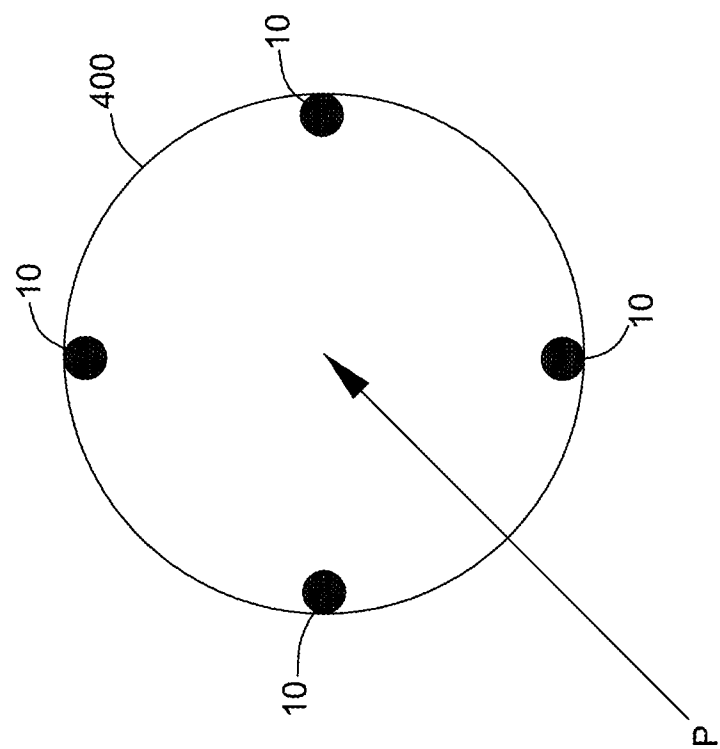


FIG. 2

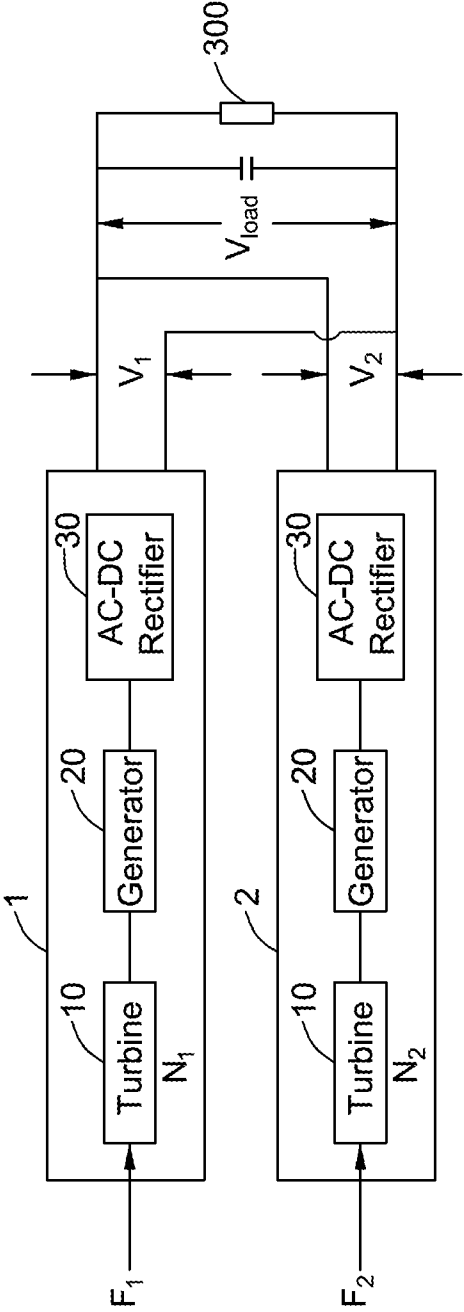


FIG. 3

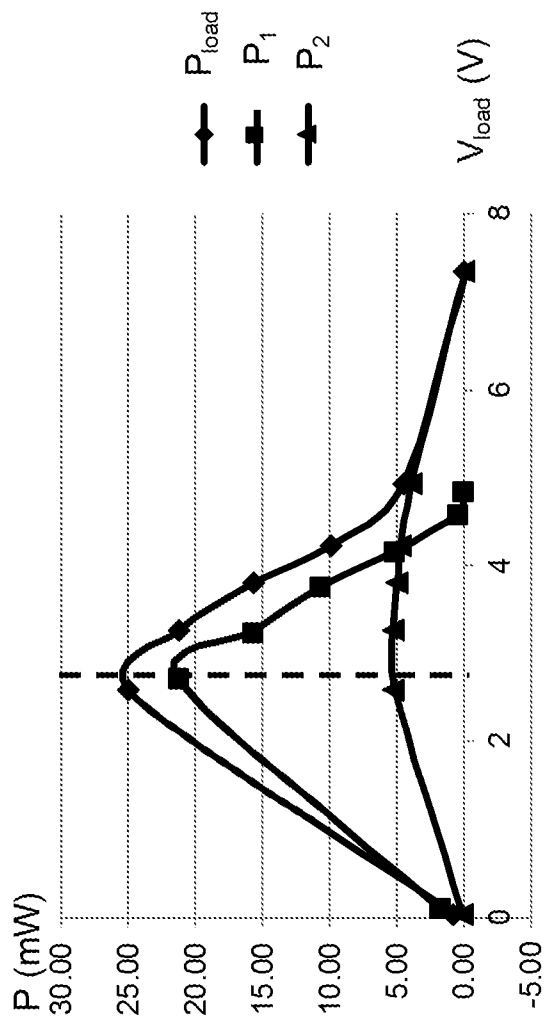


FIG. 4

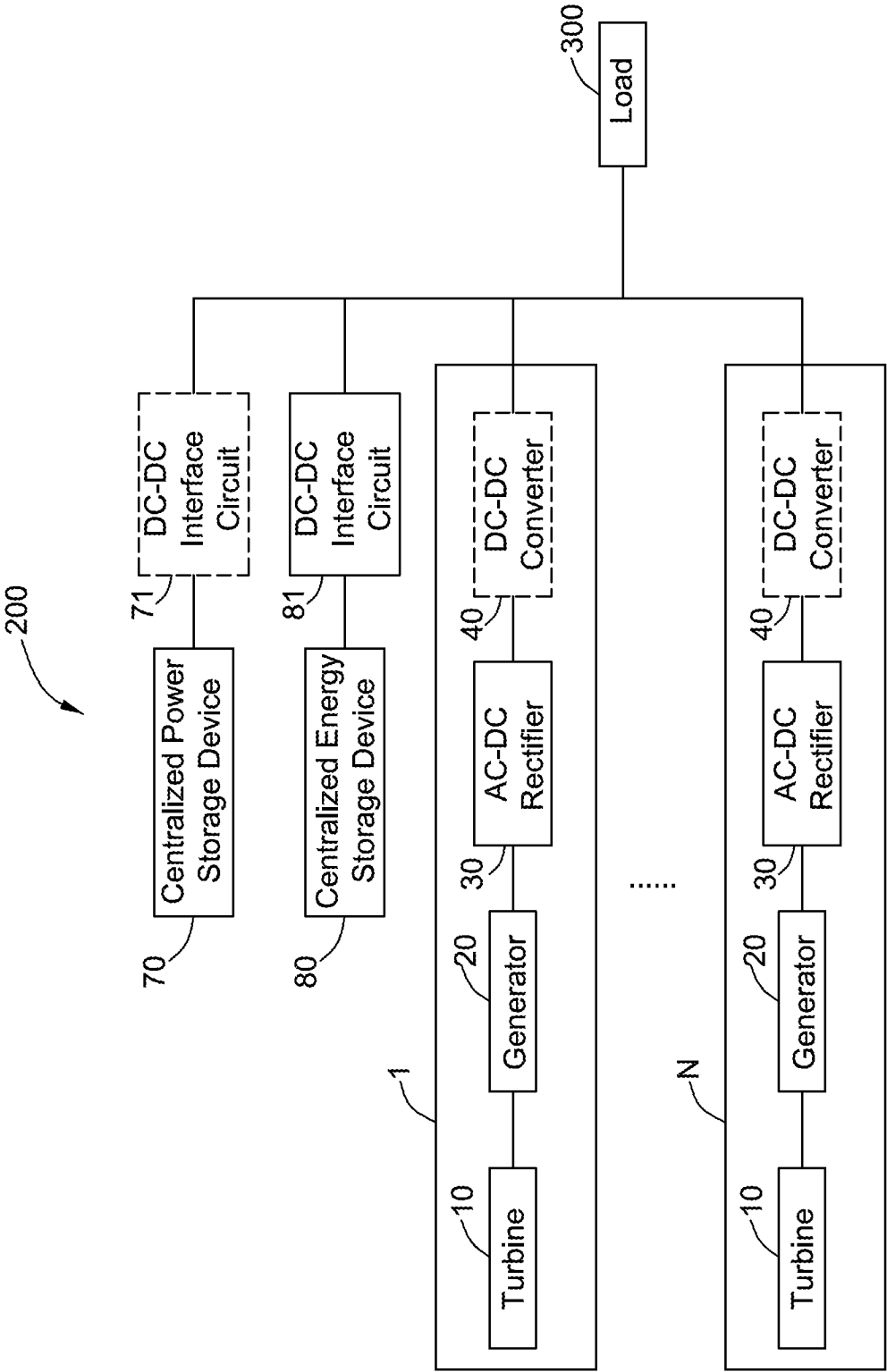


FIG. 5

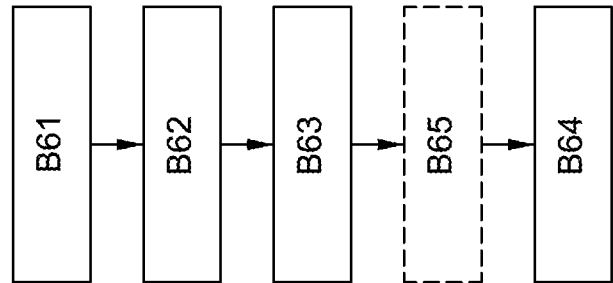


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2018/029047**A. CLASSIFICATION OF SUBJECT MATTER****E21B 41/00(2006.01)i, H02J 3/38(2006.01)i, H02P 9/02(2006.01)i**

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)

E21B 41/00; E21B 44/00; H02J 3/12; H02K 7/18; H02K 7/20; F03B 13/10; H02J 3/38; H02P 9/02

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & keywords: downhole, power generation system, turbine, generator, rectifier and power storage device

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2016-0090819 A1 (KIM, NAMHYO) 31 March 2016 See paragraphs [0020]-[0033] and figures 1-4, 8.	1-19
Y	US 2014-0354081 A1 (SCHLUMBERGER TECHNOLOGY CORPORATION) 04 December 2014 See paragraph [0020] and figures 2, 3.	1-19
Y	US 2016-0265315 A1 (HALLIBURTON ENERGY SERVICES, INC.) 15 September 2016 See paragraph [0039] and figure 5.	5, 6, 10-12, 14, 15, 17, 18
A	WO 2016-039748 A1 (HALLIBURTON ENERGY SERVICES, INC.) 17 March 2016 See page 5, line 12 - page 6, line 19 and figures 3, 4.	1-19
A	US 2015-0091306 A1 (NATIONAL OILWELL VARCO, L.P.) 02 April 2015 See paragraphs [0023]-[0025] and figure 2.	1-19

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:

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Date of the actual completion of the international search

08 August 2018 (08.08.2018)

Date of mailing of the international search report

08 August 2018 (08.08.2018)

Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2018/029047

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US 2015-0091306 A1	02/04/2015	None	