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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
2 October 2008 (02.10.2008)

PCT

(10) International Publication Number
WO 2008/117290 A2

(51) International Patent Classification:
H02P 9/30 (2006.01)

(21) International Application Number:
PCT/IL2008/000426

(22) International Filing Date: 27 March 2008 (27.03.2008)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/907,248 27 March 2007 (27.03.2007) US

(71) Applicant *(for all designated States except US)*: **C.A.P.S. ENERGY LTD.** [IL/IL]; 46-48 Menachem Begin, Migdal Aviv, Migdal A, Room 603, 66180 Tel Aviv (IL).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **NADAM, Dror** [IL/IL]; 12 Hohit St, 40697 Eyn-Sarid (IL). **BEN-DAVID, Rahamim** [IL/IL]; 79 David Israel St, 76100 Rehovot (IL).

(74) Agent: DR. D. GRAESER LTD.; 13 HaSadna St, PO Box 2496, 43650 Raanana (IL).

(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, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, 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, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report*

(54) Title: SYSTEM AND METHOD FOR GENERATING AN ALTERNATING CURRENT OUTPUT SIGNAL

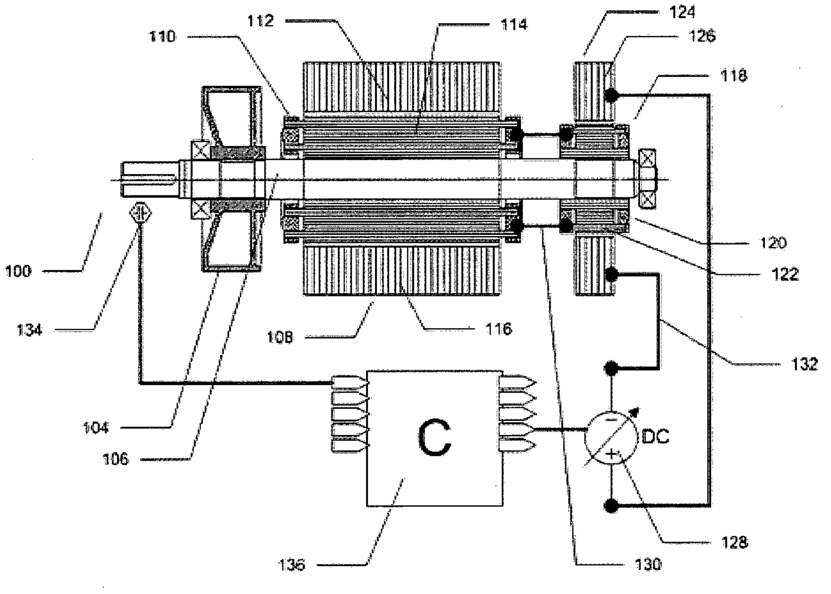


Figure 1

(57) Abstract: A system and device for providing AC signal. The system includes: an AC generator that outputs an AC output signal and includes an AC rotor that communicates with a shaft that is rotated at a rotation speed; a speed sensor for sensing the rotation speed; and a controller for controlling a magnetic field of the AC generator in response to the rotation speed; wherein the controller comprises a direct current (DC) generator that generates a current that is provided to the AC generator so as to control the magnetic field of the AC generator.

WO 2008/117290 A2

System and method for generating an alternating current output signal

RELATED APPLICATIONS

This application claims priority from US Provisional application 60/907,248, filing date March 27 2007, hereby incorporated by reference as if fully set forth herein.

FIELD OF THE PRESENT INVENTION

The present invention is related to a system and device for generating electricity according to a constant output yet with potentially variable speed, and in particular, to such a system and device which feature a voltage regulation system.

BACKGROUND OF THE PRESENT INVENTION

The generation of electricity through the use of electrical generators is important for modern life. These generators require some source of external energy to operate, which may for example be some type of fossil fuel and/or renewable energy. The generator then consumes the energy source in order to generate electricity. However, it is important that the power output remain constant in order for the generated electricity to be usable.

The power output can remain constant if the shaft speed of the generator remains constant. However, the shaft speed of the generator cannot always be held to a constant rate. Therefore, some generators have relied on maintaining at least a minimum speed, such that the power output provided is determined according to the minimum speed of the shaft. If the shaft speed increases beyond the minimum, the excess power produced is discarded and hence is wasted.

Various solutions have been attempted but none has completely solved the problem for alternating current (AC) generators. For example, US Patent No. 5541483 provides a method for controlling a direct current (DC) motor or generator, particularly those of the permanent magnet type. Due to functional differences between AC and DC generators, the described solution would not be operative for an AC generator.

US Patent Application No. 2004/0257050 describes a method and device for constant current generation, which attempts to overcome drawbacks associated with potentially variable shaft speed through controlling the current that is output by the generator, thereby achieving a constant level of output current. Therefore, the described invention relates to current stabilization which is relatively complex.

Various attempted solutions for achieving stabilized voltage output have included using inertia or friction as a mean of moderating the shaft speed fluctuations; using torque control in order to control the shaft speed; or converting the fluctuating AC electricity to DC electricity, and then converting it again into the standard grid AC power. Clearly all of these methods are very wasteful of energy.

In an effort to use sources of renewable energy, systems and devices have been introduced which use "natural" energy such as wind, through the use of wind turbines; sun, through the use of solar panels; water power, such as wave or tidal power; and the like. Wind energy may be particularly variable, given that wind tends to increase and decrease in power, and/or change direction, quite regularly.

However, all of the “natural” energy sources may be expected to suffer from instability of power levels. Thus, for renewable energy, the ability to convert non-stable mechanical power to stable electrical power has major demand in a variety of applications.

Various solutions have been proposed in this area to overcome the instability of renewable energy sources, particularly with regard to wind generation. For example, US Patent No. 7068015 provides a solution for wind power by adjusting the magnetic field according to the rotation speed of the wind turbine according to feedback determined by measuring output voltage or current. US Patent Application No. 2004/0119292 provides a method for controlling the shaft speed of the generator by controlling its torque, a solution which is disadvantageous as noted above. The taught method further requires a diode rectifier for operation, which is another disadvantage.

US Patent No. 5083039 controls the power output by controlling the magnetic field of the generator, by controlling the stator current. However, changes to the stator current cause changes to the generator torque. In order to compensate for changes to the torque, the shaft speed is controlled by changing the pitch of the “wings” or blades of the turbine, which may be disadvantageous due to wind conditions, and which is disadvantageous in any case because it requires an additional expenditure of energy. US Patent No. 6137187 is similarly disadvantageous as it requires a pitch control system.

SUMMARY OF THE INVENTION

The term "constant electrical output" means an alternating current output signal that has a constant peak voltage.

The present invention provides a system and method for sensing a rotation speed of a shaft that rotates at a variable rotation speed and controlling the magnetic field of the AC generator in response to the sensed speed. The controlling includes utilizing a DC generator that supplies a current to the AC generator. This current determines the magnetic field of the AC generator. The magnetic field can be controlled in a manner that maintains a peak voltage of an output signal of the AC generator substantially constant despite changes in the rotation speed of the shaft.

The electro magnetic force induced by an AC generator is governed by Faraday's law:

$$\mathbf{EMF=\acute{\omega}\ x\ L\ x\ B\ x\ sin(\theta)}$$

In which:

EMF (electromagnetic field) is the output voltage. $\acute{\omega}$ is the tangential speed of the winding.

L is the length of the winding that crosses the magnetic flux.

B is the magnetic field intensity.

sin(θ) is the sin of the angle between the winding & the magnetic flux.

The above equation indicates that the peak voltage of an AC output signal of the AC generator is dependent on the shaft rotation speed, which in turn depends upon the mechanical power used to rotate the shaft. If the level of mechanical power is variable then the shaft rotation speed is in turn variable. However, even if the shaft rotation speed is variable, the peak voltage should be maintained substantially constant.

Therefore, the present invention does not require the shaft rotation speed to be constant, which is useful for a wide variety of applications, including but not limited to power generation by renewable energy or "natural" energy sources or any other energy source having variable output. Instead, according to embodiments of the present invention, the measurement of the shaft rotation speed is used to control the magnetic field intensity (B) through a feedback or control mechanism (that includes a DC generator) according to the speed of rotation of the shaft, thereby providing a constant voltage output and hence stable power generation.

According to embodiments of the present invention, control of the magnetic field intensity of the AC generator is preferably provided with a DC generator, featuring a rotor winding connected to the rotor winding of the AC generator. The rotation speed of the shaft of the AC generator is measured; according to this measurement, the operation of the DC generator is then used to increase or decrease the magnetic field intensity, thereby maintaining a constant voltage output even if the rotation speed of the shaft varies. The DC generator optionally and preferably has a separate power source. Preferably the amount of power required for management and control of the voltage output is relatively low as compared to the output of the generator itself; for example, tests described below indicated that the control power required was less than 30W for a 5KW generator. Optionally and preferably, the rotor winding of the DC generator is connected to the rotor winding of the AC generator, for controlling the magnetic field of the AC generator.

A system for providing an alternating current (AC) output signal, the system includes: an AC generator that outputs an AC output signal and comprises an AC rotor that communicates with a shaft that rotates at a rotation speed; a speed sensor for sensing the rotation speed; and a controller for controlling a magnetic field of the AC generator in response to the rotation speed; wherein the controller comprises a direct current (DC) generator that generates a current that is provided to the AC generator so as to control the magnetic field of the AC generator.

Conveniently, the DC generator includes a DC rotor that communicates with the shaft.

Conveniently, the DC rotor is connected to the AC rotor.

Conveniently, the DC rotor is connected to the AC rotor by rigid wiring.

Conveniently, the DC generator comprises a DC stator that if fed by an excitation voltage that has an amplitude that is responsive to the rotation speed.

Conveniently, the controller includes a voltage regulation system that receives rotation speed information from the speed sensor and determines an amplitude of an excitation voltage to be provided to the DC generator.

Conveniently, the voltage regulation system determines the amplitude of the excitation voltage in response to a relationship between the rotation speed and a peak voltage of the AC output voltage.

Conveniently, the voltage regulation system includes: an analog to digital converter that converts analog rotation speed information to digital rotation speed information; a low pass filter for filtering the digital rotation speed information to provide filtered rotation speed information; a processor, for determining the excitation voltage in response to the filtered digital rotation speed information and to a relationship between the rotation speed and a peak voltage of the AC output voltage; and a digital to analog converter, for converting a digital control signal outputted from the processor to an analog control signal that controls the amplitude of the excitation voltage.

Conveniently, the system includes a speed sensor that generated digital rotation speed information.

Conveniently, the controller includes a voltage regulation system that receives rotation speed information from the speed sensor and a requested peak voltage of the AC output signal and determines an amplitude of an excitation voltage to be provided to the DC generator.

Conveniently, the shaft is rotated by a mechanical input element that is powered by a renewable energy source.

Conveniently, the renewable energy is selected from a group consisting of wind, water, solar and geothermal.

Conveniently, the system further includes a mechanical input element that rotates the rotor.

Conveniently, the system further includes a cooling fan that communicates with the shaft.

Conveniently, the controller controls the magnetic field of the AC generator so as to maintain a peak voltage of the AC output substantially constant despite changes in the rotation speed.

Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. The materials, methods, and examples provided herein are illustrative only and not intended to be limiting.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is herein described, by way of example only, with reference to the accompanying drawings. With specific reference now to the drawings in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the embodiments of the present invention only, and are presented in order to provide what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than is necessary for a fundamental understanding of the invention, the description taken with the drawings making apparent to those skilled in the art how the several forms of the invention may be embodied in practice.

In the drawings:

Figure 1 is of an exemplary, illustrative AC generator system according to the present invention;

Figure 2 is of an exemplary, illustrative method according to the present invention for control of the operation of the generator of Figure 1;

Figure 3 is a more detailed but still schematic diagram of a voltage regulation system according to the present invention;

Figure 4 is a schematic block diagram of an illustrative system according to the present invention for generation of a constant level of voltage by a generator that is at least partially powered by a renewable energy source or "natural" energy;

Figure 5 shows results of a test of an exemplary system according to the present invention;

Figure 6 illustrates in greater details a voltage regulation system and a rotation speed sensor, according to an embodiment of the invention;

Figure 7 illustrates in greater details a voltage regulation system and a rotation speed sensor, according to an embodiment of the invention;

Figure 8 illustrates in greater details a voltage regulation system and a rotation speed sensor, according to an embodiment of the invention;

Figures 9 and 10 illustrates the relationships between control current and rotation speed of the shaft for different values of the peak voltage of the AC output signal; and

Figure 11 illustrates a method according to an embodiment of the invention.

DESCRIPTION OF THE VARIOUS EMBODIMENTS

The present invention is of a system and device for providing constant voltage power (meaning – an alternating current output signal that has a substantially constant peak voltage) by an AC generator, through control of the magnetic field intensity of the AC generator, wherein the control utilizes a DC generator. The magnetic field intensity is controlled by a current supplied by the DC generator and according to the rotation speed of the shaft of the AC generator, such that variations of the rotation speed of the shaft are compensated by changes to the magnetic field intensity.

According to embodiments of the present invention, the DC generator, featuring a rotor winding electrically connected to the rotor winding of the AC generator. The rotation speed of the shaft of the AC generator is preferably measured; according to this measurement, the operation of the DC generator is then used to increase or decrease the magnetic field intensity, thereby maintaining a constant voltage output even if the rotation speed of the shaft varies.

Optionally and preferably, the rotor winding of the DC generator is connected to the rotor winding of the AC generator, for controlling the magnetic field of the AC generator.

The present invention may optionally be used with any type of mechanical power source, but is useful with regard to any mechanical power input source which is characterized by variability. Examples of such mechanical power input sources include but are not limited to any type of renewable or “natural” energy source, including but not limited to wind, water, solar or geothermal.

According to optional embodiments of the present invention, rather than providing a constant voltage output, optionally the magnetic field of the AC generator is controlled according to some criterion, such as a set point for example. The set point may optionally be a minimal required set point or a maximal permitted set point for the voltage output, and/or a within a range of permitted set point values.

The principles and operation of the present invention may be better understood with reference to the drawings and the accompanying description.

Referring now to the drawings, Figure 1 is of an exemplary, illustrative AC generator system **100** for generating a constant level of output voltage. Generator system **100** features a connection to a mechanical power from a power source (not shown), which causes a shaft **106** of an AC generator **108** to rotate. Shaft **106** also optionally features a cooling fan **104** for cooling the operations of generator system **100**. AC generator **108** is preferably a three phase, double winding generator, and features a rotor **110** and a stator **112**. Rotor **110** preferably features rotor winding **114** while stator **112** preferably features stator winding **116**.

An auxiliary DC generator **118** is optionally and preferably installed onto shaft **106** as shown, for controlling the intensity of the magnetic field of AC generator **108**. DC generator **118** features a DC rotor **120** with DC rotor winding **122**, and a DC stator **124** with DC stator winding **126**. DC rotor winding **122** is preferably connected to rotor winding **114** of AC generator **108** through a connector **130**, which preferably comprises some type of wiring, which may optionally be rigid wiring as DC rotor winding **122** rotates at the same speed as rotor winding **114**. DC stator winding **126** is connected to a DC power source **128** through a suitable connector **132** as is known in the art.

A rotation speed sensor **(also referred to as speed sensor) 134** is preferably connected to shaft **106**, for sensing the speed of rotation of shaft **106**. Rotation speed sensor **134** may optionally feature any suitable speed sensing device, including but not limited to a shaft encoder, resolver, tachometer, a Hall effect sensor or any type of proximity sensor that reads the motion of a mark point on the perimeter of shaft **106**. The mark point may be any type of marking, including but not limited to, a notch, screw or hole.

A voltage regulation system **136** is electrically connected to rotation speed sensor **134** and to DC power source **128**. Voltage regulation system **136** is preferably PLC (programmable logic controller) based, although any type of programmable or computational device, or digital circuit, or any device featuring software, firmware or hardware, or a combination thereof, could also optionally be used.

AC generator system **100** preferably operates as follows. Mechanical power (not shown) is supplied to shaft **106** of AC generator **108**, causing shaft **106** to rotate. An initial excitation voltage is induced on DC stator **124** by DC power source **128**, causing DC rotor **120** to be subjected to an external magnetic field. DC power source **128** also causes DC rotor **120** to rotate. The combination creates an EMF in DC generator **118**, thus current (also referred to as control current) flows from DC rotor **120** to rotor **110** of AC generator **108**, thus creating a rotating magnetic field in rotor **110**. As a result, an EMF is created in the output of AC generator **108** (ie AC generator **108** generates electricity).

Rotation speed sensor **134** senses the speed of rotation of shaft **106**. This information is fed to voltage regulation system **136**, which controls DC power source **128** in order to change the excitation voltage in DC stator **124**, thereby changing the EMF output by DC generator **118**. In turn, this controls the magnetic field intensity of AC generator **108**, by changing the current in rotor winding **114**.

The excitation voltage is optionally and preferably determined by voltage regulation system **136** according to a method shown in Figure 2. Figure 2 is of an exemplary, illustrative method according to the present invention for control of the operation of the generator of Figure 1. As shown, in stage 1, the actual rotation speed (also referred to as shaft speed) of the AC generator shaft is measured by the rotation speed sensor. In stage 2, the voltage regulation system changes the value of the DC power source control input, which preferably causes the excitation voltage of the DC stator to be changed. Stage 1 is then repeated at least once, although optionally and preferably both stages are repeated as needed.

Preferably, initially the output voltage is measured in relation to the rotation speed in order to define the control voltage curve for a particular generator. Once this curve has been established for the generator, it is used for performing the above method.

The method may optionally also be used for changing the "set point" of the output signal of the AC generator. For example, such a method could optionally be used to increase or decrease the peak voltage of the output signal to be provided by the AC generator. Optionally, increasing or decreasing the peak voltage of the output signal could be useful under a variety of circumstances, for example if the level of input mechanical power to the AC generator were to change. As described in greater detail below, such changes of input mechanical power may occur with regard to any type of energy source, but may be particularly prevalent with regard to renewable energy sources such as wind power or other types of "natural" energy sources. Preferably, such increasing or decreasing the level of output voltage is performed for any mechanical power input source which is characterized by variability.

Figure 3 is a more detailed but still schematic diagram of a voltage regulation system according to the present invention. In stage 1, as previously described, the control voltage curve is determined for each generator system, preferably during system integration. This stage is not necessarily repeated once the system is operational.

Stages 2-5 are preferably repeated at least once and are more preferably performed continuously as necessary, as a loop. In stage 2, the AC generator is operational and the AC generator's shaft is rotating. In stage 3, rotation speed of the shaft is measured by the rotation speed sensor as described in Figure 1. In stage 4, using the rotation speed of the shaft and the control voltage curve, the amount of control voltage to be output is determined. In stage 5, the control voltage is output by the control voltage output generator, which as described in Figure 1, is preferably an associated DC generator.

Figure 4 is a schematic block diagram of an illustrative system according to the present invention for generation of a constant level of voltage by a generator that is at least partially powered by a renewable energy source or "natural" energy. As shown, a system **400** features a mechanical power source **402**, which is preferably a device powered by some type of renewable energy source or "natural" energy, optionally and preferably selected from the group consisting of wind, solar, water and geothermal. System **400** also preferably features an AC generator system **404**, which may for example be implemented as described with regard to Figures 1 and/or 2 and/or 3.

Mechanical power source **402** is mechanically connected to a shaft **406** of an AC generator **408** which is part of AC generator system **404**, thereby causing shaft **406** to rotate. Mechanical power source **402** is optionally and preferably a variable power source, in the sense that the output level of mechanical power may optionally be variable. Such variation causes variation in the speed of rotation of shaft **406**. However, a voltage regulation system **410** of AC generator system **404** controls the magnetic field in AC generator **408**, such that AC generator system **404** provides an AC output signal that has a peak voltage that is maintained in a constant level, regardless of any variation of the speed of rotation of shaft **406**.

Among the many advantages of the exemplary embodiment of the present invention shown in Figure 4 is that the provision of a constant peak voltage of the AC output signal may be made without altering or affecting the structure or function of the wind, water (hydroelectric), solar, geothermal or other type of turbine. Therefore, the function and design of the turbine itself may be selected for most effective capture of energy from the renewable energy source. No background art reference teaches or suggests such a system or device for generating a constant level of output voltage from a renewable energy source.

EXAMPLE 1

TESTING OF AN ILLUSTRATIVE SYSTEM

This Example describes a test performed on an exemplary, illustrative non-limiting system according to the present invention. The system featured a hybrid, dual winding three phase generator as is known in the art, which includes both a DC generator and an AC generator, product number ECO3-2S4 (Mecc Alte S.p.A., Italy); and a voltage regulation system based on a CQM-45 (Omron Inc., USA) Programmable Logic Controller (PLC). The set point voltage of the system was 285 Vac. The AC generator was powered by an electric motor connected to a variable speed motor driver. The speed of rotation of the AC generator shaft was then altered according to the speed of the motor. For each rotation speed, the excitation voltage of the auxiliary DC generator was changed, until the peak voltage of the AC output reached the set point value (285Vac).

Figure 5 shows the auxiliary excitation voltage values of the DC generator according to the speed of the shaft of the AC generator, as required to maintain a constant voltage output by the AC generator.

Figure 6 illustrates in greater detail voltage regulation system 136 and rotation speed sensor 134, according to an embodiment of the invention.

Rotation speed sensor 134 provides an analog rotation speed information to analog to digital converter 161 that converts the analog rotation speed information to digital rotation speed information. The digital rotation speed information is provided to low pass filter 162 that filters the digital rotation speed information to provide filtered rotation speed information. Low pass filter 162 can apply a Fast Fourier Transformation filtering process but this is not necessarily so.

Processor, such as FPGA 164 determines the excitation voltage in response to the filtered digital rotation speed information and to a relationship between the rotation speed and a peak voltage of the AC output voltage. Information representing this relationship can be stored in the FPGA, wherein instructions that are executed by FPGA can be stored in a memory unit such as EPROM 165.

Processor 164 outputs a digital control signal that represents the determination to digital to analog converter 166. Digital to analog converter 166 converts the digital control signal to an analog control signal that controls the amplitude of the excitation voltage. The analog control signal is fed to current driver 168 that provides a current signal that is provided to DC power source 128 and determines the excitation voltage outputted by power source 128. The signal outputted by current driver 168 or the analog control signal can be measured by voltage gauge 171 and displayed on a display of the voltage gauge. A multiplexer 169 or other sampling circuit can be provided between current driver 168 and the output port of voltage regulation system 136 in order to enable such a measurement as well as the provision of the current signal to DC power source 128.

Conveniently, digital to analog converter 166 includes a potentiometer that is used for determining the output range of the digital to analog converter 166, especially for allowing it to output a zero voltage analog control signal.

Protocol converter 163 or another port or interface can be used for providing to voltage regulation system 136 the required peak voltage.

A port or an interface (or an additional port or interface) can be used for providing web based management, as illustrated by figure 8. A web based management entity 175 of voltage regulation system 136 can permit data regarding rotation speed measurements and/or measurements of the analog signal outputted to DC power source 128 to be output to one or more external devices, and/or to permit one or more interactions of a user with the voltage regulation system 136. Web based management entity 175 can be software, firmware, hardware or a combination thereof.

Referring back to figure 6, voltage regulation system 136 can be mounted on a printed circuit board. Additionally or alternatively it can communicate with a web server (not shown) which can provide one or more web pages. These web pages act as an interface for the voltage regulation system 136 for the user, for example for simple configuration options, as is known in the art.

Voltage regulation system 136 can output information to a display such as rotation speed display 172 as well as to a display of voltage gauge 171 or a combination thereof. The information can be provided via a port or an interface.

According to another embodiment of the invention the rotation speed sensor provides digital rotation speed information and not an analog rotation speed information. Figure 7 illustrates rotation speed sensor as including incremental encoder 134'. Incremental encoder 134' generates digital rotation speed information thus various components (such as analog to digital converter 161 and digital low pass filter 162) of voltage regulation system 136 are not required.

Figures 9 and 10 illustrate the relationships between control current and rotation speed of the shaft for different values of the peak voltage of the AC output signal, wherein the curves in figure 10 correspond to the values included in the table of figure 9..

Multiple curves represent the relationship between control current and rotation speed of the shaft for different peak voltages of the AC output signal.

Figure 11 illustrates method 300 according to an embodiment of the invention.

Method 300 starts by stage 310 or by stage 320.

Stage 310 includes determining a requested peak voltage of an AC output signal to be outputted by a AC generator.

Stage 320 includes receiving information representative of a requested peak voltage of an AC output signal to be outputted by the AC generator.

Stages 310 and 320 are followed by stage 330 of sensing a rotation speed of a shaft.

Method 300 can include rotating the shaft by a mechanical input element. This stage is not shown for simplicity of explanation. The shaft can be rotated by a mechanical input element that is powered by a renewable energy source. The renewable energy can be wind, water, solar or a geothermal energy source.

Stage 330 is followed by stage 340 of controlling a magnetic field of an AC generator in response to the rotation speed.

According to various embodiments of the invention, stage 340 can include at least one of the following stages or a combination thereof:

(i) Stage 342 of determining an amplitude of the excitation voltage to be provided to a DC stator of a DC generator in response to a relationship between the rotation speed and a peak voltage of the AC output voltage. The DC generator can have a DC rotor that communicates with the shaft. The DC rotor can be connected to the AC rotor, for example by rigid wiring. The amplitude can be determined so as to maintain a peak voltage of the AC output signal substantially constant despite changes in the rotation speed.

(ii) Stage 344 of feeding the DC stator of the DC generator by the excitation voltage, wherein the excitation voltage has an amplitude that is responsive to the rotation speed.

(i) Stage 346 of providing a control current by the direct current (DC) generator to the AC generator; wherein the control current is responsive to the amplitude of the excitation voltage. This control current controls the magnetic field of the AC generator.

Stage 340 is followed by stage 350 of outputting, by the AC generator, an AC output voltage. The peak voltage of the AC output signal is responsive to the magnetic field of the AC generator. The AC generator includes an AC rotor that communicates with the shaft.

Stage 342 of the determining can include at least one of the following stages or a combination thereof: (i) stage 342(1) of receiving rotation speed information from the speed sensor; (ii) stage 342(2) of receiving a requested peak voltage of the AC output voltage; and (iii) stage 342(3) of determining the amplitude of the excitation voltage in response to a relationship between control current and rotation speed of the shaft; (iv) stage 342(4) of determining the amplitude of the excitation voltage in response to a relationship between control current values, rotation speed of the shaft and a requested peak voltage of the AC output voltage.

It is noted that by changing the requested peak voltage of the AC output signal, the "set point" of the system is changed. When the peak voltage is changed the determination should select the relevant curve (or formula). Accordingly, stage 344 can involve selecting between curves such as those illustrated in figure 10.

According to an embodiment of the invention the determination is executed in the digital domain. Thus, stage 344 can include: (i) converting analog rotation speed information to digital rotation speed information; (ii) low pass filtering the digital rotation speed information to provide filtered rotation speed information; (iii) determining the excitation voltage in response to the filtered digital rotation speed information and to a relationship between the rotation speed and a peak voltage of the AC output voltage; (iv) generating a digital control signal that is responsive to the determining; and (v) converting the digital control signal to an analog signal that controls the amplitude of the excitation voltage.

Method 300 can also include stage 370 of activating a cooling fan that communicates with the shaft. The cooling fan is activated by the shaft. Method 300 can also include stage 380 of displaying information.

It is noted that the mentioned above system and method alter the magnetic field of the AC generator without measuring the current or voltage generated by the AC generator. There is no need to estimate the power outputted by the AC generator or to compare the estimated power to a reference power. This simplifies the control scheme.

While the invention has been described with respect to a limited number of embodiments, it will be appreciated that many variations, modifications and other applications of the invention may be made.

What is claimed is:

1. A system for providing an alternating current (AC) voltage, the system comprises:

an AC generator that outputs an AC output signal and comprises an AC rotor that communicates with a shaft rotates at a rotation speed;

a speed sensor for sensing the rotation speed; and

a controller for controlling a magnetic field of the AC generator in response to the rotation speed;

wherein the controller comprises a direct current (DC) generator that generates a current that is provided to the AC generator so as to control the magnetic field of the AC generator.

2. The system according to claim 1 wherein the DC generator comprises a DC rotor that communicates with the shaft.

3. The system according to claim 2 wherein the DC rotor is coupled to the AC rotor.

4. The system according to claim 2 wherein the DC rotor is coupled to the AC rotor by rigid wiring.

5. The system according to claim 1 wherein the DC generator comprises a DC stator that if fed by an excitation voltage that has an amplitude that is responsive to the rotation speed.

6. The system according to claim 1 wherein the controller comprises a voltage regulation system that receives rotation speed information from the speed sensor

and determines an amplitude of an excitation voltage to be provided to the DC generator.

7. The system according to claim 6 wherein the voltage regulation system determines that amplitude of the excitation voltage in response to a relationship between the rotation speed and a peak voltage of the AC output voltage.

8. The system according to claim 6 wherein the voltage regulation system comprises:

an analog to digital converter that converts analog rotation speed information to digital rotation speed information;

a low pass filter for filtering the digital rotation speed information to provide filtered rotation speed information;

a processor, for determining the excitation voltage in response to the filtered digital rotation speed information and to a relationship between the rotation speed and a peak voltage of the AC output voltage; and

a digital to analog converter, for converting a digital control signal outputted from the processor to an analog signal that controls the amplitude of the excitation voltage.

9. The system according to claim comprising a rotation speed sensor that generated digital rotation speed information.

10. The system according to claim 1 wherein the controller comprises a voltage regulation system that receives rotation speed information from the speed sensor and a requested peak voltage of the AC output signaland determines an amplitude of an excitation voltage to be provided to the DC generator.

11. The system according to claim 1 wherein the shaft is rotated by a mechanical input element that is powered by a renewable energy source.

12. The system according to claim 1 wherein the renewable energy is selected from a group consisting of wind, water, solar and geothermal.

13. The system according to claim 1 further comprising a mechanical input element that rotates the rotor.

14. The system according to claim 1 further comprising a cooling fan that communicates with the shaft.

15. The system according to claim 1 wherein the controller controls the magnetic field of the AC generator so as to maintain a peak voltage of the AC output signalsubstantially constant despite changes in the rotation speed.

16. The system according to claim 15 wherein the DC generator comprises a DC rotor that communicates with the shaft.

17. The system according to claim 16 wherein the DC rotor is coupled to the AC rotor.

18. The system according to claim 15 wherein the DC generator comprises a DC stator that if fed by an excitation voltage that has an amplitude that is responsive to the rotation speed.

19. The system according to claim 15 wherein the controller comprises a voltage regulation system that receives rotation speed information from the speed sensor and determines an amplitude of an excitation voltage to be provided to the DC generator.

20. The system according to claim 15 wherein the shaft is rotated by a mechanical input element that is powered by a renewable energy source.

21. A method for providing an alternating current (AC) voltage, the method comprises:

sensing a rotation speed of a shaft;

controlling a magnetic field of an AC generator in response to the rotation speed; wherein the controlling comprises providing a current by a direct current (DC) generator to the AC generator; and

outputting, by the AC generator, an AC output voltage; wherein a peak voltage of the AC output signalis responsive to the magnetic field of the AC generator; wherein the AC generator comprises an AC rotor that communicates with the shaft.

22. The method according to claim 21 wherein the controlling comprises providing the current by the DC generator; wherein the DC generator has a DC rotor that communicates with the shaft.

23. The method according to claim 22 wherein the DC rotor is coupled to the AC rotor.

24. The method according to claim 21 wherein the DC rotor of the DC generator is coupled to the AC rotor by rigid wiring.

25. The method according to claim 21 comprising feeding a DC stator of the DC generator by an excitation voltage that has an amplitude that is responsive to the rotation speed.

26. The method according to claim 21 comprising receiving rotation speed information from the speed sensor and determining an amplitude of an excitation voltage to be provided to the DC generator.

27. The method according to claim 26 comprising determining the amplitude of the excitation voltage in response to a relationship between the rotation speed and a peak voltage of the AC output voltage.

28. The method according to claim 26 comprising: converting analog rotation speed information to digital rotation speed information; low pass filtering the digital rotation speed information to provide filtered rotation speed information; determining the excitation voltage in response to the filtered digital rotation speed information and to a relationship between the rotation speed and a peak voltage of the AC output voltage; generating a digital control signal that is responsive to the determining; and converting the digital control signal to an analog signal that controls the amplitude of the excitation voltage.

29. The method according to claim 28 comprising providing a digital rotation speed information by a rotation speed sensor.

30. The method according to claim 28 comprising receiving rotation speed information from the speed sensor and a requested peak voltage of the AC output signal and determining an amplitude of an excitation voltage to be provided to the DC generator.

31. The method according to claim 21 wherein the shaft is rotated by a mechanical input element that is powered by a renewable energy source.

32. The method according to claim 21 wherein the renewable energy is selected from a group consisting of wind, water, solar and geothermal.

33. The method according to claim 21 comprising rotating the shaft by a mechanical input element.

34. The method according to claim 21 comprising activating a cooling fan that communicates with the shaft.

35. The method according to claim 21 comprising controlling the magnetic field of the AC generator so as to maintain a peak voltage of the AC output signal substantially constant despite changes in the rotation speed.

36. The method according to claim 34 wherein the DC generator comprises a DC rotor that communicates with the shaft.

37. The method according to claim 35 wherein the DC rotor is coupled to the AC rotor.

38. The method according to claim 34 wherein the shaft is rotated by a mechanical input element that is powered by a renewable energy source.

39. The method according to claim 34 comprising feeding a DC stator of the DC generator by an excitation voltage that has an amplitude that is responsive to the rotation speed.

40. The method according to claim 34 comprising receiving rotation speed information from the speed sensor and determining an amplitude of an excitation voltage to be provided to the DC generator.

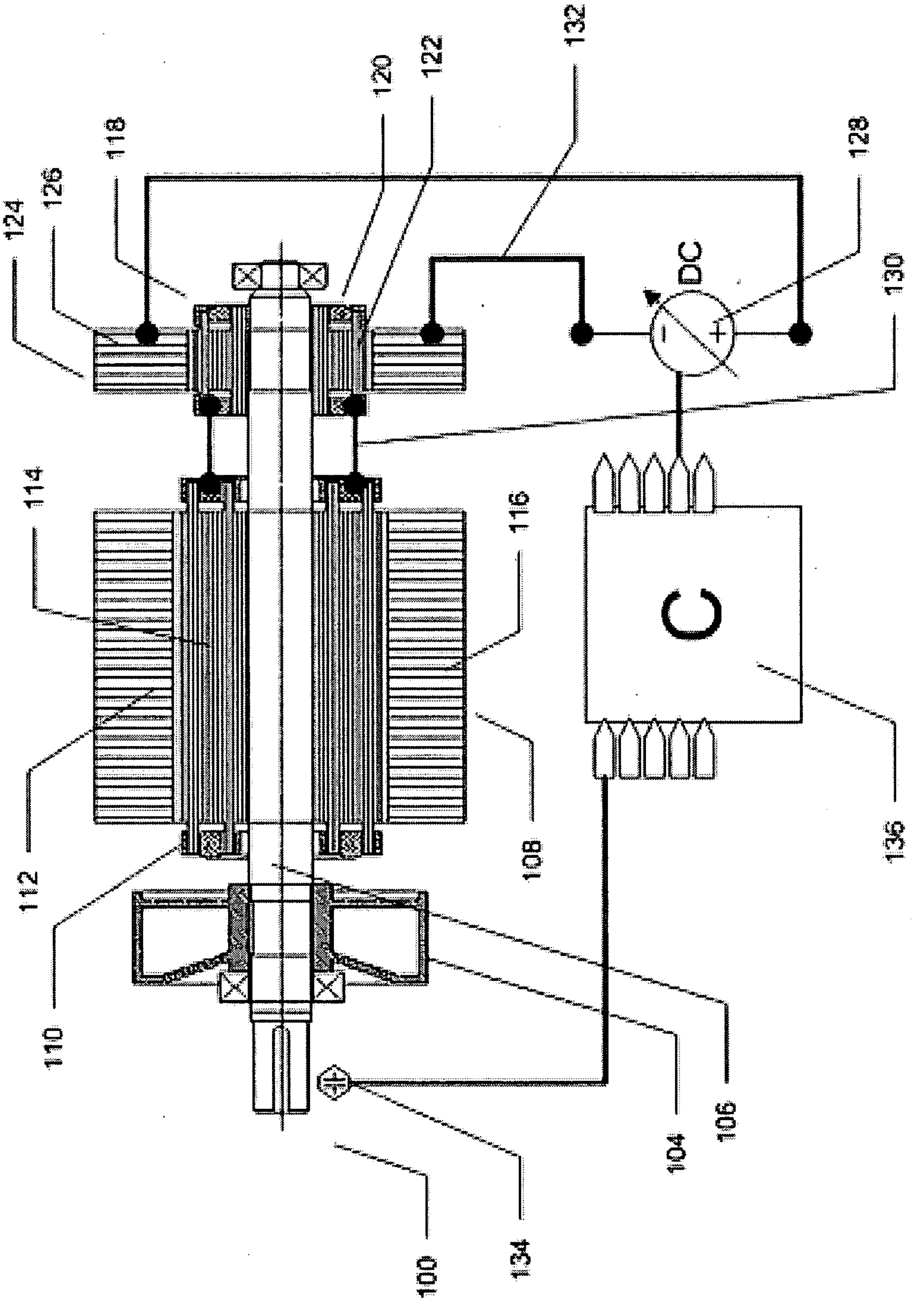

124
126
118
120
122
132
128
DC
-
+
130
114
116
C
112
108
136
110
106
104
134
100

Figure 1

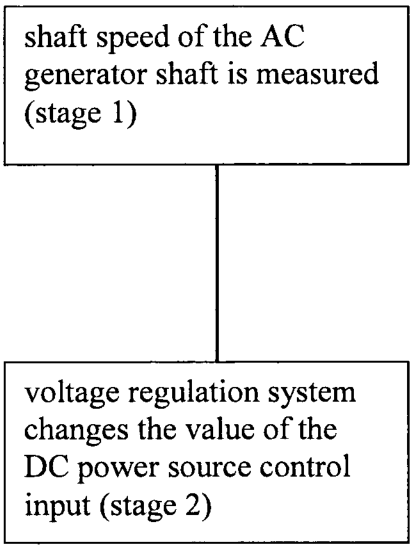
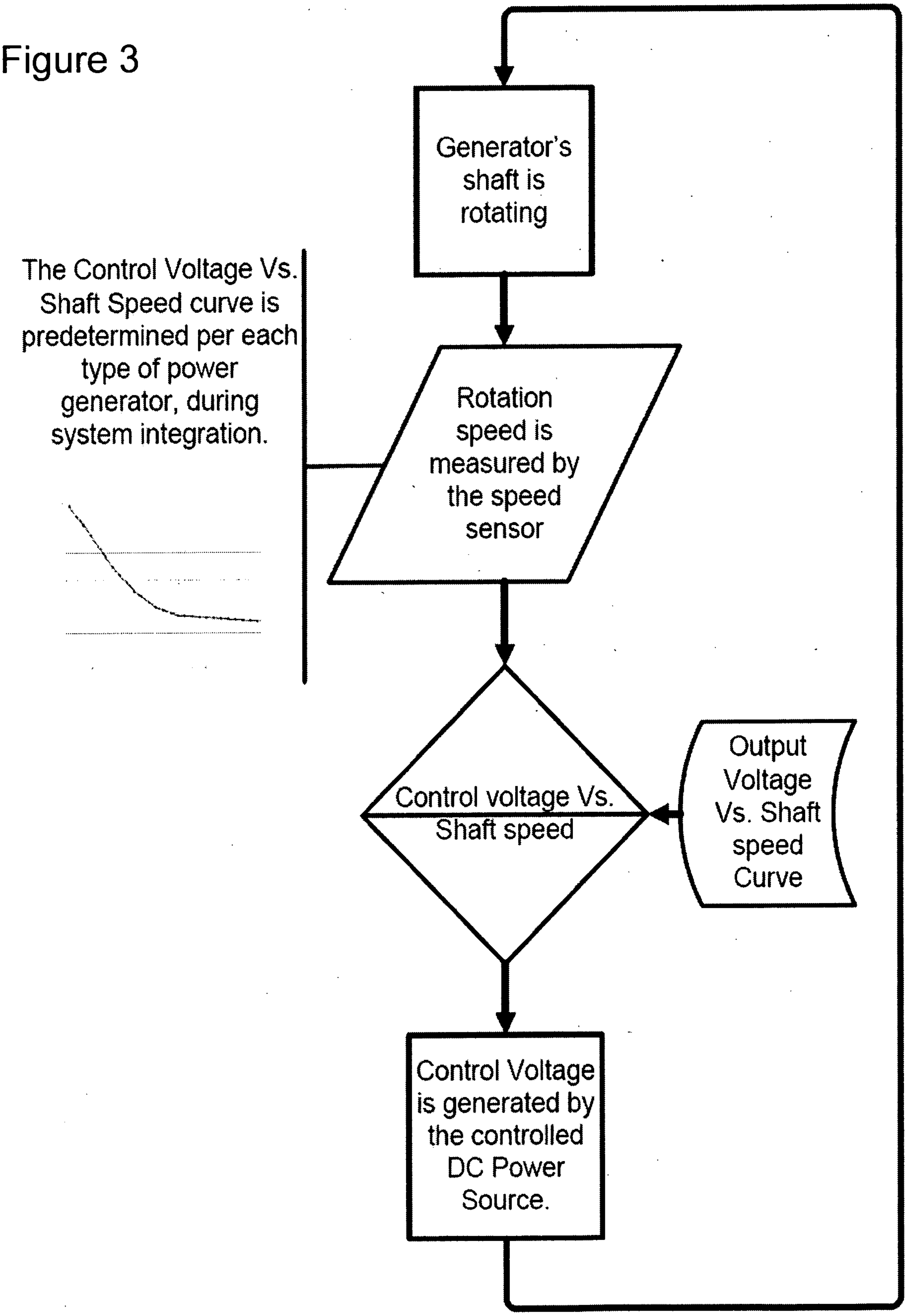

shaft speed of the AC generator shaft is measured (stage 1)
voltage regulation system changes the value of the DC power source control input (stage 2)

Figure 2

Figure 3


Generator's shaft is rotating
The Control Voltage Vs. Shaft Speed curve is predetermined per each type of power generator, during system integration.
Rotation speed is measured by the speed sensor
Control voltage Vs. Shaft speed
Output Voltage Vs. Shaft speed Curve
Control Voltage is generated by the controlled DC Power Source.

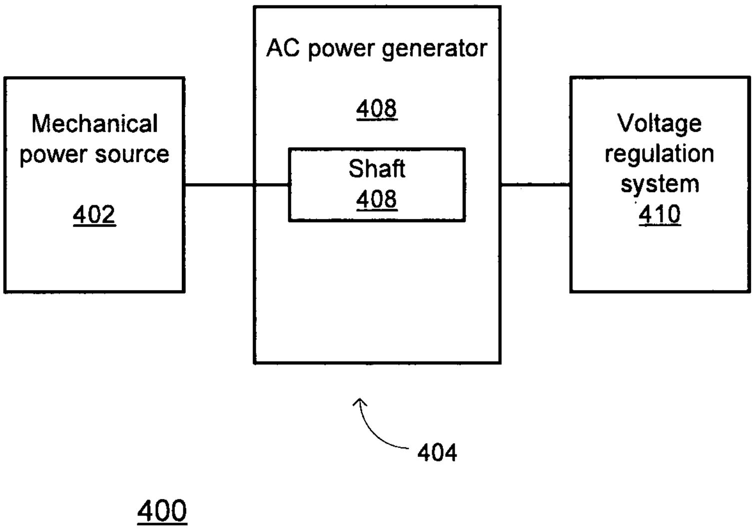

Mechanical power source
402
AC power generator
408
Shaft
408
Voltage regulation system
410
404
400

Figure 4

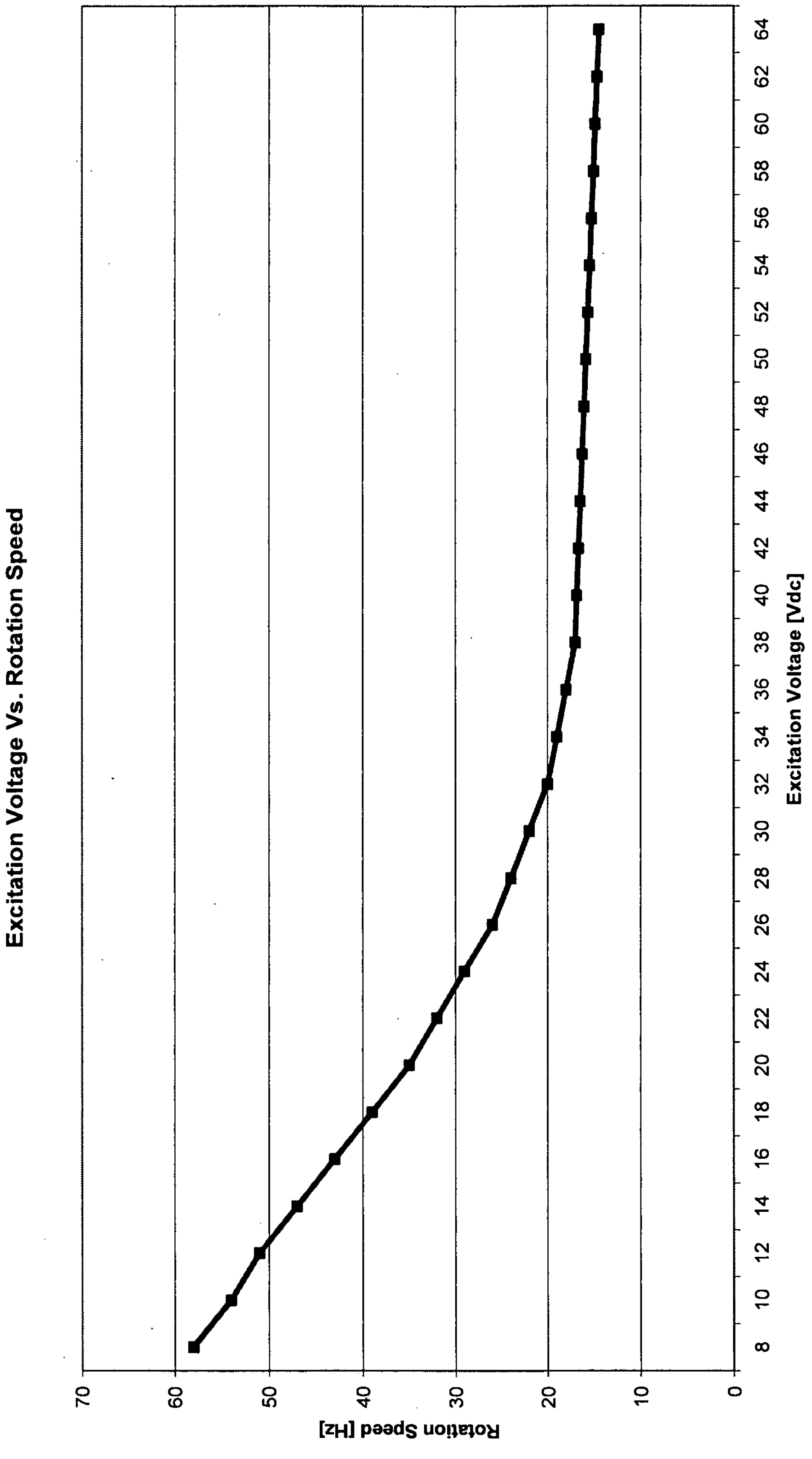

Excitation Voltage Vs. Rotation Speed
Rotation Speed [Hz]
70
60
50
40
30
20
10
0
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
54
56
58
60
62
64
Excitation Voltage [Vdc]

Figure 5

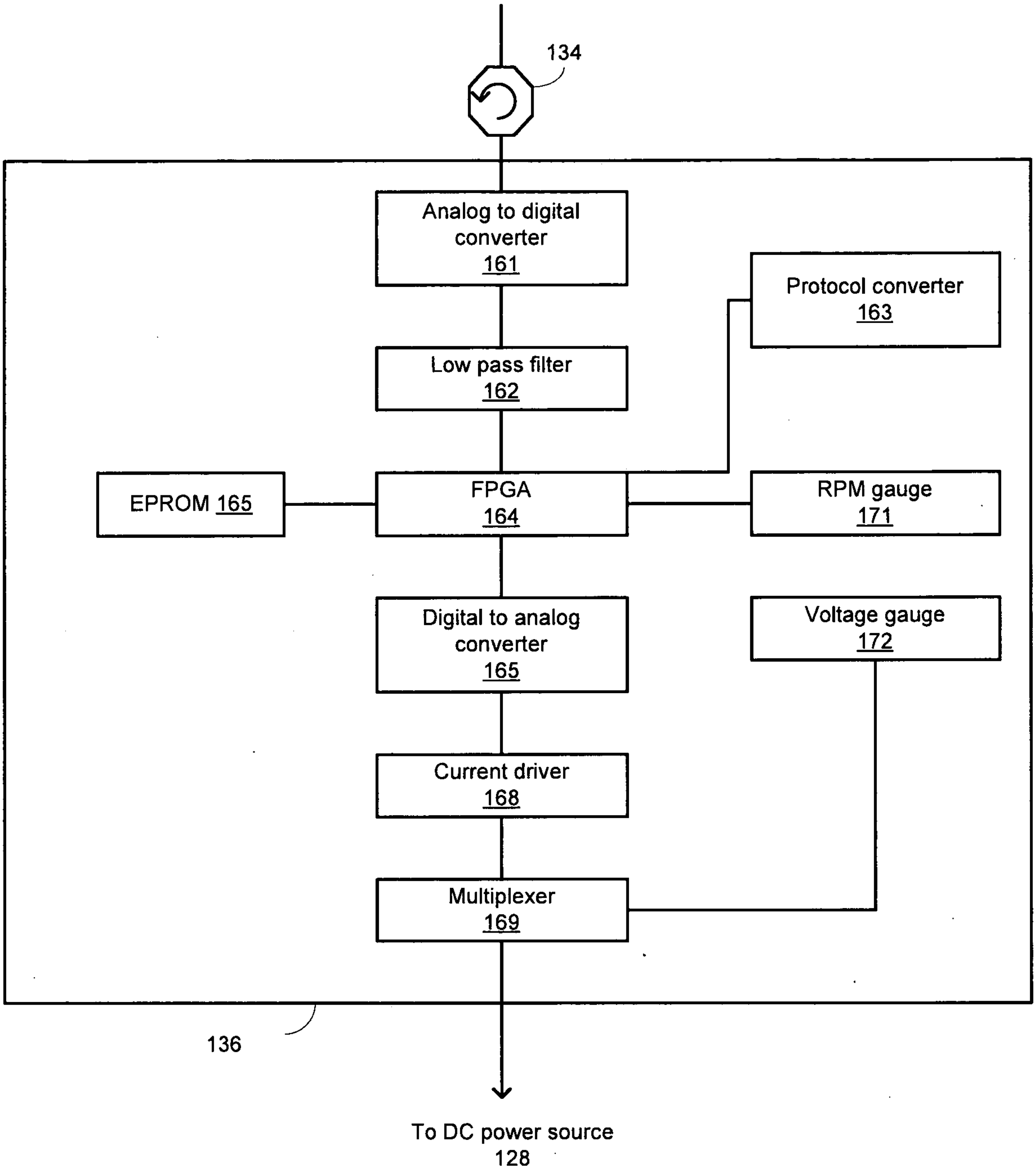

134
Analog to digital converter 161
Low pass filter 162
Protocol converter 163
EPROM 165
FPGA 164
RPM gauge 171
Digital to analog converter 165
Voltage gauge 172
Current driver 168
Multiplexer 169
136
To DC power source 128

Figure 6

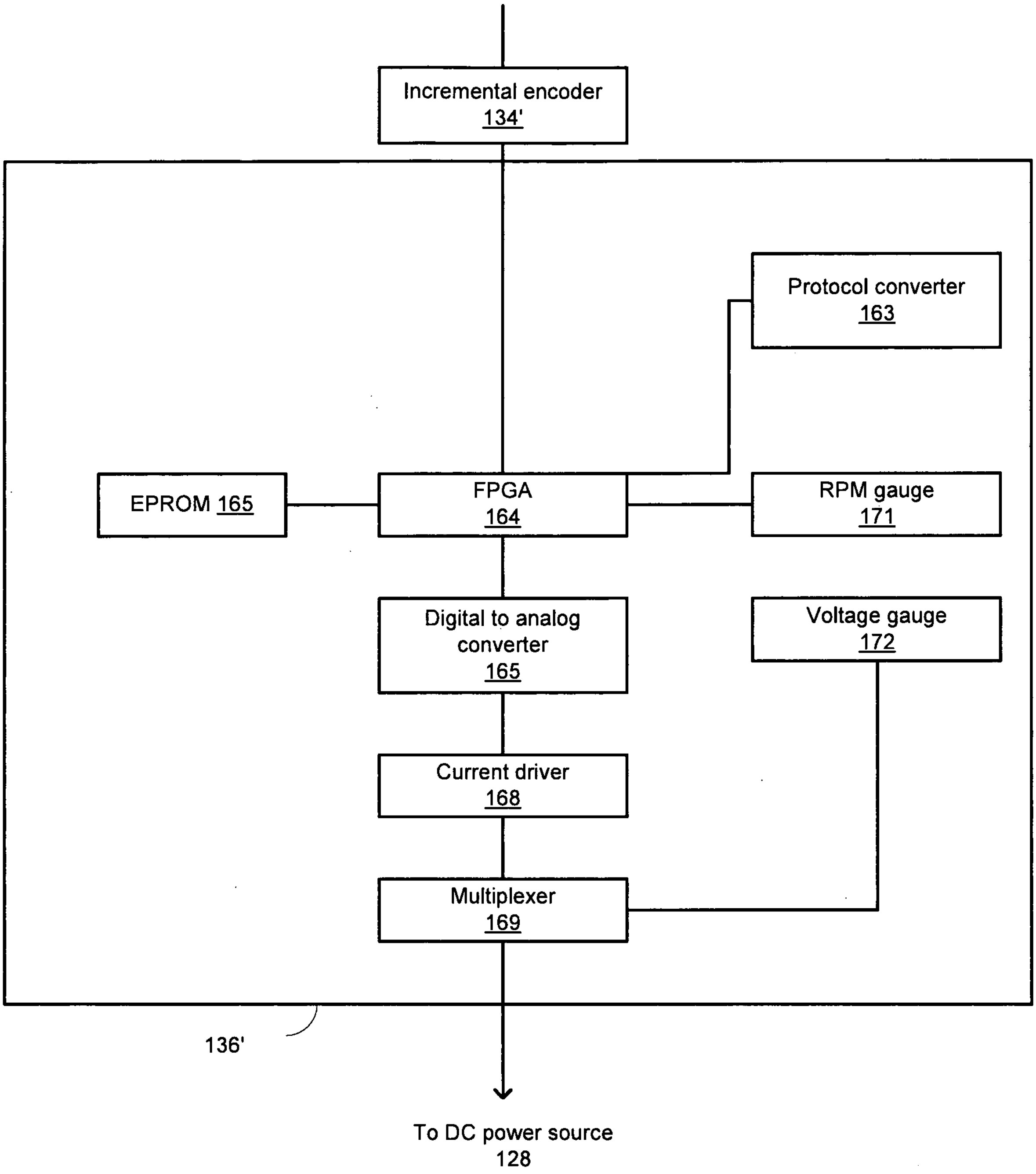

Incremental encoder
134'
Protocol converter
163
EPROM 165
FPGA
164
RPM gauge
171
Digital to analog
converter
165
Voltage gauge
172
Current driver
168
Multiplexer
169
136'
To DC power source
128

Figure 7

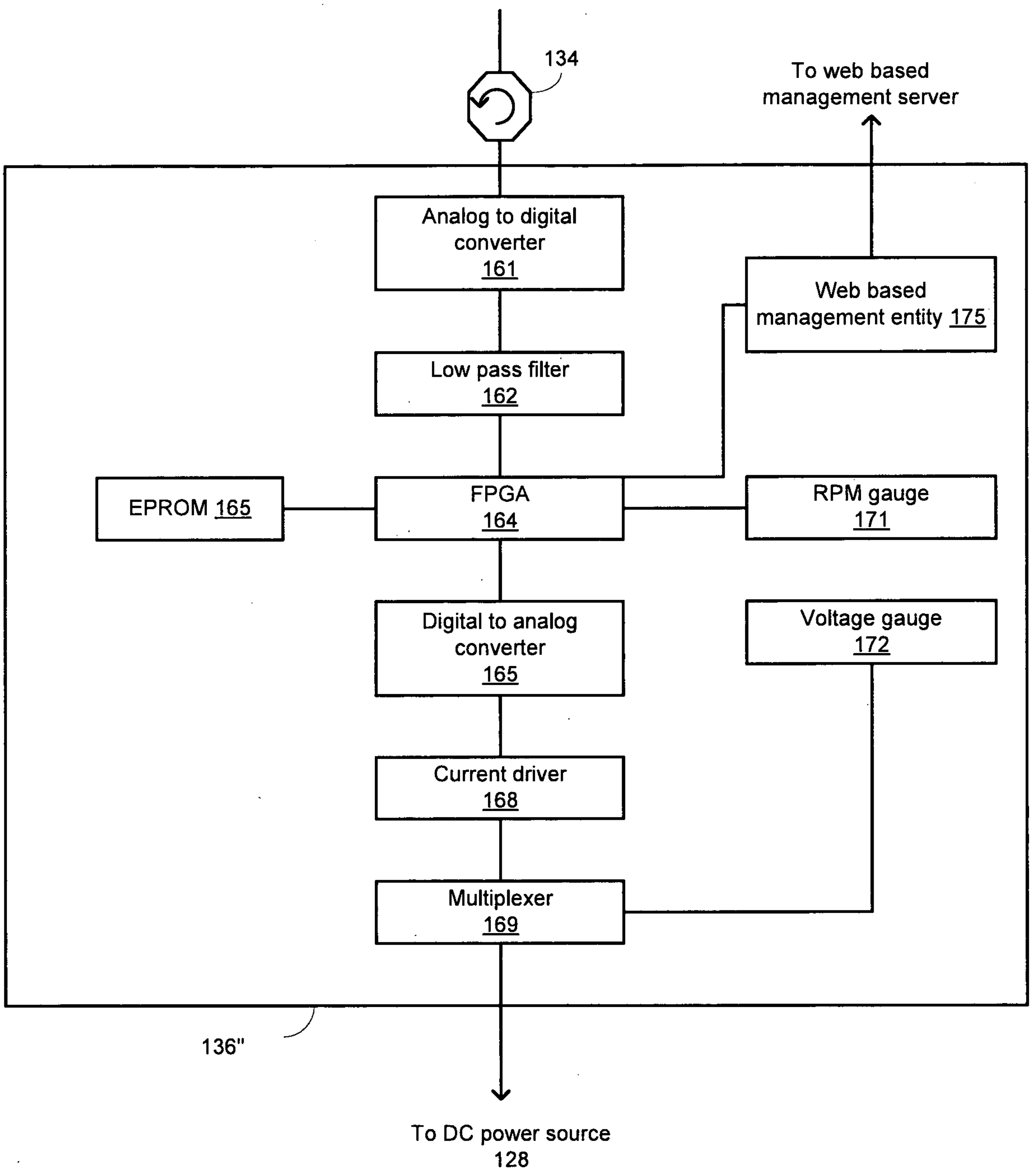

134
To web based management server
Analog to digital converter 161
Web based management entity 175
Low pass filter 162
EPROM 165
FPGA 164
RPM gauge 171
Digital to analog converter 165
Voltage gauge 172
Current driver 168
Multiplexer 169
136"
To DC power source 128

Figure 8

Output Voltage	200Vac	225Vac	250Vac	275Vac	300Vac
RPM	Exciter's Control Voltage [Vdc]				
632	37.620				
712	13.965	25.650			
792	9.833	13.110	22.230		
872	6.840	9.006	12.730	19.950	
952	5.454	6.609	8.550	11.828	18.810
1032	4.458	5.281	6.538	8.550	12.730
1112	3.720	4.470	5.281	6.538	8.871
1192	3.173	3.797	4.521	5.320	6.508
1272	2.706	3.176	3.762	4.475	5.130
1352	2.334	2.787	3.330	3.827	4.506
1432	1.976	2.391	2.806	3.221	3.767
1565	0.855	1.710	0.718	1.094	2.736
1698	-2.001	-2.052	-2.394	0.359	0.855
1831	-2.394	-2.702	-3.591	-4.275	0.359
1964	-2.770	-3.283	-3.933	-5.814	-1.300
2097	-3.300	-4.104	-4.685	-6.737	-3.146
2230	-3.813	-4.617	-5.472	-9.063	-4.019
2363	-4.617	-5.472	-7.045	-12.654	-4.720
2496	-5.540	-8.721	-8.892	-21.204	-5.523

Figure 9

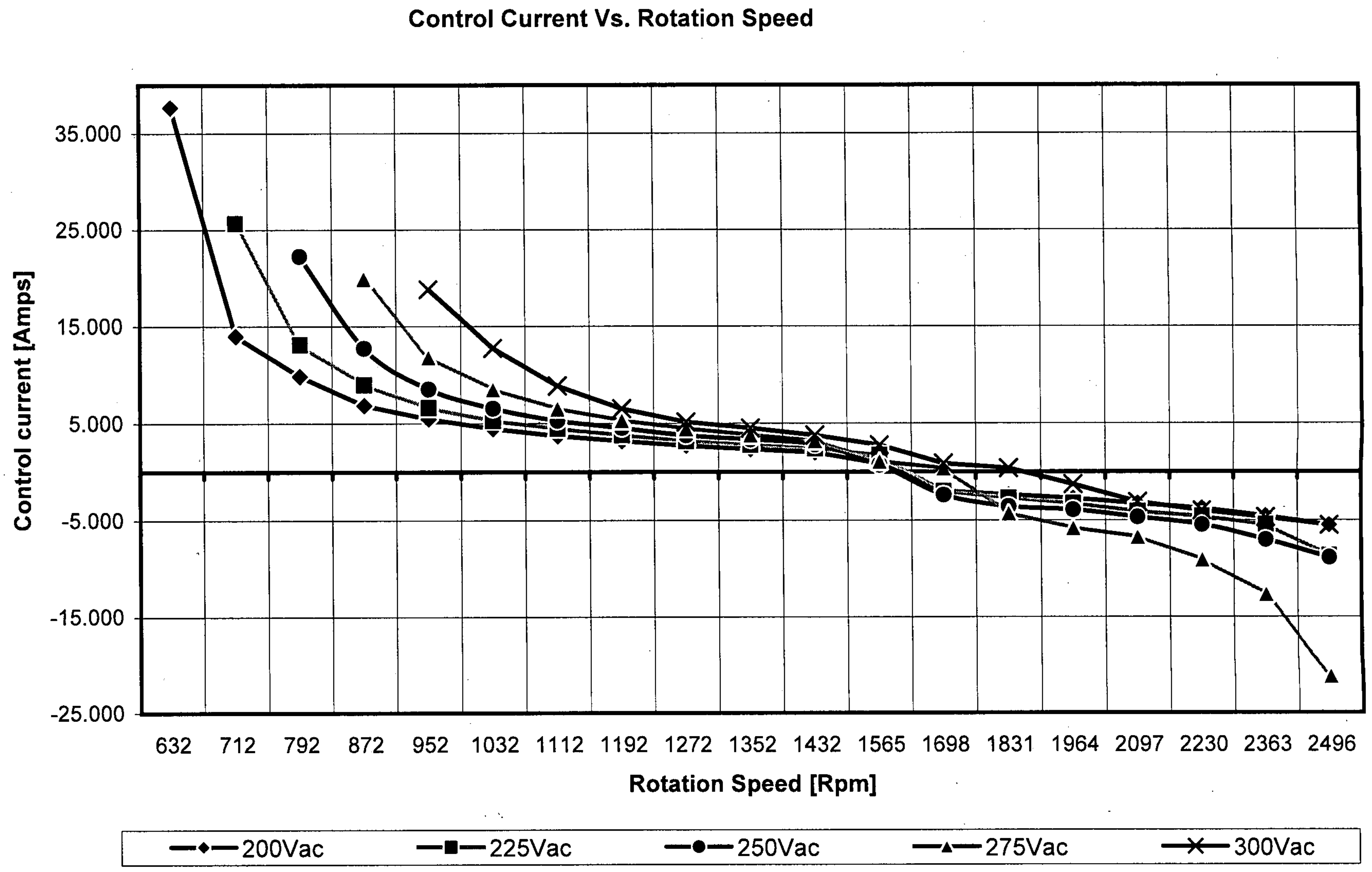
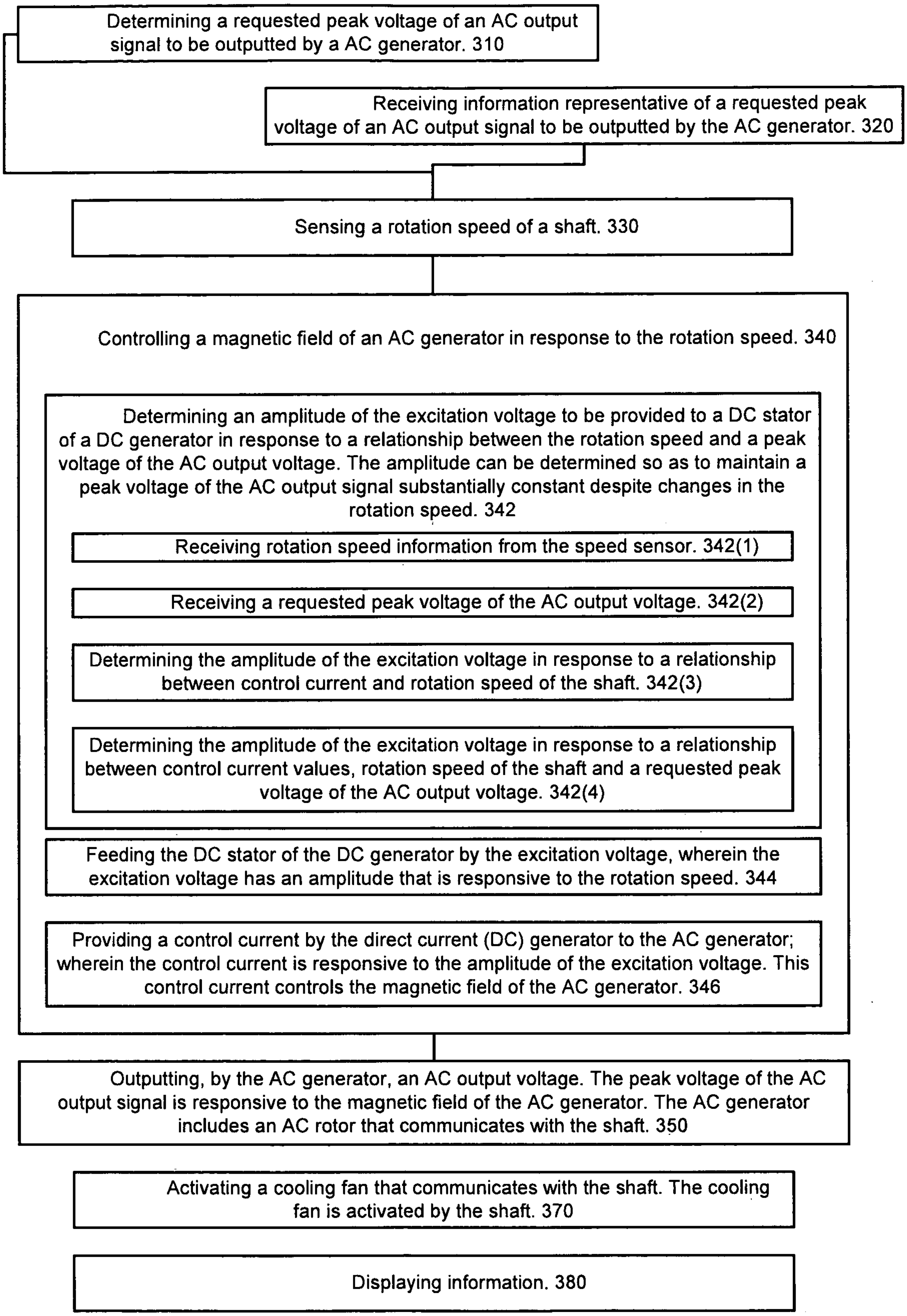

Control Current Vs. Rotation Speed
Control current [Amps]
35.000
25.000
15.000
5.000
-5.000
-15.000
-25.000
632
712
792
872
952
1032
1112
1192
1272
1352
1432
1565
1698
1831
1964
2097
2230
2363
2496
Rotation Speed [Rpm]
200Vac
225Vac
250Vac
275Vac
300Vac

Fig 10.



Determining a requested peak voltage of an AC output signal to be outputted by a AC generator. 310

Receiving information representative of a requested peak voltage of an AC output signal to be outputted by the AC generator. 320

Sensing a rotation speed of a shaft. 330

Controlling a magnetic field of an AC generator in response to the rotation speed. 340

Determining an amplitude of the excitation voltage to be provided to a DC stator of a DC generator in response to a relationship between the rotation speed and a peak voltage of the AC output voltage. The amplitude can be determined so as to maintain a peak voltage of the AC output signal substantially constant despite changes in the rotation speed. 342

Receiving rotation speed information from the speed sensor. 342(1)

Receiving a requested peak voltage of the AC output voltage. 342(2)

Determining the amplitude of the excitation voltage in response to a relationship between control current and rotation speed of the shaft. 342(3)

Determining the amplitude of the excitation voltage in response to a relationship between control current values, rotation speed of the shaft and a requested peak voltage of the AC output voltage. 342(4)

Feeding the DC stator of the DC generator by the excitation voltage, wherein the excitation voltage has an amplitude that is responsive to the rotation speed. 344

Providing a control current by the direct current (DC) generator to the AC generator; wherein the control current is responsive to the amplitude of the excitation voltage. This control current controls the magnetic field of the AC generator. 346

Outputting, by the AC generator, an AC output voltage. The peak voltage of the AC output signal is responsive to the magnetic field of the AC generator. The AC generator includes an AC rotor that communicates with the shaft. 350

Activating a cooling fan that communicates with the shaft. The cooling fan is activated by the shaft. 370

Displaying information. 380

Figure 11