(21) **3 139 970**

(12) DEMANDE DE BREVET CANADIEN
CANADIAN PATENT APPLICATION

(13) **A1**

(86) **Date de dépôt PCT/PCT Filing Date**: 2020/05/12
(87) **Date publication PCT/PCT Publication Date**: 2020/11/19
(85) **Entrée phase nationale/National Entry**: 2021/11/10
(86) **N° demande PCT/PCT Application No.**: US 2020/000017
(87) **N° publication PCT/PCT Publication No.**: 2020/231483
(30) **Priorité/Priority**: 2019/05/13 (US62/847,022)

(51) **Cl.Int./Int.Cl.** *E21B 43/26* (2006.01), *E21B 43/267* (2006.01), *E21B 44/00* (2006.01)

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(54) **Titre** : COMMANDE VECTORIELLE SANS CODEUR POUR VARIATEUR DE FREQUENCE DANS DES APPLICATIONS DE FRACTURATION HYDRAULIQUE

(54) **Title**: ENCODERLESS VECTOR CONTROL FOR VFD IN HYDRAULIC FRACTURING APPLICATIONS

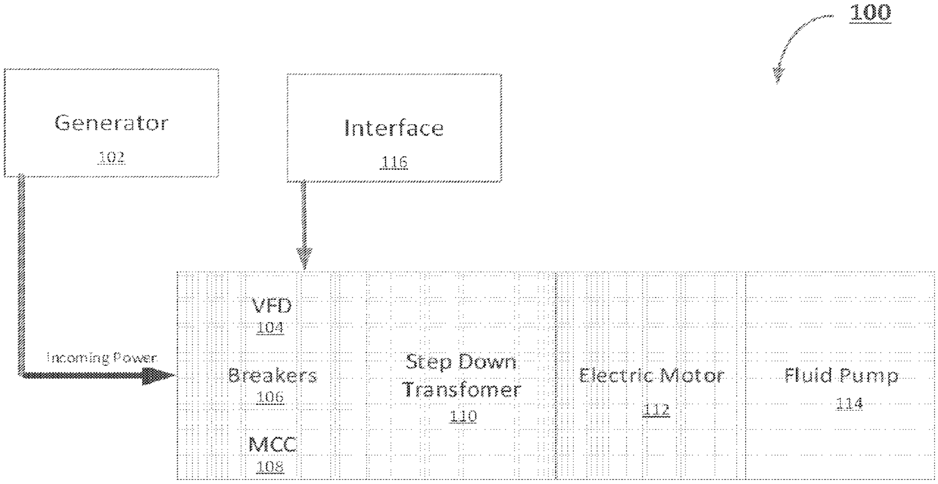

FIG. 1A

(57) **Abrégé/Abstract**:

A system (100; 150; 170) and a method (600) for use of electric motors (112; 162A, 162B;192) in fracturing operations are disclosed. The system includes an electric motor, a turbine generator (102; 152), an encoderless vector control subsystem (116, 104; 166, 158A, 158B; 186, 190), and at least one pump (114; 164A, 164B). The turbine generator is adapted to generate electric power for the system. The encoderless vector control subsystem is coupled between the turbine generator and the electric motor to control the electric motor using determined parameters (500) that are based in part on vibration induced in a feature associated with the turbine generator. The at least one pump is adapted to receive torque input from the electric motor.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
19 November 2020 (19.11.2020)

WIPO | PCT

(10) International Publication Number
WO 2020/231483 A1

(51) International Patent Classification:
E21B 43/26 (2006.01) *E21B 44/00* (2006.01)
E21B 43/267 (2006.01)

(21) International Application Number:
PCT/US2020/000017

(22) International Filing Date:
12 May 2020 (12.05.2020)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/847,022 13 May 2019 (13.05.2019) US

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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, 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, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, 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,

(54) Title: ENCODERLESS VECTOR CONTROL FOR VFD IN HYDRAULIC FRACTURING APPLICATIONS

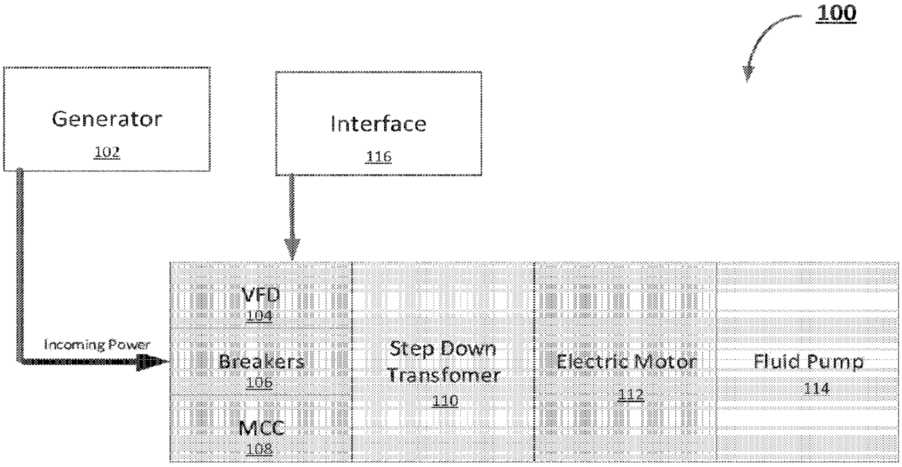

FIG. 1A

(57) Abstract: A system (100; 150; 170) and a method (600) for use of electric motors (112; 162A, 162B;192) in fracturing operations are disclosed. The system includes an electric motor, a turbine generator (102; 152), an encoderless vector control subsystem (116, 104; 166, 158A, 158B; 186, 190), and at least one pump (114; 164A, 164B). The turbine generator is adapted to generate electric power for the system. The encoderless vector control subsystem is coupled between the turbine generator and the electric motor to control the electric motor using determined parameters (500) that are based in part on vibration induced in a feature associated with the turbine generator. The at least one pump is adapted to receive torque input from the electric motor.

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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))*

ENCODERLESS VECTOR CONTROL FOR VFD IN HYDRAULIC FRACTURING APPLICATIONS

Cross Reference to Related Application(s)

[0001] This application is related to and claims the benefit of priority from U.S. Provisional Application 62/847,022, filed May 13, 2019, titled ENCODERLESS VECTOR CONTROL FOR VFD IN HYDRAULIC FRACTURING APPLICATIONS, the entire disclosure of which is incorporated by reference herein for all intents and purposes.

Reference to Material In Compact Disc

[0002] The application incorporates by reference the material on the concurrently submitted compact disc (CD) as allowed under PCT AI § 801(C), which is identified as file named "Appendix A Table 1," which is 82.8KB, created May 8, 2020, in three identical copies of the CD (the names of the files contained on each of the compact discs, their date of creation and their sizes in bytes), which may be referenced throughout this disclosure as Appendix A.

Field

[0003] At least one embodiment pertains to improvements in electric motors in fracturing operations. In at least one embodiment, the present disclosure describes fracturing pumps that are coupled to an electric motor, which in turn is controlled via an encoderless vector control subsystem.

Background

[0004] Hydraulic Fracturing is a process used to stimulate production from some hydrocarbon producing wells. The process involves injecting fluid with pumps into a wellbore at a pressure sufficient to generate fissures in the formation surrounding the wellbore. The pressurized fluid is injected into a portion of the wellbore that is pressure-isolated from the remaining length of the wellbore so that fracturing is limited to a designated portion of the formation. The fracturing fluid slurry, whose primary component may be water, includes proppant (such as sand or ceramic) that migrate into the fractures with the fracturing fluid slurry and remain to prop open the fractures after pressure is no longer applied to the wellbore.

[0005] The pumps used in hydraulic fracturing operations may be powered by diesel engines. Recently, however, some pumps may be powered by electric motors, which can in turn be controlled by a variable frequency drive (VFD). Use of these electric motors in hydraulic fracturing pumps may not achieve smooth operation.

Summary

[0006] In at least one embodiment, a system for use in fracturing operations is disclosed. The system includes an electric motor, a turbine generator, an encoderless vector control subsystem, and at least one pump. The turbine generator is adapted to generate electric power for the system. The encoderless vector control subsystem is adapted to receive the electric power from the turbine generator and to control the electric motor using determined parameters provided to the encoderless vector control subsystem. The at least one pump is adapted to receive torque input from the electric motor.

[0007] In at least one further embodiment, a method for using electric pumps in fracturing operations is also disclosed. The method includes engaging an electric motor with a turbine generator. The method also includes enabling an encoderless vector control subsystem to receive electric power from the turbine generator. The method includes a sub-process to control the electric motor using determined parameters input to the encoderless vector control subsystem. The determined parameters may be based in part on vibration induced in a feature associated with the turbine generator, such as the body of the turbine. At least one pump is engaged with the electronic motor in a further sub-process of the method so that the torque input from the electric motor may operate the at least one pump.

Brief Description of the Drawings

[0008] The present disclosure will be readily understood upon reading the detailed description of non-limiting embodiments of the present disclosure with the accompanying drawing, in which:

[0009] FIG. 1A is a block diagram of a system, as positioned on a trailer and used in a hydraulic fracturing operation with encoderless vector control, according to at least one embodiment of the present disclosure;

[0010] FIG. 1B is another block diagram of a system, as positioned on a trailer and used in a hydraulic fracturing operation with encoderless vector control, according to at least one embodiment of the present disclosure;

[0011] FIG. 1C is another block diagram of a system, as positioned on a trailer and used in a hydraulic fracturing operation with encoderless vector control, according to at least one embodiment of the present disclosure;

[0012] FIG. 2 is a section diagram of a turbine within a system used in a hydraulic fracturing operation and benefiting from encoderless vector control, according to at least one embodiment of the present disclosure;

[0013] FIG. 3 is graph illustrating system vibration and instability of a system for hydraulic fracturing that may benefit from aspects of the present disclosure;

[0014] FIG. 4 is a graph illustrating reduced system vibration and increased stability for a system for hydraulic fracturing that implements aspects of the present disclosure;

[0015] FIG. 5 illustrates select determined parameters and associated values within the encoderless vector control for a VFD used in hydraulic fracturing operations, according to at least one embodiment of the present disclosure; and

[0016] FIG. 6 illustrates a flowchart of a method for encoderless vector control for a VFD used in fracturing operations, according to at least one embodiment of the present disclosure.

Detailed Description

[0017] The foregoing aspects, features, and advantages of the present technology will be further appreciated when considered with reference to the following description of preferred embodiments and accompanying drawing, wherein like reference numerals represent like elements. In describing the preferred embodiments of the technology illustrated in the appended drawing, specific terminology will be used for the sake of clarity. However, the technology is not intended to be limited to the specific terms used, and it is to be understood that each specific term includes equivalents that operate in a similar manner to accomplish a similar purpose.

[0018] Non-oil and gas related applications may implement a VFD to power an electric motor in fluid applications, such as fluids having consistent properties. In an instance, the fluids may be air or clean water. However, in fracturing operations, variable loads may exist because of the inconsistency of the materials involved. A further driver of variable loads may be an unpredictable formation pressure which can vary by several thousand PSI (pounds per square inch) and the fracturing process itself, which nay require fluid rate changes throughout the process. Further, in fracturing operations, electric motors may be expected to power a high number (e.g., 10 to 20) of hydraulic fracturing pump. In addition, the present disclosure is also able to address adaptions and configurations directed to a single electric motor powering a single pump, multiple smaller electric motors powering a single pump, or a single electric motor powering two pumps. These different adaptions and configurations may be additionally challenging to the fracturing process by adding further uncertainties.

[0019] Still further, the hydraulic fracturing pumps may be driven by an electric motor that is manifolded together with common suction and discharge piping systems. As such, in addition to the inconsistencies of the fluid involved in a fracturing operation, the fluid dynamics generated as a result of the group of hydraulic fracturing pumps working together off of an electric motor may cause rough operation of the electric motor and may result in bad pump performance. For instance, discharge flow ripples may be caused by triplex, quintuplex, novemplex, and septuplex plunger pumps, which are the predominant type of pumps used in hydraulic fracturing,

[0020] Additional fluid dynamics that might disrupt smooth operation of the electric motor may be also caused during the well formation process itself. The act of fracturing and the pumped fluid, as well as returning fluid, are additional fluid dynamic effects that need addressing to enable the electric motor to perform smoothly. Other phenomena regarding the interaction of other connected equipment on the surface, in fracturing operations, can also affect a VFDs control behavior. For instance, the surface equipment's natural frequencies may be excited by the fluid dynamics or the electrical harmonics within the connected equipment.

[0021] Still further, observations are made of oscillations or vibrations in a body of a turbine portion of the turbine generator during operation of the turbine and electric motor system for hydraulic fracturing operations. In at least one embodiment, the oscillations or vibrations in the body may be more apparent in a shaft and in an associated coupler that extends or connects the turbine portion of the turbine generator to the generator portion. The oscillations or vibrations represent mechanical resonance of components of at least the turbine, but can also cause mechanical resonance in other parts of the system. The mechanical resonance at least on the shaft of the turbine generator is apparent in higher amplitude oscillations resulting from higher torque fluctuations of the shaft. This may be a result of feedback received from the load variation on electric motor. The resonance leads, eventually, to failure of at least the coupler in the turbine generator, but can also damage other parts of the system.

[0022] These and other challenges in hydraulic fracturing operations may be addressed by the present disclosure using determined parameters asserted in an encoderless vector control scheme for VFD control in an electric motor. In at least one embodiment, the encoderless vector control scheme of the present disclosure includes determining parameters suited for the electric motor that are based in part on vibrations induced in a feature associated with the turbine generator. For instance, the vibrations may be induced in a portion of the body of turbine and may be apparent on a shaft or a coupler of the turbine generator. The determined parameters may be determined based in part on monitoring oscillation alarm values representing the vibrations in features of the turbine generator that are made apparent at the shaft or the coupler, among other end features of the system. In at least one embodiment, the vibrations are monitored on one or more body portions of the turbine part of the turbine generator.

[0023] As such, in at least one embodiment, the oscillation alarm values represent vibration in at least one part of the system for a period of time. The oscillation alarm values may be within a range of about 15 to about 45 upon engagement of the motor with a load for the period of time. In at least one embodiment, the encoderless vector control scheme includes determining parameters suited for the electric motor based in part on the oscillation alarm values being at least less than about 70 upon engagement of the motor with a load. In at least one embodiment, the determined parameters for the encoderless vector control subsystem are selected from at least speed values, motor values, and proportional-integral-derivative (PID) control values, among other values listed in Appendix A (referencing table 1) of the present disclosure under minimum and maximum values that may work to reduce the oscillation alarm values with the encoderless vector control scheme applied to the hydraulic fracturing system. As such, Appendix A is incorporated by reference herein to illustrate other parameters that may be used to form the determined parameters, as well as their associated range of values available to enable the encoderless vector control subsystem of the present disclosure. FIG. 5 provides example predetermined parameters from Appendix A, and their associated range of values to enable an embodiment of the encoderless vector control subsystem of the present disclosure.

[0024] Encoderless vector control schemes for VFDs are provided herein to support smooth operation in high-performance electric motor over an entire speed range, to enable capability of the electric motor to generate full torque at zero speed, to improve high dynamic performance for the electric motor, and to support fast acceleration and deceleration in the electric motor. The present disclosure adapts such requirements to the benefit of hydraulic fracturing operations. In at least one embodiment, vector control in an encoderless vector control subsystem refers to a control method for electric motors via the VFD, for instance, in which certain motor input components may be referenced by its vector. The vectors may include complex current or voltage values, for instance. In at least one embodiment, reference to encoderless is made in the encoderless vector control subsystem to indicate that the determined parameters are predetermined by at least an estimation conducted, such as in a testing environment using available parameters in the system to maintain vibrations below a threshold. In at least one embodiment, the vibrations may be measured using the oscillation alarms and the thresholds set using the oscillation alarms.

[0025] FIG. 1A is a block diagram of system 100 that is positioned on a trailer and used in a hydraulic fracturing operation with encoderless vector control, according to at least one embodiment of the present disclosure. As such, the layout in FIG. 1A reflects how the system components may be positioned but not necessarily the flow of electric current or power, for instance, which is other described elsewhere throughout this description. The system 100 includes one or more generators 102 for generating power for an electric motor 112. The one or more generators may include a natural gas-powered generator. In at least one embodiment, the one or more generators may include a turbine generator. The system 100 also includes a pump, such as a fluid pump 114, to perform the hydraulic fracturing operation; a variable frequency drive (VFD) 104 for controlling the electric motor; breakers 106 to handle overloads and overdraw situations; and a motor control center (MCC) 108 for control of electrical sub-systems, including blower motors, coolant pumps, lube oil pumps, lighting, heaters, control power, receptacles, and fan motors.

[0026] In at least one embodiment, the pump 114 is configured for pumping the hydraulic fracturing fluid into a well and the associated formation. In addition, the pump 114 is adapted or configured for high pressure pumping so as to enable fracturing of the formation. The electric motor 112 may be coupled to the electric pump 114 via a high-strength steel or steel alloy shaft. One or more of these system components may be housed on main or auxiliary trailers so that they remain mobile.

[0027] In at least one embodiment, the MCC 108 may support the breakers 106 by a monitoring action. The breakers 106 support distribution of power from the generators to components of varied load requirements. In at least one embodiment, the components may be other than the system components, and may be equipment used at a wellsite, include lights, heaters, blowers, small pumps, control computers, and motors. Shorts or high draws from a load asserted through one or more of the breakers may cause the breakers 106 to trip for protection.

[0028] In at least one embodiment, a transformer 110 may be located on one or more trailer after the VFD 104 and prior to the electric motor 112, which may be on the same or different trailers. However, the location of the components on one or more trailers has no effect on the flow of current or power which is described separately. For instance, the generator generates electricity that may be input to VFD 104 through breakers, if needed, irrespective of the location of these components. Cables may be used to connect the various components irrespective of their locations on or off one or more trailers. As the generator 102 may support other components requiring power then the electric motor 112, the generator 102 may provide the required voltage via MCC 108. The transformer 110 steps down the voltage provided from the generator 102, for the VFD 104, the MCC 108, and the electric motor 112 to a manageable voltage handled by these components. The electric motor 112 drives the electric pump 114 to perform the requisite fracturing operations. In at least one embodiment, the electric motor 112 may be an induction motor or a permanent magnet motor.

[0029] In at least one embodiment, interface 116 may be used to provide the determined parameters to the VFD 104 or another component having at least a memory having instructions and a processor for executing the instructions to perform functions. In at least one embodiment, the memory may also store the determined parameters. In at least one embodiment, the functions include distributing the determined parameters to various system components for setting the system components according to the determined parameters.

[0030] FIG. 1B is another block diagram of a system 150 that is positioned on a trailer and used in a hydraulic fracturing operation with encoderless vector control, according to at least one embodiment of the present disclosure. As such and as in the case of FIG. 1, the layout in FIG. 1B reflects how the system components may be positioned, but not necessarily the flow of current or power, which is described elsewhere throughout this description otherwise. In at least one embodiment, as in the system 100, the system 200 of FIG. 1B includes one or more generators

152 for generating power for one or more electric motors 162A, B. The one or more generators 152 may include a natural gas-powered generator. In at least one embodiment, the one or more generators 152 may include a turbine generator. The system 150 also includes one or more pumps, such as a fluid pumps 164A, B, to perform the hydraulic fracturing operation; one or more variable frequency drives (VFDs) 158A, B for controlling the respective electric motors 162A, B; breakers 156A, B to handle respective overloads and overdraw situations associated with a respective electric motor 162A, B; and a motor control center (MCC) 168 for control of electrical sub-systems, including blower motors, coolant pumps, lube oil pumps, lighting, heaters, control power, receptacles, and fan motors.

[0031] In at least one embodiment, the pumps 164A, B are individually configured for pumping the hydraulic fracturing fluid into a well. In at least one embodiment, the pumps draw slurry, representing the fracturing fluid, from the blender at a low pressure, boost the slurry to a high pressure for application into the well that connected to the formation. In addition, the pumps 164A, B are individually adapted or configured for high pressure pumping so as to enable cracking of the formation. Furthermore, each electric motor 162A; 162B may be coupled to one or more pumps 164A, B, but each electric motor 162A; 162B may be couple to individual ones of the one or more pumps 164A, 164B. Each electric motor 162A, B may be coupled to the one or more electric pumps 164A, B via a high-strength steel or steel alloy shaft. One or more of these system components may be housed on main or auxiliary trailers so that they remain mobile.

[0032] In at least one embodiment, the MCC 160 may support the breakers 156A, B by a monitoring action. The breakers 156A, B support distribution of power from the generator(s) 152 to components of varied load requirements. In at least one embodiment, the components may be other than the system components, and may be equipment used at a wellsite, include lights, heaters, blowers, small pumps, control computers, and motors. Shorts or high draws from a load asserted through one or more of the breakers may cause the breakers 156A, B to trip for protection.

[0033] In at least one embodiment of FIG. 1B distinct from the system 100 of FIG. 1A, the transformer 154 may be located on one or more trailers after the generator 102 and prior to the breakers 156A, B or even the VFDs 158A, B, which may be on the same or different trailers. However, the location of the components on one or more trailers has no effect on the flow of current or power which is described separately. For instance, the generator generates electricity that passes through breakers 156A, B and to VFDs 158A, B. As the generator(s) 152 may support other components than illustrated that also require power, the generator 152 may be a high voltage generator. The transformer 154, therefore, steps down the voltage to a manageable voltage handled by the VFD 158A, B, and as required by components coupled to the MCC 160. In at least one embodiment, the electric motor 162A, B may be an induction motor or a permanent magnet motor, as in the system 100 of FIG. 1A.

[0034] Furthermore, applying an encoderless vector control scheme within the VFD in the present systems 100; 150 may not solve every one of the above-described problems, but focusing on certain parameters or many (e.g., thousands) of parameters available for control of the system allows for resolution of at least the vibrations, oscillations, or resonance associated with the turbine, the shaft, and/or coupler. In at least one embodiment, determined parameters from the available system parameters are adjusted and set for the application in any given situation, such as before a load is engaged with the system 100; 150. While each component, such as the electric motors 112; 162A, B, or the turbines 102; 152 have ratings or default parameters, these are not defined to the requirements of a hydraulic fracturing system.

[0035] In at least one embodiment, a vibration sensor is used with the system 100; 150, for example, at the turbine 102; 152 to determine parameters from the available parameters of the systems' components. In at least one embodiment, the determined parameters are coded into the VFD prior to engaging the electric motor with the respective electric pump. In at least one embodiment, the assertion of the determined parameters for of the VFD may override the default settings for the systems' components. The determined parameters have a range of settings that are, therefore, enable proper tuning of the electric motor for the hydraulic fracturing application, to obtain desired motor control behaviors. The tuned set of parameters described in concurrently submitted Appendix A forms part of this disclosure and may be selected based in part on monitoring vibration from various points of the turbine.

[0036] In at least one embodiment, the encoderless vector control scheme utilizes parameters associated with respective VFDs to enable an electric motor to drive a hydraulic fracturing pump smoothly over the motor's entire speed range, to generate full torque at zero speed, and to have high dynamic performance, including fast acceleration and deceleration of the hydraulic fracturing pumps. Also, natural frequencies present in the connected equipment may be isolated by the VFD having the determined parameters, and any excitement previously in the system 100; 150 may be limited after adopting encoderless vector control scheme as demonstrated by the discussion in at least FIG. 4, where specific tuned parameters or determined parameters were applied after monitoring effects of the vibration at the turbine. The determined parameters are not excited or affected during operation of the system 100; 150 after adopting encoderless vector control.

[0037] In at least one embodiment, interface 166, as in the case of the embodiment in FIG. 1A may be used to provide the determined parameters to the VFD 158A, B or another component having at least a memory having instructions and a processor for executing the instructions to perform functions. In at least one embodiment, the memory may also store the determined parameters. In at least one embodiment, the functions include distributing the determined parameters to various system components for setting the system components according to the determined parameters.

[0038] FIG. 1C is another block diagram of a system 170, as positioned on a trailer and used in a hydraulic fracturing operation with encoderless vector control, according to at least one embodiment of the present disclosure. Incoming power, from a generator, for instance, may pass through an incoming breaker 172. The incoming breaker 172 is optional as noted. A transformer 174 steps down the voltage of the income power from the generator. The transformer may feed one or more components. As illustrated, a further breaker in the form of an MCC breaker 176 enables power from the transformer to reach auxiliary components 178. These components 178 include one or more small motors and an auxiliary load center. The transformer may separately or concurrently feed a VFD through VFD breakers 180 and fuses 182. One or more of these breakers and fuse may be optional. The VFD is illustrated as one or more of components 184-190. The VFD may include an alternating current (AC) reactor 184, a rectifier 186, a direct current (DC) choke 188, and one or more inverters 190 that may be an IGBT (insulated-gate bipolar transistor)-type inverter. The rectifier 186 enables conversion of the AC to the DC power, which the inverters 190 then convert to pulse-width-modulated (PWM) AC power. The PWM

AC power is used to power the electric pump or motor 192. FIG. 1C also illustrates that parameters from FIG. 5 (or Appendix A) may relate to one or more of the components in FIG. 1C and applied values for the parameters may adapt the operations of one or more of the components in FIG. 1C to reduce vibrations in at least the turbine features discussed with respect to at least FIG. 2.

[0039] FIG. 2 is a section diagram of a turbine 200 within a system used in a hydraulic fracturing operation and benefiting from encoderless vector control, according to at least one embodiment of the present disclosure. The turbine 200 includes low compressor section 202, a high compressor section 204, a gas generator section 206, a combustor section 208, a high/low turbine section 210, a power turbine section 212, and a gear box 228 for the high compressor section 204. A shaft 214, along with a coupler 216, translates the generated rotational motion to a generator to provide the electricity requirements for the electric motor.

[0040] In at least one embodiment, the turbine 200 is associated with one or more vibration monitors 222, which receive or monitor vibration at one or more sensors 220 (one is marked for reference) at one or more locations throughout the turbine 200. The locations may be on the body 228 adjacent to a section 202-212 within the body or may be directly within the sections. In at least one embodiment, physical connectors (represented in the example by reference numeral 218) carry signals from the one or more sensors 222 to the monitor(s) 220. In at least one embodiment, the vibrations monitored at the one or more locations are apparent on the shaft 214 and/or coupler 216, and may result in damage to the coupler. As such, even though no sensor is provided at the coupler, the monitor 220 provides sufficient information via Ethernet interface 224, for instance, to enable the determine parameters that may be asserted for an encoderless vector control scheme of the present disclosure. In at least one embodiment, FIG. 5 provides examples of determined parameters that may be used in the encoderless vector control scheme.

[0041] In at least one embodiment, the monitor 220 provides information pertaining to the oscillation alarms via Ethernet interface 224, for applied determined parameters of the system. The applied determined parameters are qualified for use with a similar application, under a similar configuration, as the determined parameters for the VFD to ensure that the vibrations are the least possible, as reflected by the oscillation alarms being reduced in reference to at least FIG. 4.

[0042] FIG. 3 is graph 300 illustrating system vibration and instability of a system for hydraulic fracturing that may benefit from aspects of the present disclosure. The y-axis 302 represents Number of Shaft Oscillation Alarm Values and the x-axis 304 represents Date and Time of Alarm, when an oscillation alarm occurs. In at least one embodiment, the oscillation alarm represents a monitored vibration beyond an acceptable vibration set within the monitor 220 of FIG. 2 for each of the one or more locations referenced in FIG. 2. Further, the oscillation alarm represents, in at least one embodiment, vibration that is associated with at least one turbine of a hydraulic fracturing system that may include one or more turbines, generators, or turbine generators.

[0043] The graph 300 in FIG. 3 illustrates system vibration and instability prior to implementation of an encoderless vector control scheme. In at least one embodiment, the graph represents the number of oscillation alarms received when the system is in operation over different dates and times as noted in the x-axis of the graph.

[0044] As illustrated, further, the instability is pertinently represented by a non-uniform scope of the oscillation alarms. In at least one embodiment, the vertical scale is a dimensionless value or number that is proportional to vibration (rpm/sec) for a portion or at least a feature of the equipment. In at least one embodiment, the feature is on the surface during pumping operations and the value or number may indicate a natural frequency of an excited system under operation. As illustrated the peak of the values in graph 300 approaches 350. A desired value is however lower, for instance, at around 20. At the lower value, instability is reduced or halted when pumping operations are ongoing, but in graph 300, the lower values are obtained only when pumping operations is significantly slowed, which is not desirable during hydraulic fracturing operations.

[0045] FIG. 4 is a graph 400 illustrating reduced system vibration and increased stability for a system for hydraulic fracturing that implements aspects of the present disclosure. In at least one embodiment, FIG. 4 illustrates a graph 400 having reduced system vibration and increased stability after implementation of an encoderless vector control scheme. Pertinently, however, even though the scale and dimensions on the x and the y-axes 402, 404 are similar to those of Fig. 3. The left side 406 of the graph 400 represents vibrations present at one or more of the monitored locations referenced in FIG. 2, but with some order, during each individual hydraulic fracturing stage, prior to encoderless vector control being implemented. The right side 408 of the graph 400, on the other hand, represents reduced vibrations monitored at the one or more locations referenced in FIG. 2, after implementation of the encoderless vector control scheme.

[0046] In at least one embodiment, the oscillation alarm values in the right side 408 of the graph 400 represent vibration in at least one part of the system for a period of time and may be within a range of about 15 to about 45 upon engagement of the motor with a load for the period of time. In at least one embodiment, the encoderless vector control scheme includes determining parameters suited for the electric motor based in part on the oscillation alarm values being at least less than about 45 or less than about 70 upon engagement of the motor with a load. These values are represented as attainable by the monitoring system indicating graph points within these values on the right side 408 of the graph 400.

[0047] FIG. 5 illustrates a table 500 of select determined parameters 502 and corresponding values 504, 506, with units 508, within the encoderless vector control for a VFD used in hydraulic fracturing operations, according to at least one embodiment of the present disclosure. Selected determined parameters 502 represent example parameters that may be tuned or adjusted for the encoderless vector control, at least as input for the VFD. The example parameters include example maximum and minimum values 504, 506, and their units 508. Table 1, in concurrently filed Appendix A, includes a set of further possible encoderless vector control determined parameters and some of the ranges of values that can be implemented for a fracturing pump VFD.

[0048] The VFD encoderless vector control system of the present disclosure enable the electric motor to drive a hydraulic fracturing pump in a smooth operating curve over the motor's entire speed range, to generate full torque at zero speed, and to have high dynamic performance, including fast acceleration and deceleration of the fracturing pump. Also, natural frequencies that were present within the connected equipment, and prone to excitation prior to adopting encoderless vector control and the specific tuned parameters, were not prone to excitation after adopting encoderless vector control and tuned parameters.

[0049] FIG. 6 illustrates a flowchart 600 of a method for encoderless vector control for a VFD used in fracturing operations, according to at least one embodiment of the present disclosure. In at least one sub-process 602, an electric motor is engaged with a turbine generator; to receive electric supply indirectly from the turbine generator, for instance. The engagement includes electrical coupling and/or mechanical coupling to associate these two system components together for a fracturing operation. Alternatively, sub-process 602 prepares the turbine generator to generate power by following the required starting and regulating protocols for the turbine generator, for instance. Sub-process 604 couples an encoderless vector control subsystem, such as an encoderless vector control VFD, between the electric motor and the turbine generator. Additional components including breakers and/or transformers may be required and may be recognized and implemented from the disclosure herein, but may be omitted for discussion of FIG. 6.

[0050] In at least one embodiment, sub-process 606 enables an interface to receive the determined parameters for the subsystem. In at least one embodiment, the encoderless vector control subsystem includes at least the VFD. The values may be loaded by an executable program or code provided to a machine interface of the VFD or to a component connected to the VFD. As such, the VFD may include or be associated with a processor and a memory including instructions executable by the processor to perform functions for the encoderless vector control subsystem. In at least one embodiment, the functions enable settings for one or more system components of the fracturing system. For instance, speed reference (vales from FIG. 5), motor current, and motor voltage may be all provided from a computer functioning as an interface (e.g., interfaces 116, 166 of FIGS. 1A, 1B), external to the VFD or the system.

[0051] Sub-process 608 determines if the encoderless vector control subsystem received values associated with the determined parameters. In at least one embodiment, sub-process 608 may use values from a prior application of the encoderless vector control subsystem to achieve stable operation of the system. Alternatively, sub-process 608 may be applied in a test environment using the vibration sensors and using the monitors previously referenced, prior to method 600 being applied in a real-time environment using the determined parameters from the test environment.

[0052] In at least one embodiment, when the determined parameters are available, sub-process 610 controls the electric motor using the determined parameters input to the encoderless vector control subsystem that may include the VFD and may include one or more additional component capable of providing settings for one or more system components of an encoderless vector control system for hydraulic fracturing. Sub-process 612 engages at least one pump with torque input provided from the electric motor when the fracturing operation is performed. Sub-process 606 for the interface remains available for updates to the determined parameters or to override the determined parameters previously provided, for instance.

[0053] In at least one embodiment, the system discussed herein for implementing aspects in accordance with various embodiments are computer-based environments having hardware and software capabilities. For instance, a computer-based environment may include human-machine interfaces, processors, memory components, and communication components for receiving input from external computers. Further, different computing environments may be used, as appropriate, to implement various embodiments. External computers may be used to interact with various embodiments and can include any appropriate device operable to send and receive requests, messages, or information over an appropriate network and convey information back to a user of the device. Examples of such external computers may include personal computers, smart phones, handheld messaging devices, laptop computers, and the like. The network can include any appropriate network, including an intranet, the Internet, a cellular network, a local area network, or any other such network or combination thereof. Components used for such a system can depend at least in part upon the type of network and/or environment selected. Protocols and components for communicating via such a network are well known and will not be discussed herein in detail. Communication over the network can be enabled by wired or wireless connections, and combinations thereof using communication component, such as discussed throughout this disclosure.

[0054] While the technology has been shown or described in only some of its forms, it should be apparent to those skilled in the art that it is not so limited, but is susceptible to various changes without departing from the scope of the technology. Furthermore, it is to be understood that the above disclosed embodiments are merely illustrative of the principles and applications of the present technology. Accordingly, numerous modifications can be made to the illustrative embodiments and other arrangements can be devised without departing from the spirit and scope of the present technology as defined by the appended claims.

Claims

What is claimed is:

1. A system (100; 150; 170) for use in fracturing operations, the system characterized by:

an electric motor (112; 162A, 162B; 192);

a turbine generator (102; 152) to generate electric power;

an encoderless vector control subsystem (116, 104; 166, 158A, 158B; 186, 190) to receive the electric power from the turbine generator and to control the electric motor using determined parameters (500) provided to the encoderless vector control subsystem; and

at least one pump (114; 164A, 164B) to receive torque input from the electric motor.

2. The system of claim 1, further characterized by:

a vibration sensor (222) for monitoring vibration induced in a feature (202-216) associated with a turbine (200) of the turbine generator and providing input for the determined parameters based in part on the vibration.

3. The system of claim 1, further characterized by:

the vibration sensor associated with a body (228) of the turbine generator for monitoring the vibration induced in the body of the turbine of the turbine generator, in part, due to a feedback resonance received to the turbine.

4. The system of claim 1, further characterized by:

an encoderless variable frequency drive (VFD) functioning as the encoderless vector control subsystem.

5. The system of claim 1, further characterized by:

a machine interface (116) to receive the determined parameters for the encoderless vector control subsystem; and

at least one processor to apply the determined parameters to the electric motor prior to engagement of a load with the electric motor.

6. The system of claim 1, wherein the determined parameters for the encoderless vector control subsystem is determined based in part on oscillation alarm values representing vibration in at least a portion of a body associated with the turbine generator, for a period of time, being within a range of about 15 to about 45 upon engagement of the motor with a load.

7. The system of claim 1, wherein the determined parameters for the encoderless vector control subsystem is determined based in part on oscillation alarm values representing vibration in at least a portion of a body associated with the turbine generator, for a period of time, being less than about 70 upon engagement of the motor with a load.

8. The system of claim 1, wherein the determined parameters for the encoderless vector control subsystem is selected from at least speed values, motor values, and proportional-integral-derivative (PID) control values.

9. The system of claim 1, further characterized by:

one or more triplex, quintuplex, novemplex, or septuplex plunger pumps adapted to receive the torque input from the electric motor.

10. A method (600) for using electric pumps in fracturing operations characterized by:

engaging (602) an electric motor with a turbine generator;

enabling (604) an encoderless vector control subsystem to receive electric power from the turbine generator;

controlling (610) the electric motor using determined parameters input to the encoderless vector control subsystem; and

engaging (612) at least one pump with the torque input from the electric motor.

11. The method of claim 10, wherein the determined parameters are based in part on vibration induced in a feature associated with the turbine generator.

12. The method of claim 11, further characterized by:

monitoring (606, 608) the vibration induced in a body of a turbine associated with the turbine generator, the determined parameters based in part on the vibration induced in the body, in part, due to a feedback resonance received to the turbine generator.

13. The method of claim 10, further characterized by:

using an encoderless variable frequency drive (VFD) as the encoderless vector control subsystem.

14. The method of claim 10, further characterized by:

enabling (606) a machine interface to receive the determined parameters for the encoderless vector control subsystem; and

applying, using at least one processor, the determined parameters to the electric motor prior to engagement of a load with the electric motor.

15. The method of claim 10, wherein the determined parameters for the encoderless vector control subsystem is determined based in part on oscillation alarm values, representing vibration in at least a body of a turbine associated with the turbine generator, having values from a range of about 15 to about 45 upon engagement of the motor with a load.

16. The method of claim 10, wherein the determined parameters for the encoderless vector control subsystem is determined based in part on oscillation alarm values, representing vibration in at least a body of a turbine associated with the turbine generator, having decreased values less than a range of about 70 to about 80 upon engagement of the motor with a load.

17. The method of claim 10, wherein the determined parameters for the encoderless vector control subsystem is selected from at least speed values, motor values, and proportional-integral-derivative (PID) control values.

18. The method of claim 10, further characterized by:

engaging one or more triplex, quintuplex, novemplex, or septuplex plunger pumps with the electric motor to receive the torque out from the electric motor.

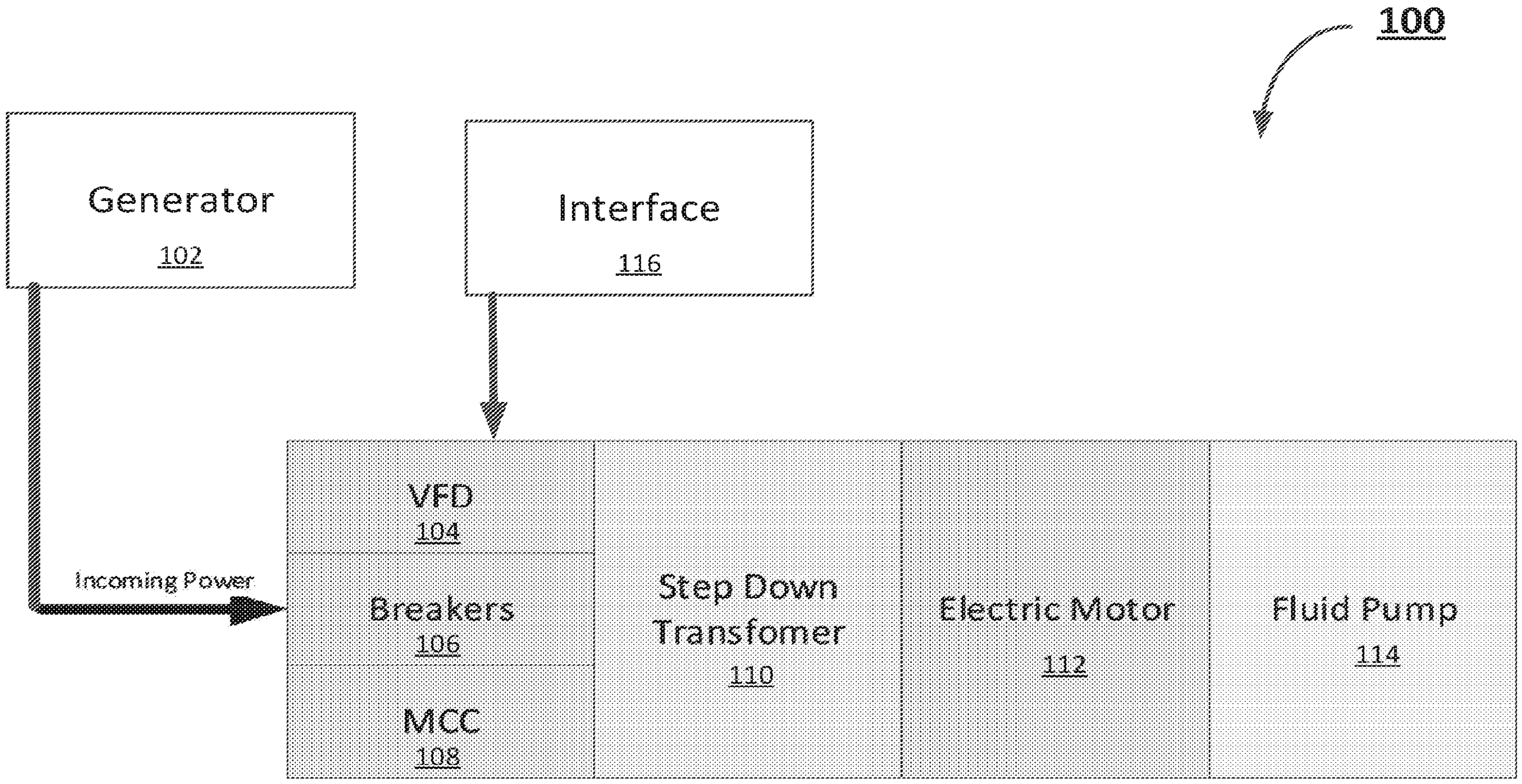

100
Generator
102
Interface
116
Incoming Power
VFD
104
Breakers
106
MCC
108
Step Down
Transfomer
110
Electric Motor
112
Fluid Pump
114

FIG. 1A

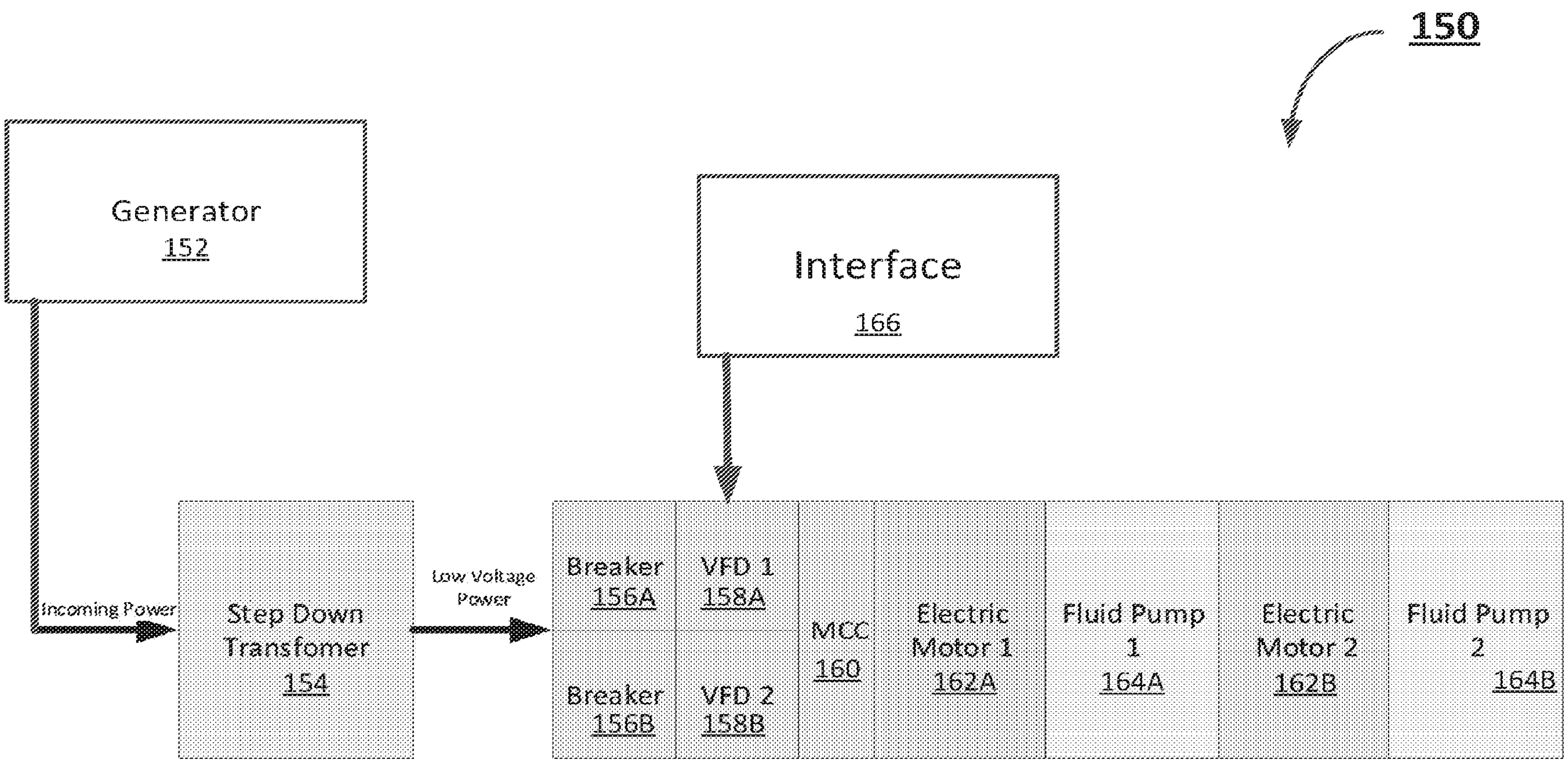

150
Generator
152
Interface
166
Incoming Power
Step Down
Transfomer
154
Low Voltage
Power
Breaker
156A
VFD 1
158A
Breaker
156B
VFD 2
158B
MCC
160
Electric
Motor 1
162A
Fluid Pump
1
164A
Electric
Motor 2
162B
Fluid Pump
2
164B

FIG. 1B

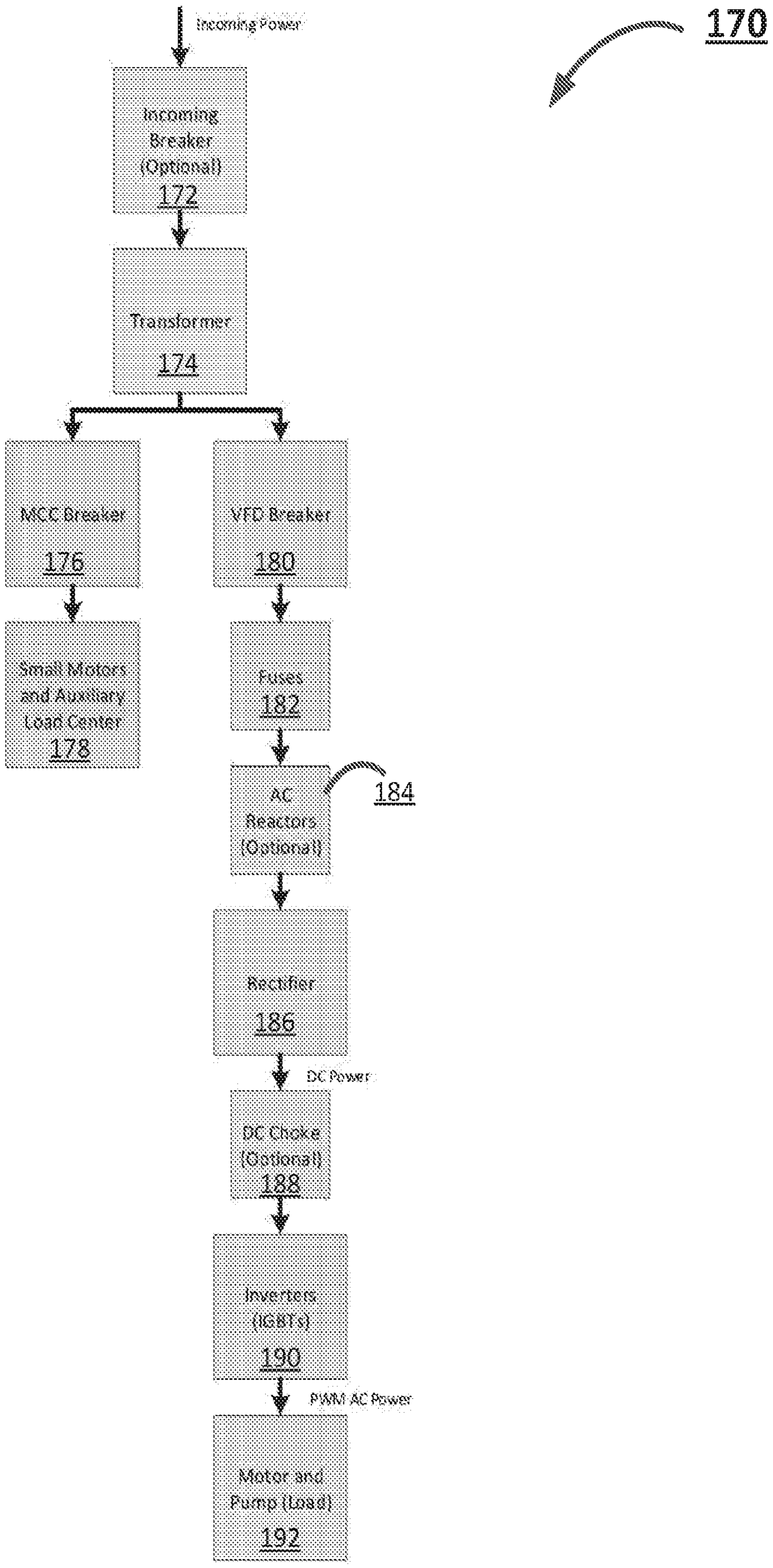

170
Incoming Power
Incoming Breaker (Optional) 172
Transformer 174
MCC Breaker 176
Small Motors and Auxiliary Load Center 178
VFD Breaker 180
Fuses 182
AC Reactors (Optional)
184
Rectifier 186
DC Power
DC Choke (Optional) 188
Inverters (IGBTs) 190
PWM AC Power
Motor and Pump (Load) 192

FIG. 1C

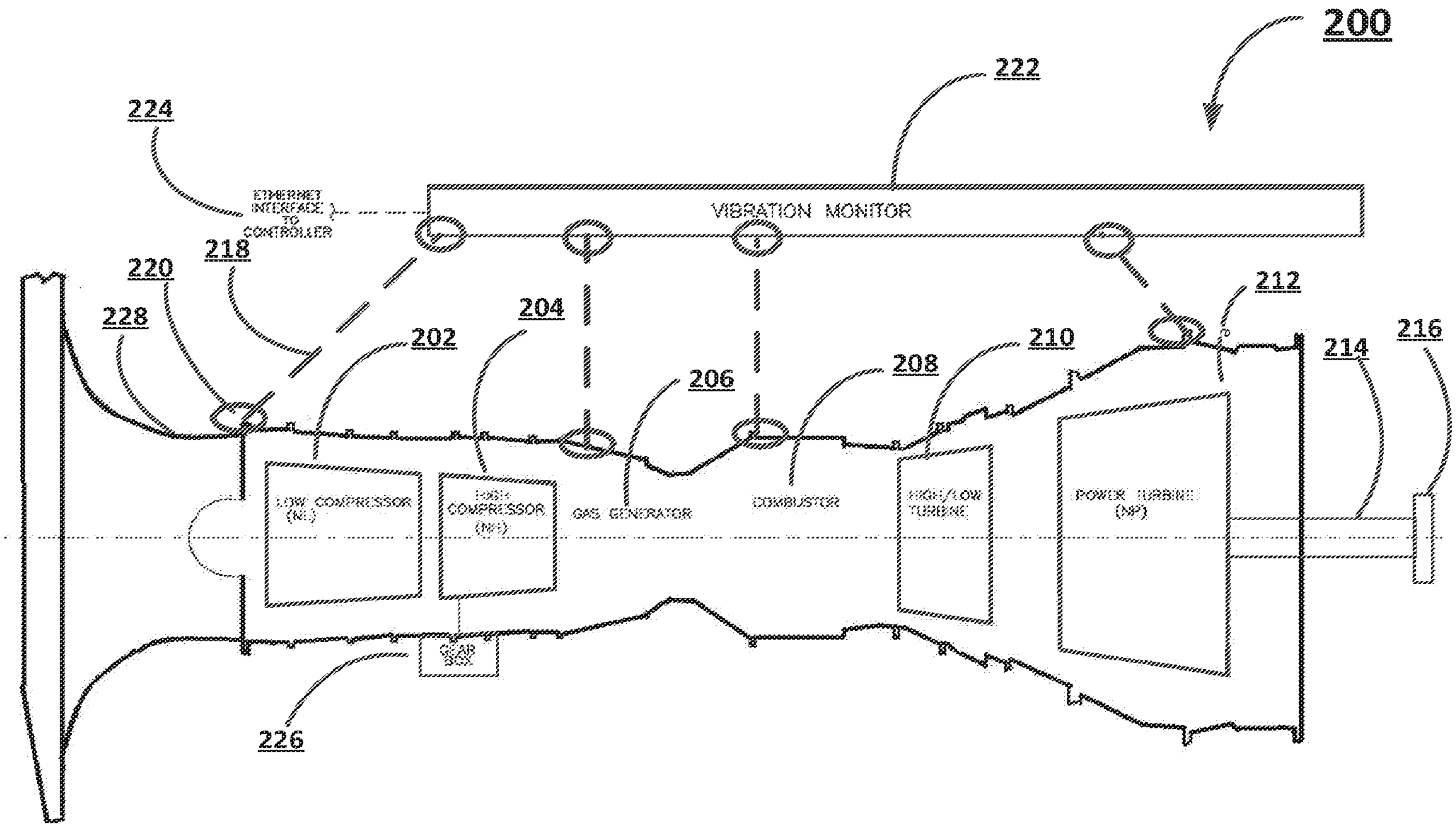

200
222
224
VIBRATION MONITOR
ETHERNET INTERFACE TO CONTROLLER
218
220
228
202
204
206
208
210
212
214
216
226
LOW COMPRESSOR (NL)
HIGH COMPRESSOR (NH)
GAS GENERATOR
COMBUSTOR
HIGH/LOW TURBINE
POWER TURBINE (NP)
GEAR BOX

FIG. 2

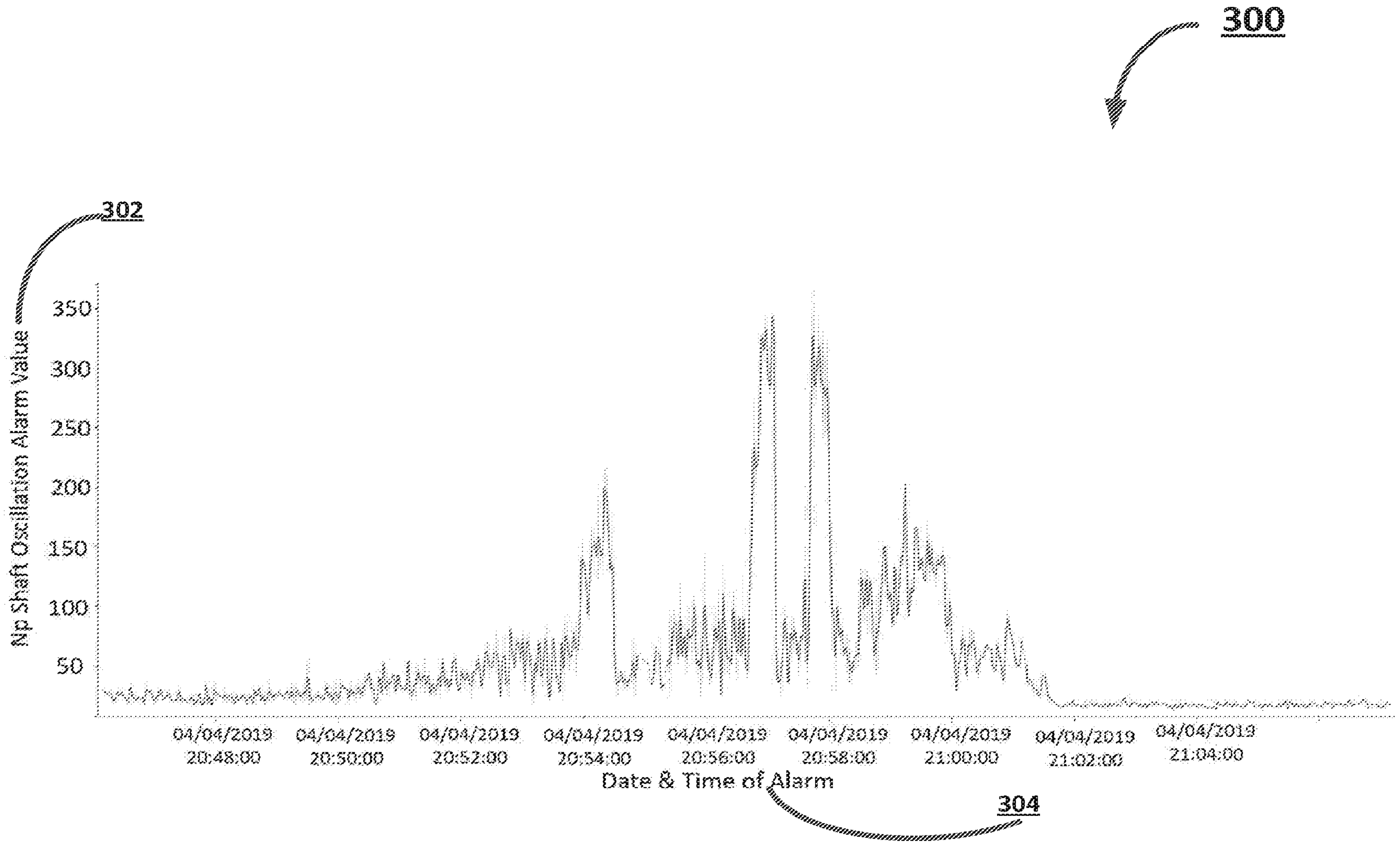

300
302
Np Shaft Oscillation Alarm Value
350
300
250
200
150
100
50
04/04/2019 20:48:00
04/04/2019 20:50:00
04/04/2019 20:52:00
04/04/2019 20:54:00
04/04/2019 20:56:00
04/04/2019 20:58:00
04/04/2019 21:00:00
04/04/2019 21:02:00
04/04/2019 21:04:00
Date & Time of Alarm
304

FIG. 3

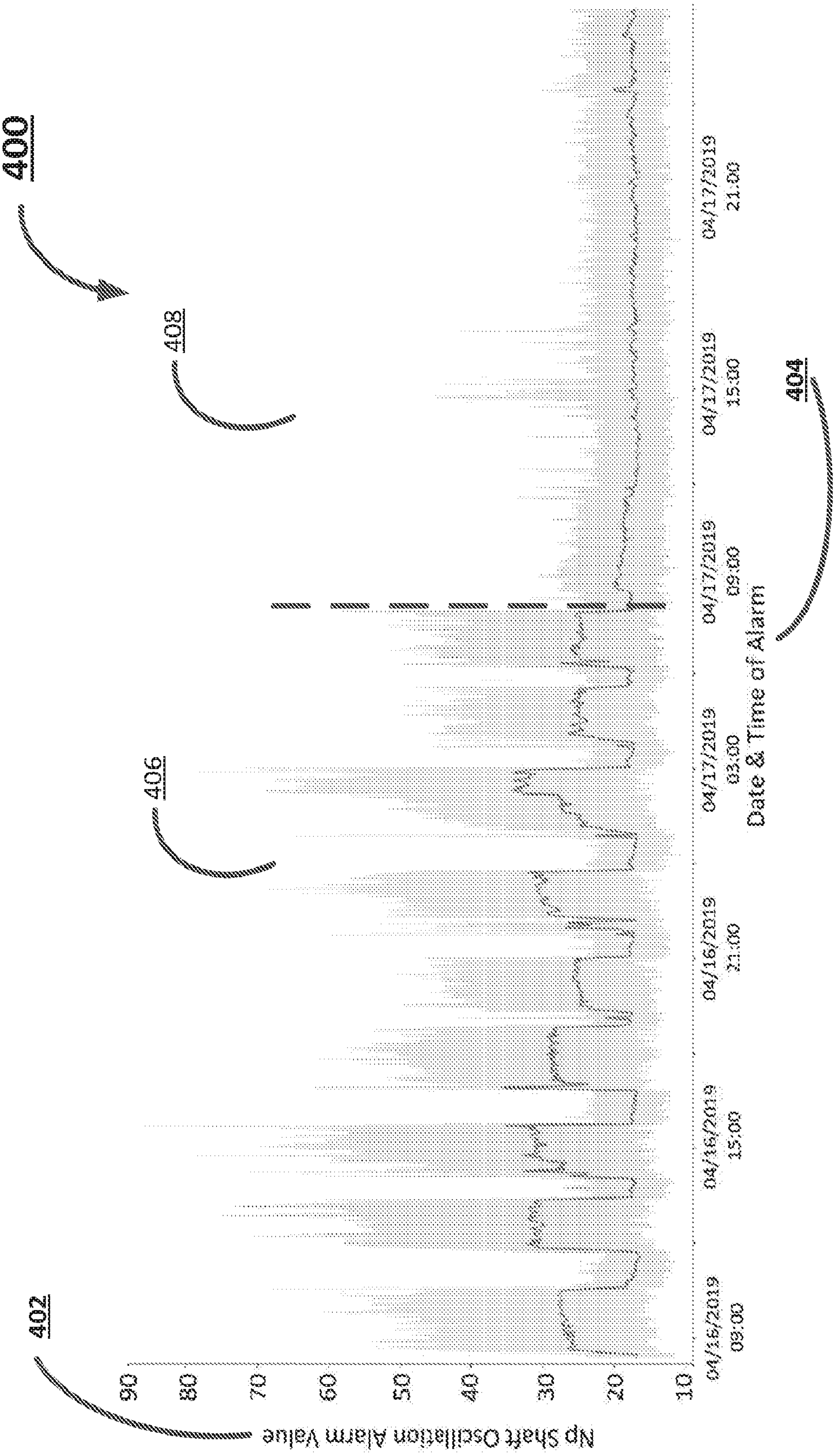
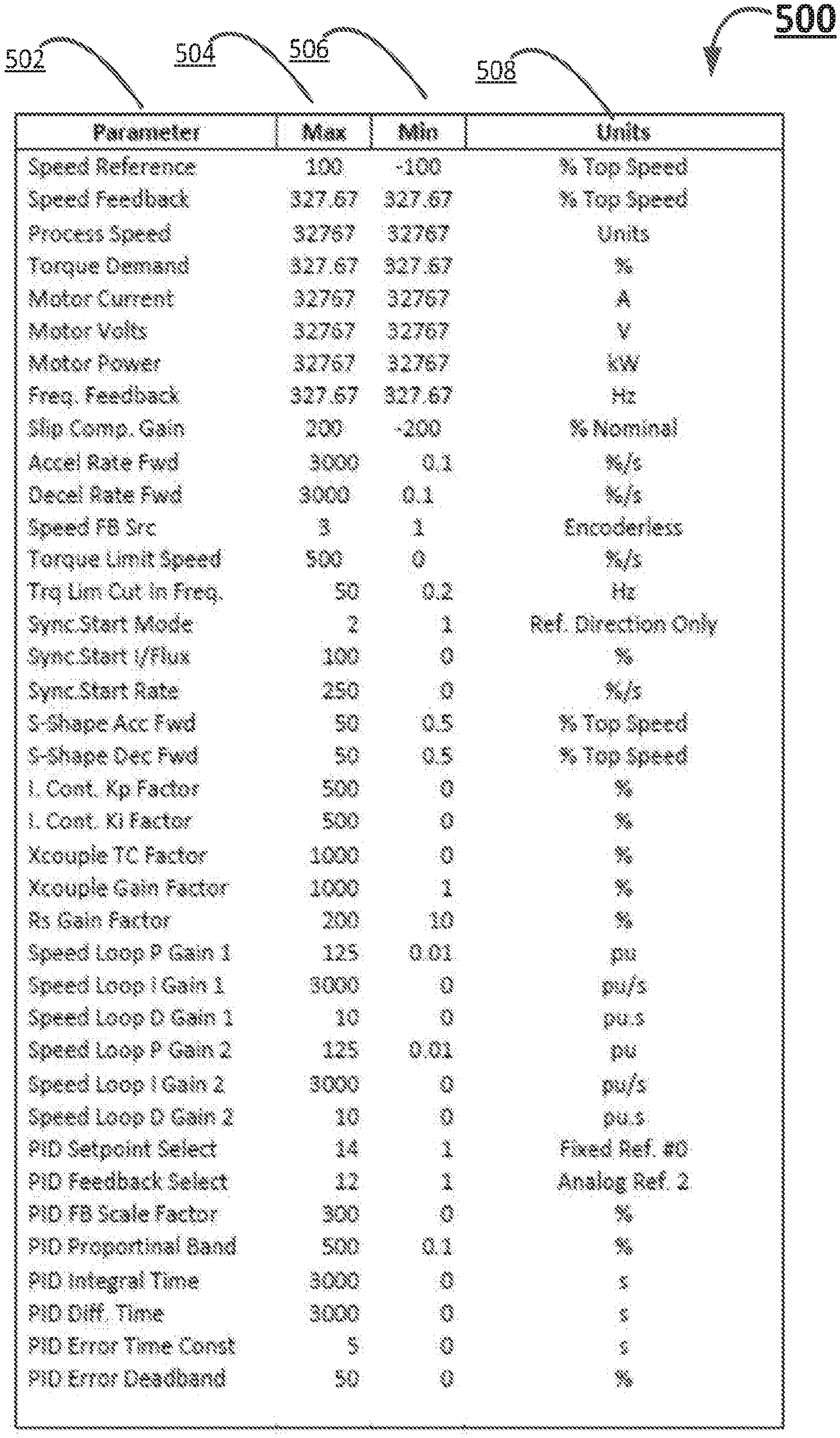

400
402
406
408
404
Np Shaft Oscillation Alarm Value
90
80
70
60
50
40
30
20
10
04/16/2019 03:00
04/16/2019 15:00
04/16/2019 21:00
04/17/2019 03:00
04/17/2019 09:00
04/17/2019 15:00
04/17/2019 21:00
Date & Time of Alarm

FIG. 4



Parameter	Max	Min	Units
Speed Reference	100	-100	% Top Speed
Speed Feedback	327.67	327.67	% Top Speed
Process Speed	32767	32767	Units
Torque Demand	327.67	327.67	%
Motor Current	32767	32767	A
Motor Volts	32767	32767	V
Motor Power	32767	32767	kW
Freq. Feedback	327.67	327.67	Hz
Slip Comp. Gain	200	-200	% Nominal
Accel Rate Fwd	3000	0.1	%/s
Decel Rate Fwd	3000	0.1	%/s
Speed FB Src	3	1	Encoderless
Torque Limit Speed	500	0	%/s
Trq Lim Cut In Freq.	50	0.2	Hz
Sync.Start Mode	2	1	Ref. Direction Only
Sync.Start I/Flux	100	0	%
Sync.Start Rate	250	0	%/s
S-Shape Acc Fwd	50	0.5	% Top Speed
S-Shape Dec Fwd	50	0.5	% Top Speed
I. Cont. Kp Factor	500	0	%
I. Cont. Ki Factor	500	0	%
Xcouple TC Factor	1000	0	%
Xcouple Gain Factor	1000	1	%
Rs Gain Factor	200	10	%
Speed Loop P Gain 1	125	0.01	pu
Speed Loop I Gain 1	3000	0	pu/s
Speed Loop D Gain 1	10	0	pu.s
Speed Loop P Gain 2	125	0.01	pu
Speed Loop I Gain 2	3000	0	pu/s
Speed Loop D Gain 2	10	0	pu.s
PID Setpoint Select	14	1	Fixed Ref. #0
PID Feedback Select	12	1	Analog Ref. 2
PID FB Scale Factor	300	0	%
PID Proportinal Band	500	0.1	%
PID Integral Time	3000	0	s
PID Diff. Time	3000	0	s
PID Error Time Const	5	0	s
PID Error Deadband	50	0	%

FIG. 5

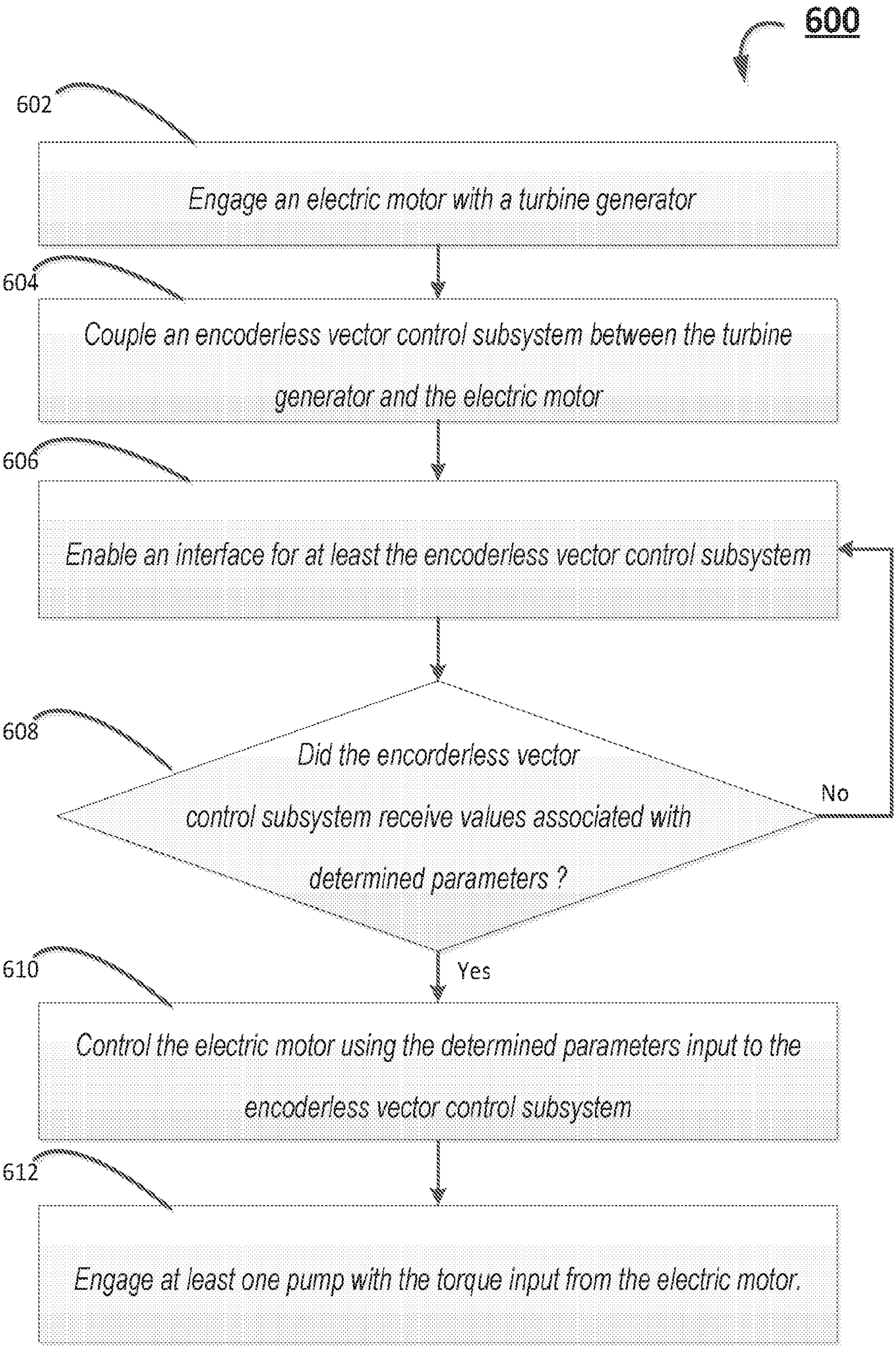

600
602
Engage an electric motor with a turbine generator
604
Couple an encoderless vector control subsystem between the turbine generator and the electric motor
606
Enable an interface for at least the encoderless vector control subsystem
608
Did the encorderless vector control subsystem receive values associated with determined parameters ?
No
Yes
610
Control the electric motor using the determined parameters input to the encoderless vector control subsystem
612
Engage at least one pump with the torque input from the electric motor.

FIG. 6

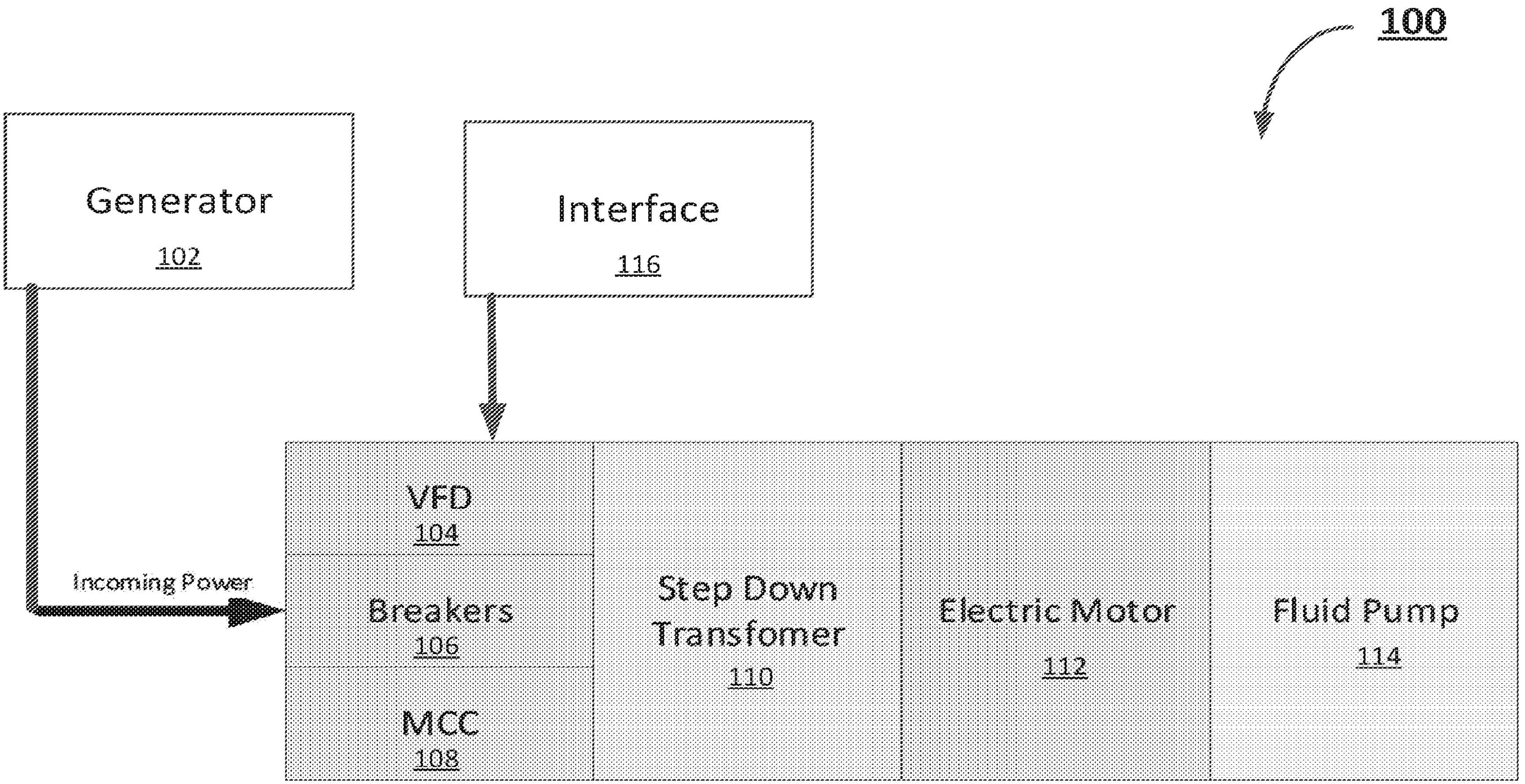

100
Generator
102
Interface
116
Incoming Power
VFD
104
Breakers
106
MCC
108
Step Down Transfomer
110
Electric Motor
112
Fluid Pump
114

FIG. 1A