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(71) Applicant *(for all designated States except US)*: **VARIABLE WIND SOLUTIONS LTD.** [—/IL]; 28 Yitzhak Sade st., PO Box 51701, Tel-Aviv (IL).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **NADAM, Dror** [IL/IL]; 12 Hohit st., 40697 Eyn-Sarid (IL). **KAPLAN, Ian** [IL/IL]; 28 Yitzhak Sade st., PO Box 51701, Tel-Aviv (IL). **PADOWICZ, Ronen** [IL/IL]; 3 Zalman Shneur St., 46364 Herzliya (IL).

(74) Agent: **DR. D. GRAESER LTD.**; 13 Hasadna St., Pob 2496, 43650 Raanana (IL).

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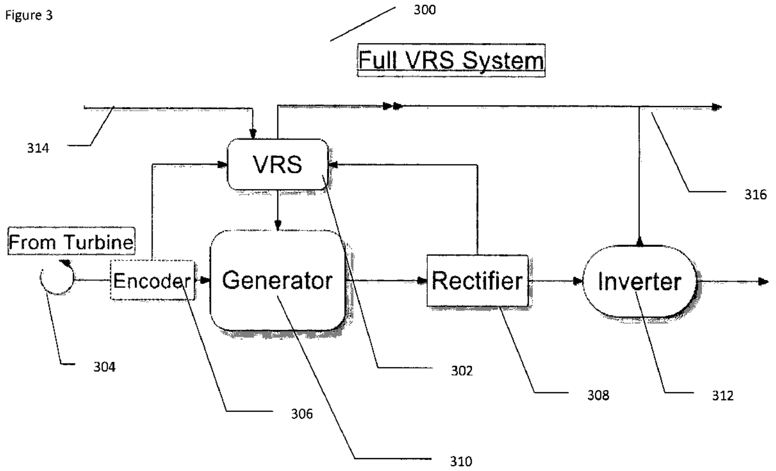
Figure 3



(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 Field Exciter for providing a current to the AC generator so as to control the magnetic field of the AC generator.

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System and method for generating an alternating current output signal

Inventors: Dror NADAM, Ian KAPLAN and Ronen PADOWICZ

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 but not exclusively, 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:

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

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.

$\sin(\theta)$ 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 at least some embodiments of the present invention, there is provided a method for providing an alternating current (AC) voltage, the method comprising:

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 determining a control current to be provided by a Field Exciter to the AC generator according to the rotation speed by calculating said current to be provided by the Field Exciter, issuing a signal to said Field Exciter according to a result of said calculating, wherein said signal incorporates a power parameter regarding a power of said signal, and providing said current by said Field Exciter to said AC generator according to said power parameter of said signal; and outputting, by the AC generator, an AC output current; wherein a peak voltage of the AC output current is responsive to the magnetic field of the AC generator; wherein the AC generator comprises an AC rotor that communicates with the shaft.

Optionally said issuing said signal comprises modulating said power of said signal in time to determine said power parameter.

Preferably said modulating said power of said signal comprises modulating said signal according to PWM (pulse width modulation) to provide a PWM signal.

More preferably said sensing said rotation speed of said shaft comprises directly sensing said rotation speed according to an encoder.

Also more preferably said sensing said rotation speed of said shaft comprises indirectly sensing said rotation speed by emulation according to a determination of said AC output current.

Also more preferably said calculating said current comprises comparing said rotation speed to a plurality of possible rotation speed values, each of said plurality of possible rotation speed values being associated with a precalculated current, and selecting said current according to said comparing.

Optionally and more preferably the method further comprises heuristically determining each precalculated current for being associated with a rotation speed value.

Optionally and more preferably said modulating said signal according to PWM comprises selecting a PWM according to said rotation speed value to form a selected

PWM; determining a hysteresis parameter according to said rotation speed value; and correcting said selected PWM according to said hysteresis parameter.

Most preferably said determining said hysteresis parameter comprises calibrating said generator according to a plurality of pairs of minimum and maximum rotation speed values, such that each pair of minimum and maximum rotation speed values is associated with a hysteresis parameter; determining between which pair of rotation speed values said rotation speed value of the shaft lies; and selecting said hysteresis parameter according to said pair of rotation speed values.

Also most preferably said providing said current by said Field Exciter to said AC generator is controlled according to said PWM.

Also most preferably said modulating said signal according to PWM further comprises determining whether said modulating said signal is being performed for the first time since initiation of operation of said generator; and if so, modulating said signal according to PWM to provide an incrementally increasing PWM signal.

Optionally said providing said current by said Field Exciter further comprises receiving said PWM signal by a switch; and determining said current by said switch according to said PWM signal.

Also optionally said Field Exciter comprises a direct current (DC) generator and wherein said providing said current by said Field Exciter comprises providing the current by the DC generator; wherein the DC generator has a DC rotor that communicates with the shaft and wherein the DC rotor is coupled to the AC rotor.

Preferably the method further comprises feeding a DC stator of the DC generator by an excitation voltage that has an amplitude that is responsive to the rotation speed.

Optionally the method further comprises rotating the shaft by a mechanical input element that is powered by a renewable energy source.

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

Optionally said Field Exciter comprises a brushes mechanism and wherein said brushes mechanism comprises a plurality of low friction brushes and a plurality of conductive rings.

According to at least some embodiments of the present invention, there is provided 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 of the shaft selected from the group consisting of a shaft rotation sensor for directly sensing the rotation speed of the shaft and a rotation speed emulator for indirectly sensing the rotation speed of the shaft according to output voltage of the AC generator; and

a controller for controlling a magnetic field of the AC generator in response to the rotation speed; wherein the controller comprises a Field Exciter that provides a current that is provided to the AC generator so as to control the magnetic field of the

AC generator, and 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 Field Exciter, 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 and wherein the voltage regulation system comprises a processor for determining the amplitude of the excitation voltage and a voltage controller for controlling the amplitude of the excitation voltage, wherein said processor sends a signal to said voltage controller regarding the amplitude of the excitation voltage, said signal comprising a power parameter such that the amplitude of the excitation voltage is determined according to said power parameter, wherein the voltage regulation system comprises a digital portion containing said processor and an analog portion containing said voltage controller.

Optionally said power of said signal is modulated in time to determine said power parameter.

Preferably said signal from said processor comprises a PWM (pulse width modulation) signal and wherein said analog portion comprises a switch for determining the excitation voltage according to said PWM signal.

Optionally and more preferably the Field Exciter comprises a direct current (DC) generator that generates said current and wherein said DC generator comprises a DC rotor that communicates with the shaft and that is coupled to the AC rotor, and wherein the DC generator comprises a DC stator that is fed by an excitation voltage that has an amplitude that is responsive to the rotation speed.

Optionally and more preferably said Field Exciter comprises a brushes mechanism, wherein said brushes mechanism comprises a plurality of low friction brushes and a plurality of conductive rings.

Optionally said shaft rotation sensor for directly sensing the rotation speed of the shaft comprises an encoder.

Also optionally rotation speed emulator for indirectly sensing the rotation speed of the shaft according to output voltage of the AC generator comprises a rectifier.

Also optionally the shaft is rotated by a mechanical input element that is powered by a renewable energy source.

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

Optionally the system further comprises a rectifier and an inverter for receiving said output AC signal and for stabilizing a frequency of said output AC signal.

According to at least some embodiments of the present invention, there is provided 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 Field Exciter that provides a current that is provided to the AC generator so as to control the magnetic field of the AC generator, wherein said Field Exciter comprises a brushes mechanism; wherein said brushes mechanism comprises a plurality of low friction brushes and a plurality of conductive rings.

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:

Figures 1A and 1B are of exemplary, illustrative AC generator systems according to various embodiments of the present invention;

Figure 2 is a schematic diagram of a voltage regulation system according to the present invention;

Figure 3 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 through voltage regulation;

Figure 4 shows an exemplary, non-limiting illustrative method for operation of the VRS as described herein according to at least some embodiments of the present invention;

Figure 5 shows an exemplary, illustrative non-limiting of a VRS implemented as an analog device according to at least some embodiments of the present invention;

Figure 6 shows an exemplary, illustrative non-limiting of a VRS implemented with a digital board according to at least some embodiments of the present invention;

Figure 7 shows an exemplary, illustrative non-limiting of a complete VRS implemented with the analog card of Figure 5 and the digital board of Figure 6 according to at least some embodiments of the present invention;

Figure 8 shows the excitation voltage values of the brushes mechanism according to the speed of the shaft of the AC generator in RPM (rotations per minute), as required to maintain a constant voltage output by the AC generator;

Figure 9 shows an exemplary, non-limiting illustrative voltage control method according to at least some embodiments of the present invention;

Figure 10 shows some of the voltage/RPM values obtained in a tested system using the method of Figure 9; and

Figures 11-13 show the results of tests performed with simulated inputs of 3 Kw, 5 Kw and 10 Kw.

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.

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, Figures 1A and 1B are of exemplary, illustrative AC generator systems according to various embodiments of the present invention. Figure 1A shows an exemplary generator system which is brushless according to at least some embodiments of the present invention, while Figure 1B shows a corresponding exemplary generator system with brushes according to at least some embodiments of the present invention.

Figure 1A 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**. However, optionally AC generator **108** is a single phase generator (not shown). Rotor **110** preferably features rotor winding **114** while stator **112** preferably features stator winding **116**.

An auxiliary DC generator **118** is provided as a non-limiting illustrative example of a Field Exciter; 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.**

Figure 1B shows a similar exemplary, illustrative AC generator system **150** for generating a constant level of output voltage. Components having an identical or at least similar function as components in Figure 1A are shown with the same reference numbers.

AC generator system **150** differs from that shown in Figure 1A as follows. A brushes mechanism **152** is provided in place of auxiliary DC generator **118** as shown as another illustrative, non-limiting example of a Field Exciter. Brushes mechanism **152** optionally and preferably features conductive rings **158** and **160** connected to the rotor shaft **106**, and conductive brushes **162** and **164**. Brushes **162** and **164** are preferably also low friction; for example brushes **162** and **164** optionally comprise a low friction conductive material, such as graphite for example, and/or ceramics or composite materials. Conductive rings **158** and **160** are preferably connected to rotor winding **114** of AC generator **108** through a connector **156**, which preferably comprises some type of wiring, which may optionally be rigid wiring as described above with regard to Figure 1A. Conductive rings **158** and **160** rotate at the same speed as rotor winding **114**.

The low friction brushes **162** and **164** are preferably connected to DC power source **128** through a suitable connector **132** as is known in the art and as described above with regard to Figure 1A.

AC generator system **150** 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 low friction brushes **162** and **164** by DC power source **128**, causing low friction brushes **162** and **164** to conduct current to conductive rings **158** and **160**. Conductive rings **158** and **160** are preferably attached to shaft **106**, such that a magnetic field is induced between rotor winding **114** and stator winding **116**.

The combination creates an EMF in brushes mechanism **152**, thus current (also referred to as control current) flows from conductive rings **158** and **160** 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 low friction brushes **162** and **164**, thereby changing the EMF output by brushes mechanism **152**. In turn, this controls the magnetic field intensity of AC generator **108**, by changing the current in rotor winding **114**.

Figure 2 is a schematic diagram of a flow process for 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 Figures 1A and 1B, is preferably an associated DC power source.

Figure 3 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 through voltage regulation. As shown, a system **300** features a VRS (voltage regulation system) 302, non-limiting exemplary embodiments of which are described in greater detail with regard to Figures 5-7 below. VRS 302 in turn receives frequency information from a wind turbine 304, optionally through an encoder 306 as shown, which is a shaft encoder that reads the frequency information regarding the speed of rotation of the shaft (therefore technically the information relates to the speed of the generator shaft, but this speed is also the output speed of wind turbine 304). Encoder 306, for this implementation, is provided as an electro-mechanical device that converts the angular position of the generator shaft (not shown) to a digital or analog code.

Wind turbine 304 is provided as a non-limiting, illustrative example of a provider of power from a source of renewable energy; as described herein the source of renewable energy is optionally and preferably selected from the group consisting of wind, solar, water and geothermal. The frequency information is important because as previously described, renewable sources of energy are also non-limiting examples of potentially uneven or intermittent sources of energy, which provide power that is in consequence itself potentially uneven or intermittent.

VRS 302 also receives frequency information determined according to the output of a generator 310 (optionally implemented as for Figures 1A and 1B for example), which receives power from wind turbine 304. If generator 310 is an AC generator, then VRS 302 optionally receives such frequency information from a rectifier 308, which is connected to generator 310 and which converts the AC output of generator 310 to a DC signal for VRS 302 (described in greater detail below). However, rectifier 308 may also optionally not provide frequency information to VRS 302; in any case, typically rectifier 308 provides such frequency information through emulation of the frequency according to the output voltage. Thus, VRS 302 preferably receives frequency information regarding at least one of the input to, and output from, generator 310, through signals for encoder 306 and rectifier 308, respectively. However, optionally VRS 302 receives both types of frequency information.

Alternatively or additionally, rectifier 308 can provide an AC signal for VRS 302, which is proportional to the output voltage of generator 310. By measuring its frequency, the VRS 302 can calculate the shaft rotation speed. Rectifier 308 in this example, by providing the AC signal, is a non-limiting example of a rotation speed emulator for indirectly sensing the rotation speed of the shaft according to output voltage of generator 310.

Based upon the various frequency information inputs and preferably according to calculations made by a processor for example (not shown, see Figure 6 for a non-limiting example), VRS 302 then injects control voltage to generator 310 from a control voltage output generator (not shown), which as described in Figures 1A and 1B, is preferably an associated DC power source. The control voltage may optionally be injected to the rotor winding of generator 310 (as for Figure 1A) or to low friction brushes (as for Figure 1B). Such implementations are non-limiting examples only.

As a non-limiting example only, VRS 302 may optionally compare the rotation speed of the shaft to a plurality of possible rotation speed values, each of the plurality of possible rotation speed values being associated with a precalculated current, and selecting the current to be provided through such a comparison. The precalculated current may optionally be determined heuristically for being associated with a rotation speed value.

Rectifier 308 typically outputs DC power to an inverter 312, which as is known in the art, converts DC power to AC power, with fixed voltage and phase. Optionally any suitable inverter as is known in the art may be used. Inverter 312 may optionally output power to the grid, for example. Optionally the combination of rectifier 308 and inverter 312 is not implemented; however if provided, this combination stabilizes the frequency of the output AC current (and also provides conversion of the frequency to a desired frequency), and permits synchronization with the grid, such that the output of inverter 312 is grid-synchronized AC power.

VRS 302 may optionally be powered by any suitable power source 314, including but not limited to an AC or DC power source as shown.

VRS 302 may optionally be in contact with a communications port 316, for example to receive alarm indications from VRS 302. Communication port 316 also is optionally is in communication with inverter 312 to receive power output information, working hours, any other desired reportable parameters and so forth. Communication port 316 may then optionally communicate with a remote user interface for example (not shown).

Among the many advantages of the exemplary VRS embodiment of the present invention shown in Figure 3 (and without intending to be limiting in any way) 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.

Figure 4 shows an exemplary, non-limiting illustrative method for operation of the VRS as described herein according to at least some embodiments of the present invention. As shown, in stage 1, the process optionally starts with setting the value for a "soft start flag" or any indicator and/or initialization action for starting the operation of the VRS. For this example, the value of the soft start flag is set to 0 but optionally any such value may be used. In stage 2, pulses are provided that relate to RPM (rotations per minute) for the rotation speed of the generator's shaft. As previously described, the rotation speed may optionally be determined with one or more sensors; alternatively or additionally, the rotation speed may optionally be determined with an encoder. As previously described, the encoder provides a digital or analog signal regarding the speed of rotation; this signal is translated to speed in the processing unit. The encoder produces a known series of pulses per cycle and the processing unit of the VRS (not shown, see Figures 6 and 7) samples this signal. A sensor such as an encoder measures the shaft rotation speed directly; optionally, additionally or alternatively, the shaft rotation speed is measured indirectly according to the output voltage, which is then used to determine the rotation speed through emulation.

In stage 3, the processor detects each pulse (or each unit of frequency, for example for rotation speed emulation) from the sensor, optionally by sensing the rising (or falling) edge of each input signal pulse, and/or the pulse peak, or according to any other suitable means for detecting each pulse. Each detected pulse is then counted, preferably per some unit of time, in stage 4. In stage 5, the RPM (rotations per minute) is calculated according to the pulses per unit of time from stage 4.

In stage 6A, it is determined whether the RPM is greater than a minimum speed but less than a maximum speed. If so, then in stage 7, the required PWM (pulse width modulation; for voltage excitation) is obtained from a pre-calibrated look-up table (LUT; this process is described in greater detail below with regard to Figure 9). The required PWM is taken from a look-up table, wherein the PWM is determined by the look-up table. The PWM determines the overall voltage that is injected, by determining the modulation of the duty cycle of the PWM. Optionally, voltage may be injected without the use of PWM, but PWM has the advantage of providing more precise power control and also of enabling a range of voltage values to be used in a more efficient manner.

However, it should be noted that PWM is provided as a non-limiting example only of a type of modulation of a signal that is provided from the processor of the VRS to control the control current that is provided to the generator. The control current that is provided to the generator is preferably controlled according to the power parameter of the signal that is provided from the processor. Preferably, the power of the signal is modulated in time to determine the power parameter.

In stage 8, the values for the minimum and maximum RPM measurements, between which the measured RPM value falls, are optionally saved. In stage 9, these values are then preferably used to determine a hysteresis parameter, which is a heuristically determined value, which may be positive or negative, that is a correction factor for the previously determined PWM. Such a hysteresis parameter may optionally be determined as described with regard to Figure 9, but in any case is preferably determined through calibration of the generator. In stage 10, the hysteresis parameter is preferably combined with the PWM, for example through addition. In stage 11, such a combination provides a corrected PWM.

If the soft start flag value is set to 1, then in stage 12A, the processor outputs a PWM signal to a switch or other controller of the control current that is to be provided to the generator.

If the soft start flag is set to 0 at stage 11, then in stage 12B, the processor outputs an incrementally increasing PWM signal to a switch or other controller of the control current that is to be provided to the generator, which eventually reaches a certain level after a predetermined period of time. Such a "soft start" is preferably implemented to avoid causing a surge of electrical energy. In stage 13B, the processor changes the soft start flag to 1. In stage 14B, the processor outputs a PWM signal to a switch or other controller of the control current that is to be provided to the generator. The process then returns to stage 2.

Turning back to stage 6A, if the RPM is not greater than a minimum speed but less than a maximum speed, then in stage 6B, it is determined that no voltage is to be injected and the process returns to stage 2.

Figure 5 shows an exemplary, illustrative non-limiting of a VRS implemented as an analog device according to at least some embodiments of the present invention. This Figure shows the analog device as a card but in fact optionally any device implementation may be used. The connections of the analog device are assumed to be to a digital board for control purposes, forming another portion of the VRS, of which a non-limiting exemplary embodiment is shown in Figure 6; the complete VRS is shown in more detail with regard to Figure 7. For all of Figures 5-7, the diagrams shown are highly schematic and without certain components shown for the sake of clarity; one of ordinary skill in the art could easily determine the nature of these components and their connections to the embodiments shown herein.

As shown, an analog card 500 features an isolated COM (communications) port 316, for communication to and from analog card 500.

Analog card 500 is connected to generator 310 and more specifically to generator exciter 504; as previously described, such an exciter 504 may optionally comprise the rotor winding of generator 310 (as for Figure 1A) or low friction brushes (as for Figure 1B), as generator exciter 504 controls and provides the control current and voltage to be provided to generator 310. Such implementations are non-limiting examples only.

A thermocouple (not shown) provides signals regarding the temperature at generator 310 through a thermocouple output 506, which is turn preferably connected to the digital board (not shown) through an optocoupler 508. Optocoupler 508 (also known as an optical isolator) uses a short optical transmission path to transfer an electronic signal between a transmitting element of a circuit and a receiving element of a circuit. For this Figure and subsequent Figures, each optocoupler is assumed to be transferring a signal from analog card 500 to the digital board or vice versa. Other types of couplers could also optionally be used, in addition to or in place of an optocoupler, which is provided as a non-limiting example only.

The encoder signal from the encoder (not shown, see Figure 3) is preferably both connected to generator 310 through an encoder input 510 and also to the digital board (not shown) through an optocoupler 512. As previously noted, the encoder signal provides frequency information to the VRS for determining how much voltage to inject to generator exciter 504.

The PWM signal input from the digital board is provided through an optocoupler 514 to an IGBT (insulated gate bipolar transistor) 516, and determines the voltage to be injected and the control current that is to flow to generator exciter 504. IGBT 516 is a switch that selects from a plurality of voltage inputs 519 from a DC power source 518 and which also determines the frequency of pulses from such voltage inputs 519, according to the PWM signal. The PWM signal is preferably determined by the digital board, as described in greater detail with regard to Figure 6 below, optionally according to the method described in Figure 4. According to this signal input, IGBT 516 permits the injection of voltage, and causes a control current to flow, to generator exciter 504 as previously described, preferably in a range that is determined heuristically according to the nature of the power input, the generator 310 and generator exciter 504. For a 10Kw generator tested according to the implementation in the Examples below, for example, such a range was found to be 0-72 volts, 0-17 amps, with the amount of volts and amps being determined by IGBT 516 switching according to the PWM signal input.

Generator exciter 504 is connected to IGBT 516 through a circuit loop as shown; for example, the circuit loop optionally comprises a DC rotor and a DC stator (i.e. the rotor and stator of a DC generator 518 as shown) in communication with generator 310 such that control current flows from the DC rotor to the rotor of generator 310, while control of the excitation voltage in the DC stator by IGBT 516 controls the magnetic field intensity of generator 310, by changing the current and voltage in the winding of the rotor of generator 310. Also as shown, the output AC voltage with a changing frequency (from generator 310) is optionally and preferably connected to rectifier 308 which changes it to DC voltage as previously described. The output is then optionally and preferably provided to inverter 312, also as previously described, which produces AC voltage with a stable, desired frequency.

Generator exciter 504 is connected also to the ground pin of IGBT 516 as shown.

For reporting any errors (for example and without limitation, failure of DC generator 518 or voltage/current measurements that are beyond a minimum and/or maximum threshold), IGBT 516 optionally communicates with the digital board through an optocoupler 520.

Figure 6 shows an exemplary, illustrative non-limiting of a VRS implemented with a digital board according to at least some embodiments of the present invention; as previously noted, the digital board is preferably in communication with the analog device of Figure 5.

A digital board 600 optionally features a plurality of inputs and outputs as shown, for communication with a processor 612, such as a FPGA (field-programmable gate array) or any type of CPU or other processor. The previously described outputs of the analog device of Figure 5 are now received by processor 612 of digital board 600 as inputs, including but not limited to a thermocouple input 602, an encoder signal input 604, an error signal input 606 (received from the IGBT as previously described, not shown) and a power input 608 which regulates power to processor 612.

"DC generator" 518 of Figure 5 (not shown) is actually rectifier 308 as previously described. DC generator 518 optionally provides a frequency signal to the digital board, and more specifically to processor 612, regarding the emulated frequency of rotation of the generator shaft (not shown) as calculated from the output voltage.

Encoder signal input 604 is related to the input power from the renewable energy source, such as for example and without limitation, a wind turbine. For this embodiment, optionally no feedback is provided from the generator, such as the output voltage or the frequency of the output voltage. If the rectifier is present, the preferably only the emulated frequency of the output voltage is provided. Processor 612 then preferably processes these inputs, including the amount of power being provided to the generator and its power output, for example as described with regard to the method of Figure 4, to determine the PWM signal output 610 to the IGBT (not shown), which again as previously described determines the amount of volts/amps to be provided to the generator.

Thermocouple input 602 and error signal input 606 both preferably operate to indicate whether a problematic condition has arisen, such as for example excessive temperature (for thermocouple input 602) or any of the previously described unsuitable conditions (for error signal input 606). Processor 612 preferably performs a corrective action if required by these inputs and may even optionally opt to shut down generator 310 if necessary.

Digital board 600 also optionally features a COM (communications) port 614 for two-way communication, for example with the analog device of Figure 5 (not shown) and/or for providing new or updated instructions to processor 612.

Instructions, data and/or other logic may optionally be stored on a memory 616; for the purposes of illustration only and without intending to be limiting in any way, memory 616 is shown as being divided into several types of memory, including but not limited to a flash memory 618, a SDRAM memory 620 and a user flash memory 622. Flash memory 618 is shown as being read-only by processor 612, which may optionally not be able to write to this memory; for example and without limitation, operating instructions and/or other logic may optionally be stored on flash memory 618. SDRAM memory 620 is shown as being readable and writable by processor 612, for example optionally to store data on the various inputs received from the analog device and also to read such data back. Both flash memory 618 and SDRAM memory 620 may optionally be incorporated as part of the overall component for processor 612. For example, if processor 612 is implemented as a FPGA, then optionally one or more instructions may also optionally be stored on processor 612.

User flash memory 622 is also shown as being readable and writable by processor 612, and is optionally provided to allow the user to alter one or more parameters, data and/or functions. If processor 612 is implemented as a FPGA, then optionally one or more instructions may also optionally be stored on processor 612.

Processor 612 also preferably receives an input signal from an oscillator 624 for timing purposes. Optionally any suitable type of oscillator may be used, including but not limited to one or more of a crystal, a ceramic resonator, or an RC (resistor, capacitor) oscillator. Processor 612 is also optionally in two-way communication with a JTAG port 626, which is a debugging port for testing and debugging the logic and instructions of processor 612.

Figure 7 shows an exemplary, illustrative non-limiting of a complete VRS implemented with the analog card of Figure 5 and the digital board of Figure 6 according to at least some embodiments of the present invention.

As shown, a VRS 700 features analog card 500 and digital board 600. Analog card 500 is connected to generator 310 and to generator exciter 504. The outputs from operation of generator 310, including encoder output 510, generator output signal 608, and thermocouple output 506, form inputs to processor 612. Another input to processor 612 is the error signal output of IGBT 516. Based upon these inputs, processor 612 determines the PWM signal to IGBT 516, which in turns regulates the volts/amps to generator exciter 504.

EXAMPLE 1

TESTING OF AN ILLUSTRATIVE SYSTEM WITH BRUSHES

This Example describes a test performed on an exemplary, illustrative non-limiting system according to the present invention, according to an embodiment featuring a brushes mechanism. The system featured a hybrid, dual winding three phase generator as is known in the art, which includes both a brushes mechanism and an AC generator, product number STC-3, 3Kw 380V-Sphase generator, made by Fuan Lion Motor Co. Ltd., China; 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 brushes mechanism was changed, until the peak voltage of the AC output reached the set point value (285Vac).

Figure 8 shows the excitation voltage values of the brushes mechanism according to the speed of the shaft of the AC generator in RPM (rotations per minute), as required to maintain a constant voltage output by the AC generator.

The voltage regulation system of Figure 3 may also optionally be used with this embodiment and so is not described further.

Figure 9 shows an exemplary, non-limiting illustrative voltage control method according to at least some embodiments of the present invention.

As shown, in stage 1, the system is initialized. It is assumed that the desired RPM at each rotation speed of the shaft will be between the maximum possible speed and the minimum possible speed (ie Generator Min RPM < RPM < Generator Max RPM). This stage preferably features calibration, for determining the values of X1, X2... Xn for RPM of the shaft (described in greater detail below) and for determining the values of Y1, Y2... Yn for voltage. In this case, the value of Xn is set so that Generator Min RPM < Xn and the value of X1 is set so that X1< Generator Max RPM. Y1 represents the corresponding voltage at X1, while Yn represents the corresponding voltage at Xn. The value of Vbase is also determined at calibration through a look-up table, in which corresponding voltage outputs for the field exciter are determined according to the RPM inputs, for values ranging from the maximum to the minimum RPM values for the generator.

Vbase is the value determined at calibration for a plurality of curves, each curve representing the degree of saturation of the generator at a particular local maximum. Each time the local maximum changes (that is, the maximum rotation speed reached during a period of continuous operation of the generator), a new curve is preferably selected from the calibration process. If the rotation speed drops below the local maximum, the Vbase curve selected according to the local maximum may still be used; however, once the rotation speed increases above the current value of the local maximum, a new local maximum (and hence a new Vbase curve) is preferably selected.

Therefore, the actual excitation voltage is preferably determined by at least two parameters: the basic Vbase curve (showing excitation voltage vs. rotation speed) that is preferably determined during the initial calibration process; and a correction voltage (Yn) which is preferably added to the basic Voltage according to the current local maximum speed of rotation.

The values of Yn are also preferably determined during the initial calibration process, as are the values of Xn, such that the EMF error is preferably lower than some desired threshold, such as +/- 10% for example.

In stage 2, the process is initialized to find the current local maximum RPM value as described above and hence to determine the current curve for determining Yn. The process then continues to one of stages 3A, 3B or 3C, according to the measured RPM value for the shaft speed.

In stage 3A, it is determined that the measured RPM value, X2, is less than the maximum RPM value from stage 2, which in turn is smaller than the generator's maximum RPM value or X1: $X2 < \text{Max RPM} < X1$. In this case, the output voltage is equal to Vbase plus Y1, such that the previously determined curve is preferably used for the value of Yn, in this case Y1.

In stage 3B, it is determined that the measured RPM value, X2, is greater than or equal to the maximum RPM value from stage 2, which in turn is larger than X3 or X3 < Max RPM <= X2. In this case, the output voltage is equal to Vbase plus Y2 as a new curve is used to select Yn – the Y2 curve.

In stage 3C, it is determined that the currently measured RPM value Xn is greater than or equal to the maximum RPM value from stage 2, which in turn is larger than Xn+1 or Xn+1 < Max RPM <= Xn. In this case, the output voltage is equal to Vbase plus Yn, as the Yn curve is selected.

Figure 10 shows some of the voltage/RPM values obtained in a tested system using the method of Figure 9. The tested system was identical to that used for Figure 8. As shown, RPM values from 1400 to 1843 were tested; the corresponding added voltage values required are given as "add voltage for hysteresis [V]".

EXAMPLE 2

TESTING OF AN ILLUSTRATIVE SYSTEM WITH MULTIPLE POWER LOADS

This Example describes the results of several tests performed on an exemplary, illustrative non-limiting system according to the present invention, according to an embodiment featuring a brushes mechanism as described with regard to Example 1. The system featured different amounts of input power loads (3 Kw, 5 Kw and 10 Kw loads), simulating inputs from the corresponding type of wind turbine according to the power classification thereof.

Figures 11A and 11B show the torque curve and the power curve for a simulated 3 Kw wind turbine power input to the above described system according to at least some embodiments of the present invention. For Figure 11A, the y axis shows torque while the x axis shows RPM (rotations per minute) of the generator shaft, for different values of control current (360 VAC, shown as a dotted line, 400 VAC, shown as a solid line, and 440 VAC, shown as a dashed line). The smoothest power curves are obtained for 400 VAC and 440 VAC control current.

For Figure 11B, the y axis shows power (in kilo-watts) while the x axis shows RPM (rotations per minute) of the generator shaft, for different values of control current as described in Figure 11A. The smoothest power curves are obtained for 400 VAC and 440 VAC control current.

Figures 12A and 12B show data for torque and power, respectively, for a simulated 5 Kw wind turbine power input to the above described system according to at least some embodiments of the present invention; while Figures 13A and 13B show data for torque and power, respectively, for a simulated 10 Kw wind turbine power input to the above described system according to at least some embodiments of the present invention. The values shown on the X and Y axes, and the different values of control current, are as for Figures 11A and 11B. For Figures 12A and 12B, and 13A and 13B, control current of 440 VAC provided the smoothest curves.

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. Also optionally any of the embodiments described above may be combined in any suitable manner, even if such embodiments are described separately and/or are not specifically described as being combined.

What is claimed is:

1. A method for providing an alternating current (AC) voltage, the method comprising:

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 determining a control current to be provided by a Field Exciter to the AC generator according to the rotation speed by calculating said current to be provided by the Field Exciter, issuing a signal to said Field Exciter according to a result of said calculating, wherein said signal incorporates a power parameter regarding a power of said signal, and providing said current by said Field Exciter to said AC generator according to said power parameter of said signal; and

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

2. The method of claim 1, wherein said issuing said signal comprises modulating said power of said signal in time to determine said power parameter.

3. The method of claim 2, wherein said modulating said power of said signal comprises modulating said signal according to PWM (pulse width modulation) to provide a PWM signal.

4. The method of claim 3, wherein said sensing said rotation speed of said shaft comprises directly sensing said rotation speed according to an encoder.

5. The method of claim 3, wherein said sensing said rotation speed of said shaft comprises indirectly sensing said rotation speed by emulation according to a determination of said AC output current.

6. The method of claim 3, wherein said calculating said current comprises comparing said rotation speed to a plurality of possible rotation speed values, each of said plurality of possible rotation speed values being associated with a precalculated current, and selecting said current according to said comparing.

7. The method of claim 6, further comprising heuristically determining each precalculated current for being associated with a rotation speed value.

8. The method of claim 3, wherein said modulating said signal according to PWM comprises selecting a PWM according to said rotation speed value to form a selected PWM; determining a hysteresis parameter according to said rotation speed value; and correcting said selected PWM according to said hysteresis parameter.

9. The method of claim 8, wherein said determining said hysteresis parameter comprises calibrating said generator according to a plurality of pairs of minimum and maximum rotation speed values, such that each pair of minimum and maximum rotation speed values is associated with a hysteresis parameter; determining between which pair of rotation speed values said rotation speed value of the shaft lies; and selecting said hysteresis parameter according to said pair of rotation speed values.

10. The method of claims 8 or 9, wherein said providing said current by said Field Exciter to said AC generator is controlled according to said PWM.

11. The method of any of claims 8-10, wherein said modulating said signal according to PWM further comprises determining whether said modulating said signal is being performed for the first time since initiation of operation of said generator; and if so, modulating said signal according to PWM to provide an incrementally increasing PWM signal.

12. The method of claim 3, wherein said providing said current by said Field Exciter further comprises receiving said PWM signal by a switch; and determining said current by said switch according to said PWM signal.

13. The method of claim 1, wherein said Field Exciter comprises a direct current (DC) generator and wherein said providing said current by said Field Exciter comprises providing the current by the DC generator; wherein the DC generator has a DC rotor that communicates with the shaft and wherein the DC rotor is coupled to the AC rotor.

14. The method of claim 13 comprising feeding a DC stator of the DC generator by an excitation voltage that has an amplitude that is responsive to the rotation speed.

15. The method of claim 1 comprising rotating the shaft by a mechanical input element that is powered by a renewable energy source.

16. The method of claim 15 wherein the renewable energy is selected from a group consisting of wind, water, solar and geothermal.

17. The method of claim 1, wherein said Field Exciter comprises a brushes mechanism and wherein said brushes mechanism comprises a plurality of low friction brushes and a plurality of conductive rings.

18. 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 of the shaft selected from the group consisting of a shaft rotation sensor for directly sensing the rotation speed of the shaft and a rotation speed emulator for indirectly sensing the rotation speed of the shaft according to output voltage of the AC generator; and

a controller for controlling a magnetic field of the AC generator in response to the rotation speed; wherein the controller comprises a Field Exciter that provides a current that is provided to the AC generator so as to control the magnetic field of the AC generator, and 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 Field Exciter, 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 and wherein the voltage regulation system comprises a processor for determining the amplitude of the excitation voltage and a voltage controller for controlling the amplitude of the excitation voltage, wherein said processor sends a signal to said voltage controller regarding the amplitude of the excitation voltage, said signal comprising a power parameter such that the amplitude of the excitation voltage is determined according to said power parameter, wherein the voltage regulation system comprises a digital portion containing said processor and an analog portion containing said voltage controller.

19. The system of claim 18, wherein said power of said signal is modulated in time to determine said power parameter.

20. The system of claim 19, wherein said signal from said processor comprises a PWM (pulse width modulation) signal and wherein said analog portion comprises a switch for determining the excitation voltage according to said PWM signal.

21. The system of claim 20 wherein the Field Exciter comprises a direct current (DC) generator that generates said current and wherein said DC generator comprises a DC rotor that communicates with the shaft and that is coupled to the AC rotor, and wherein the DC generator comprises a DC stator that is fed by an excitation voltage that has an amplitude that is responsive to the rotation speed.

22. The system of claim 20 wherein said Field Exciter comprises a brushes mechanism, wherein said brushes mechanism comprises a plurality of low friction brushes and a plurality of conductive rings.

23. The system of claim 20 wherein said shaft rotation sensor for directly sensing the rotation speed of the shaft comprises an encoder.

24. The system of claim 20, wherein said rotation speed emulator for indirectly sensing the rotation speed of the shaft according to output voltage of the AC generator comprises a rectifier.

25. The system of claim 20, wherein the shaft is rotated by a mechanical input element that is powered by a renewable energy source.

26. The system of claim 25 wherein the renewable energy is selected from a group consisting of wind, water, solar and geothermal.

27. The system of claim 25 further comprising a rectifier and an inverter for receiving said output AC signal and for stabilizing a frequency of said output AC signal.

28. 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 Field Exciter that provides a current that is provided to the AC generator so as to control the magnetic field of the AC generator, wherein said Field Exciter comprises a brushes mechanism; wherein said brushes mechanism comprises a plurality of low friction brushes and a plurality of conductive rings.

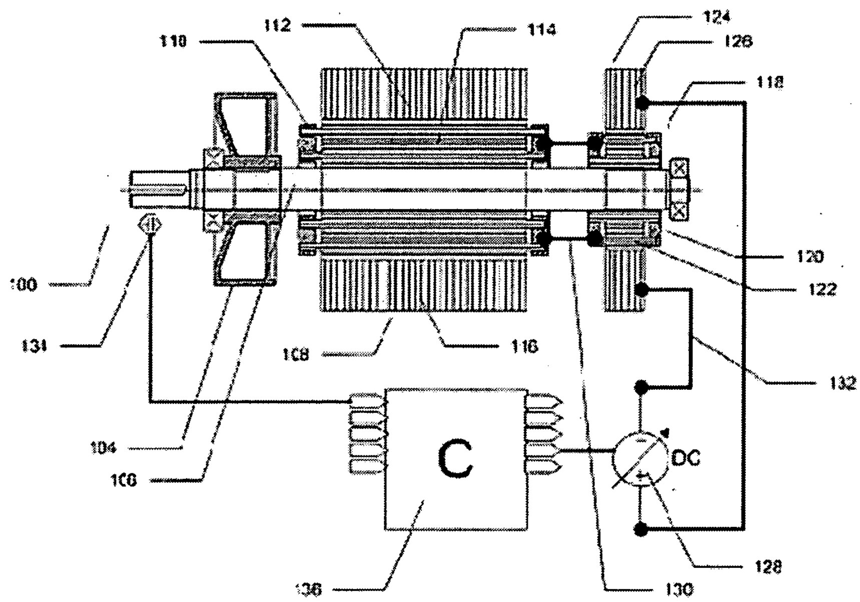

124
126
118
112
114
110
120
122
100
131
108
116
132
104
106
C
DC
128
136
130

Figure 1A

Figure 1B

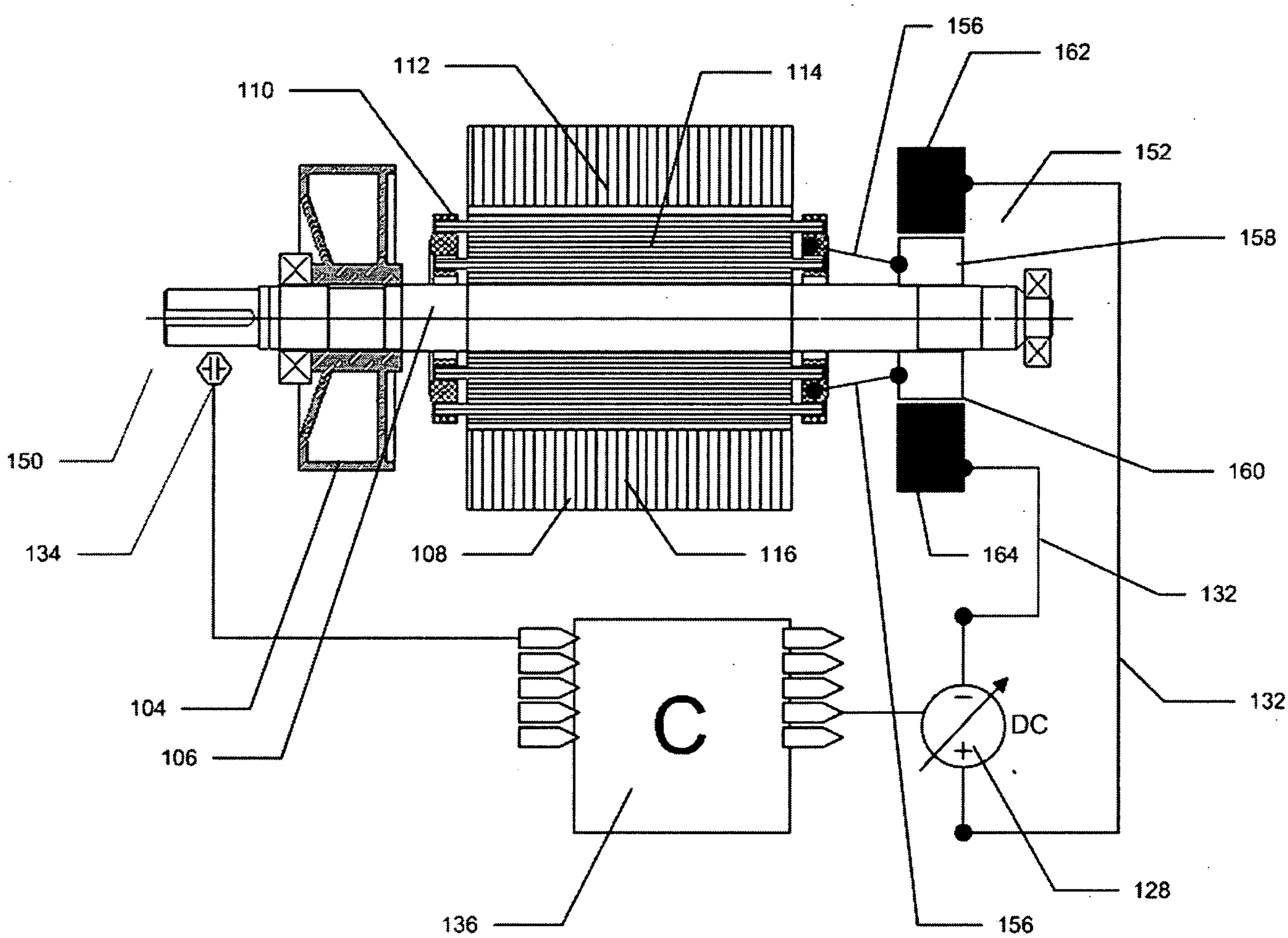
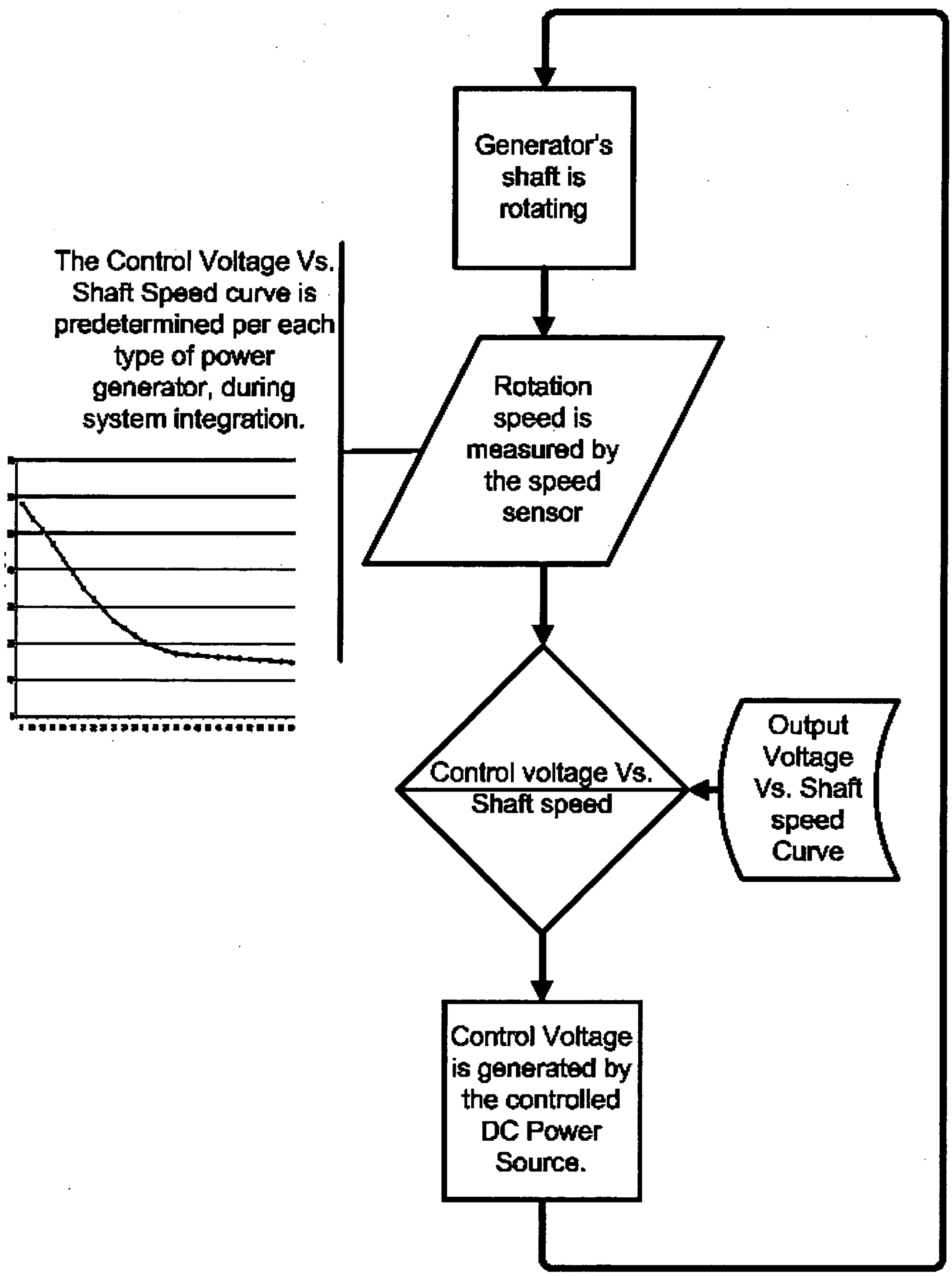

156
162
112
114
110
152
158
150
160
134
108
116
164
132
132
104
C
DC
106
128
136
156

figure 2


The Control Voltage Vs. Shaft Speed curve is predetermined per each type of power generator, during system integration.
Generator's shaft is rotating
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.

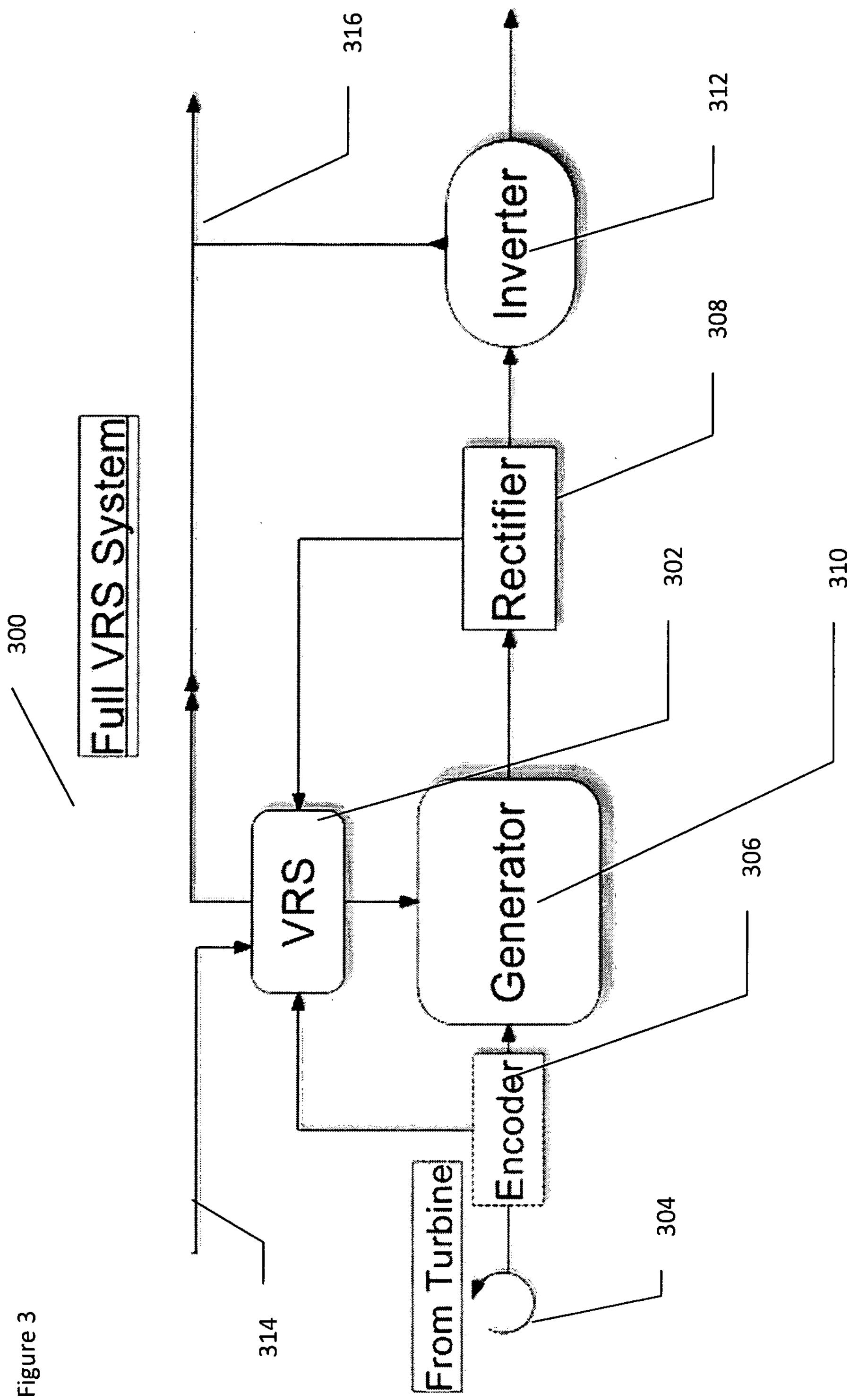
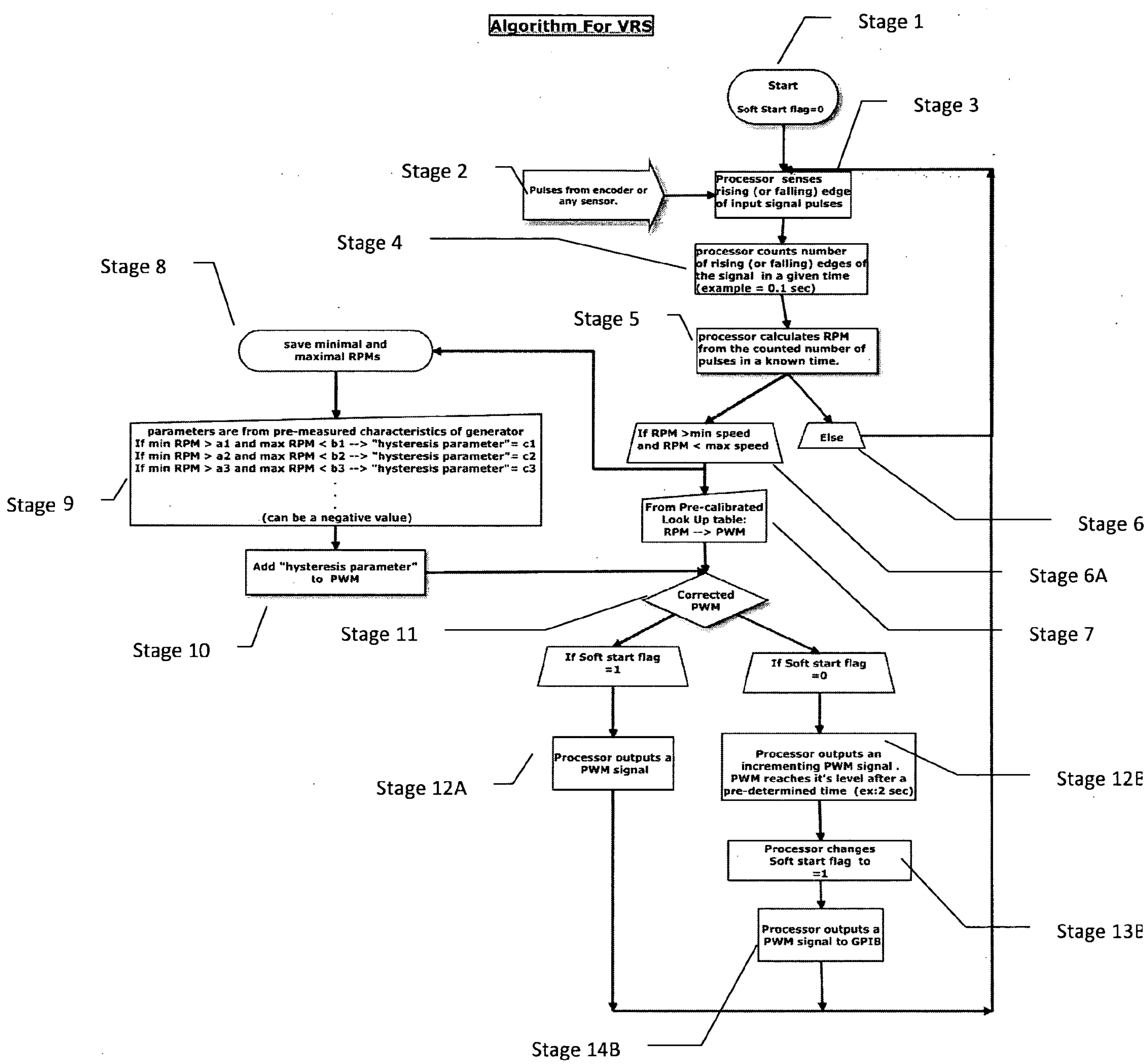

300
Full VRS System
316
312
Inverter
308
Rectifier
302
310
VRS
Generator
306
Encoder
From Turbine
304
314

Figure 3

Figure 4


Algorithm For VRS
Stage 1
Start
Soft Start flag=0
Stage 3
Stage 2
Pulses from encoder or any sensor.
Processor senses rising (or falling) edge of input signal pulses
Stage 4
processor counts number of rising (or falling) edges of the signal in a given time (example = 0.1 sec)
Stage 8
Stage 5
processor calculates RPM from the counted number of pulses in a known time.
save minimal and maximal RPMs
parameters are from pre-measured characteristics of generator
If min RPM > a1 and max RPM < b1 --> "hysteresis parameter"= c1
If min RPM > a2 and max RPM < b2 --> "hysteresis parameter"= c2
If min RPM > a3 and max RPM < b3 --> "hysteresis parameter"= c3
(can be a negative value)
If RPM >min speed and RPM < max speed
Else
Stage 9
From Pre-calibrated Look Up table: RPM --> PWM
Stage 6
Stage 6A
Add "hysteresis parameter" to PWM
Corrected PWM
Stage 10
Stage 11
Stage 7
If Soft start flag =1
If Soft start flag =0
Processor outputs a PWM signal
Processor outputs an incrementing PWM signal . PWM reaches it's level after a pre-determined time (ex:2 sec)
Stage 12A
Stage 12B
Processor changes Soft start flag to =1
Stage 13B
Processor outputs a PWM signal to GPIB
Stage 14B

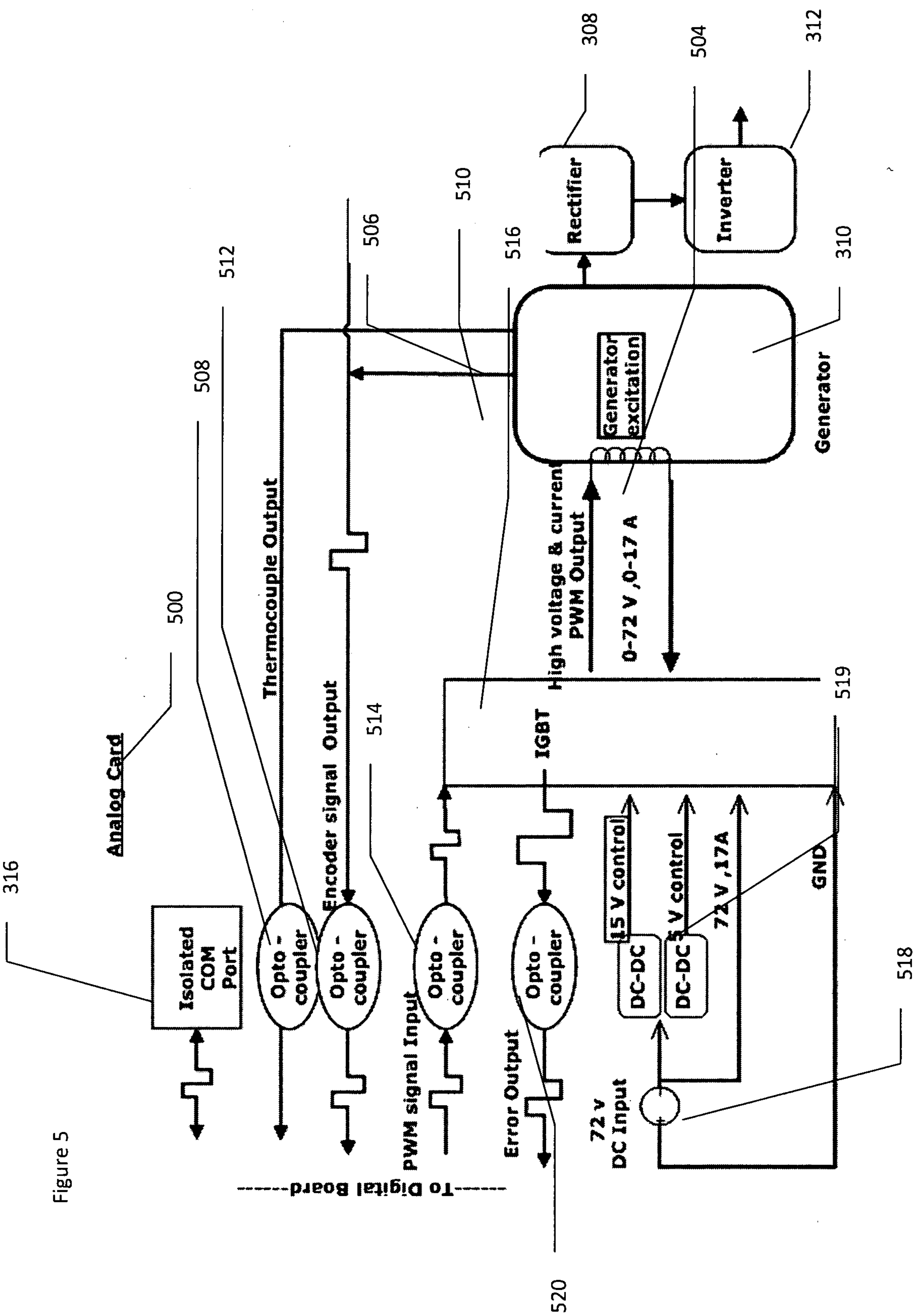

Analog Card
500
316
Isolated COM Port
Opto - coupler
Opto - coupler
Opto - coupler
Opto - coupler
508
512
514
520
Thermocouple Output
Encoder signal Output
PWM signal Input
Error Output
------To Digital Board------
IGBT
15 V control
5 V control
72 V ,17A
GND
DC-DC
DC-DC
72 v DC Input
518
519
High voltage & current PWM Output
0-72 V ,0-17 A
Generator excitation
Generator
506
510
516
504
310
Rectifier
Inverter
308
312

Figure 5

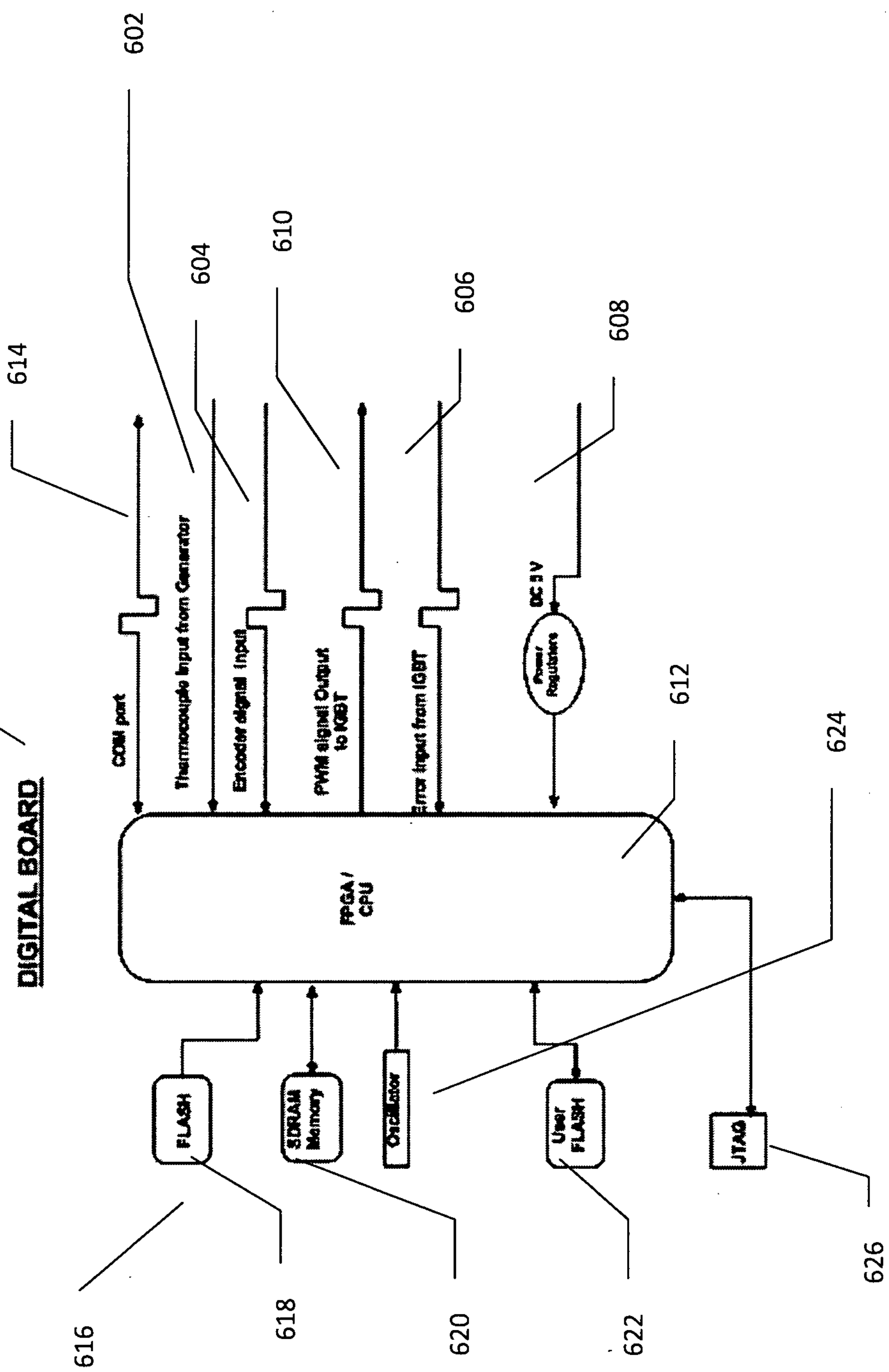

DIGITAL BOARD
600
COM port
Thermocouple Input from Generator
Encoder signal Input
PWM signal Output to IGBT
Error Input from IGBT
DC 5V
Power Regulators
FPGA / CPU
FLASH
SDRAM Memory
Oscillator
User FLASH
JTAG
602
604
606
608
610
612
614
616
618
620
622
624
626

Figure 6

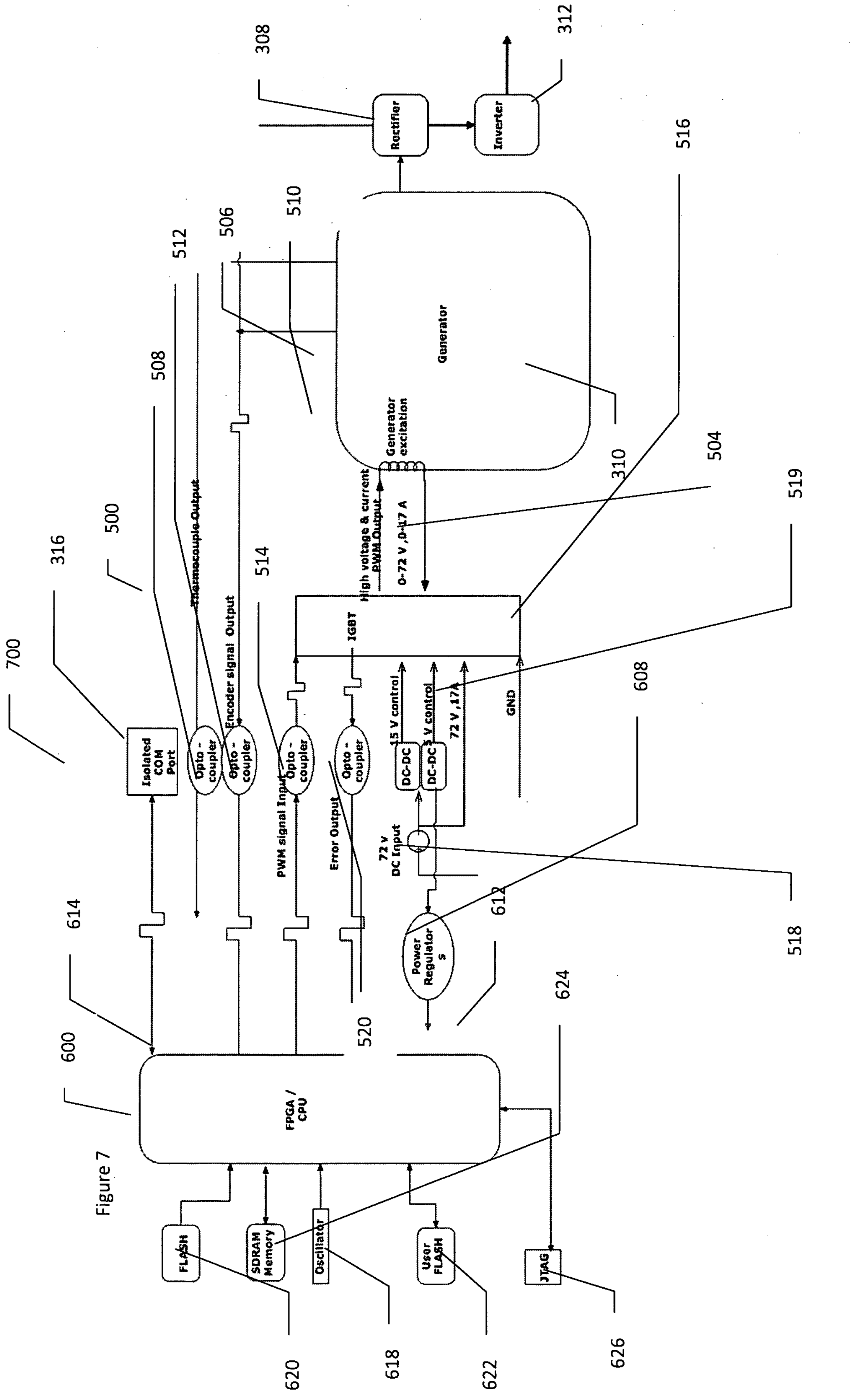
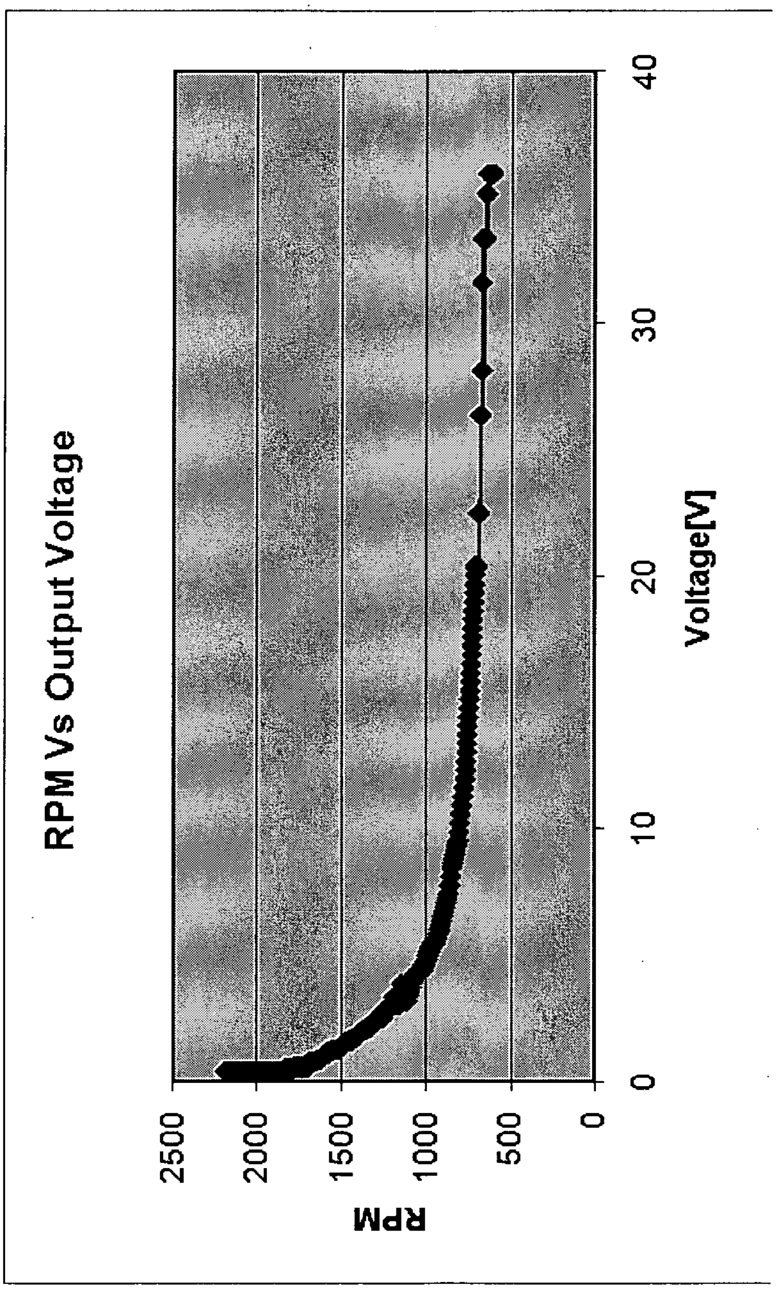

308
312
Rectifier
Inverter
516
510
506
512
Generator
508
Generator excitation
310
504
High voltage & current PWM Output
0-72 V ,0-17 A
519
500
316
Thermocouple Output
Encoder signal Output
514
IGBT
700
Isolated COM Port
Opto - coupler
Opto - coupler
Opto - coupler
Opto - coupler
15 V control
5 V control
72 V ,17A
GND
608
DC-DC
DC-DC
PWM signal Input
Error Output
72 v DC Input
614
612
518
Power Regulators
624
600
520
FPGA / CPU
FLASH
SDRAM Memory
Oscillator
User FLASH
JTAG
620
618
622
626

Figure 7

Figure 8


RPM Vs Output Voltage
RPM
2500
2000
1500
1000
500
0
0
10
20
30
40
Voltage[V]

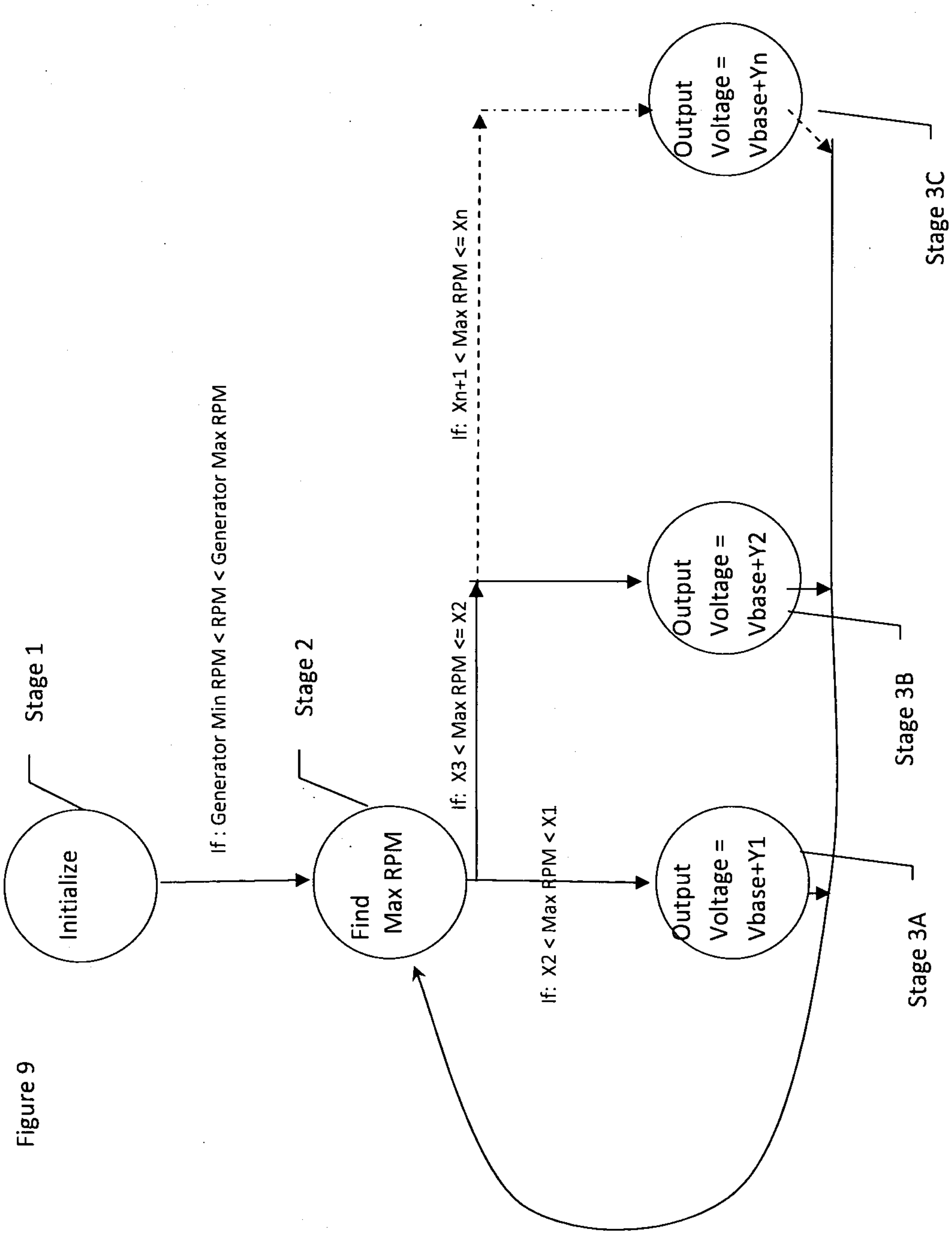

Stage 1
Initialize
If : Generator Min RPM < RPM < Generator Max RPM
Stage 2
Find
Max RPM
If: X2 < Max RPM < X1
If: X3 < Max RPM <= X2
If: Xn+1 < Max RPM <= Xn
Output
Voltage =
Vbase+Y1
Output
Voltage =
Vbase+Y2
Output
Voltage =
Vbase+Yn
Stage 3A
Stage 3B
Stage 3C

Figure 9

Figure 10

total voltage [V]	normal voltage[V	add voltage for hysteresis [V]	In algorithm		RPM	In algorithm
1.80953125	1.79	0.01953125	Y1		1400	X1
1.284414063	1.26	0.024414063	Y2		1515	X2
0.892460938	0.87	0.022460938	Y3		1616	X3
0.53953125	0.52	0.01953125	Y4		1695	X4
0.396601563	0.38	0.016601563	Y5		1843	X5

Figure 11A

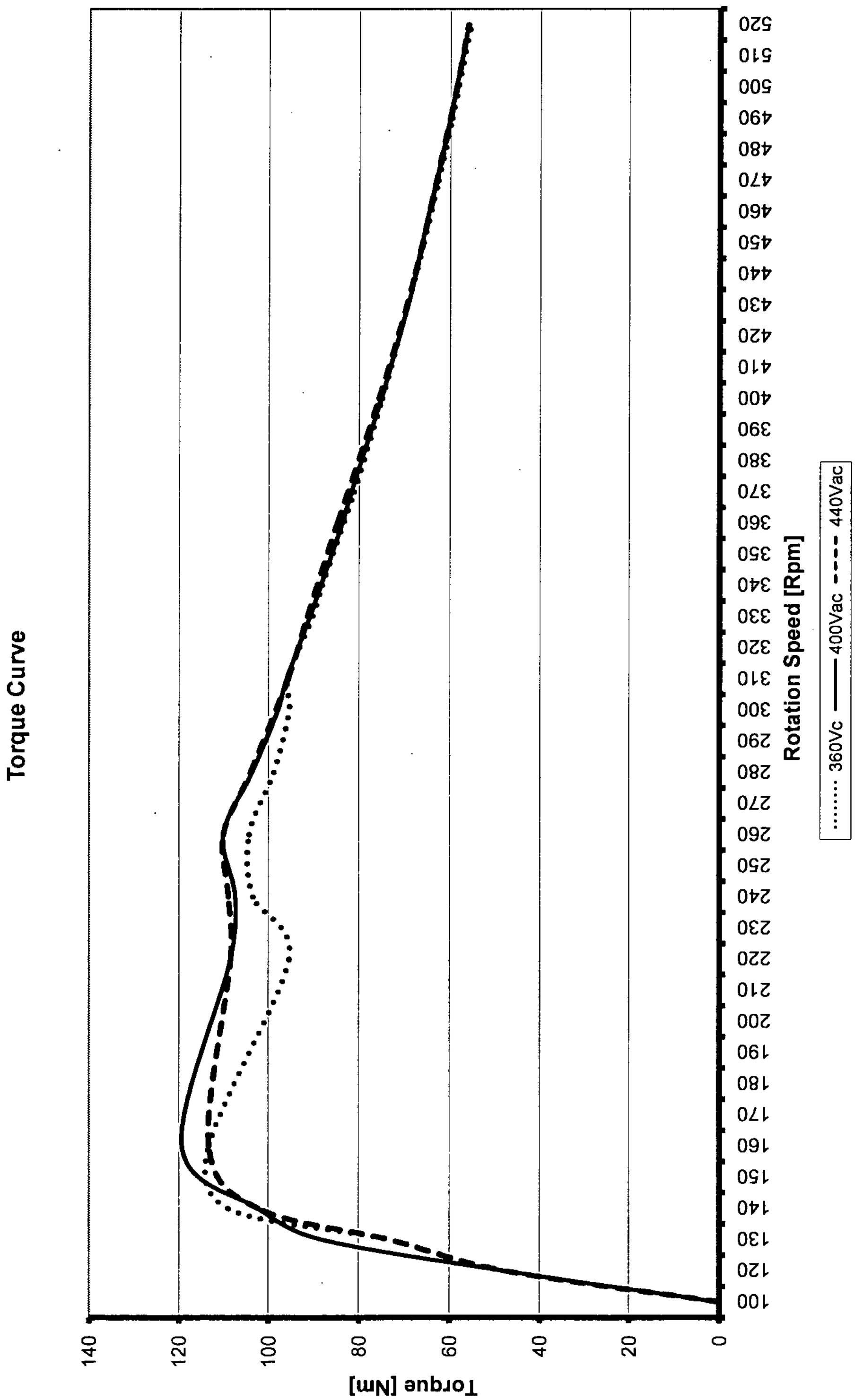
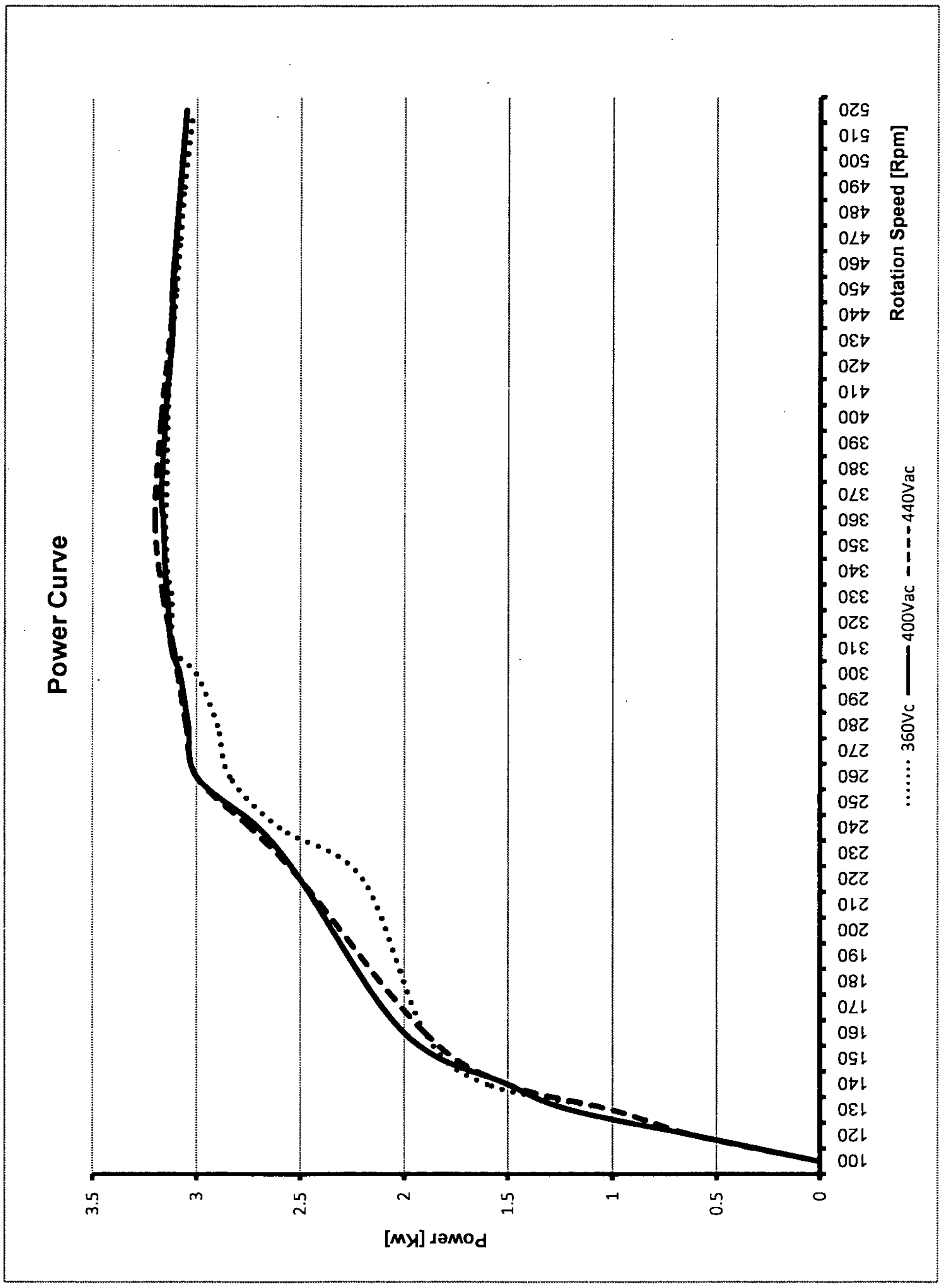

Torque Curve
Torque [Nm]
0
20
40
60
80
100
120
140
Rotation Speed [Rpm]
100
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
410
420
430
440
450
460
470
480
490
500
510
520
360Vc
400Vac
440Vac

Figure 11B


Power Curve
Power [Kw]
3.5
3
2.5
2
1.5
1
0.5
0
100 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310 320 330 340 350 360 370 380 390 400 410 420 430 440 450 460 470 480 490 500 510 520
Rotation Speed [Rpm]
360Vc
400Vac
440Vac

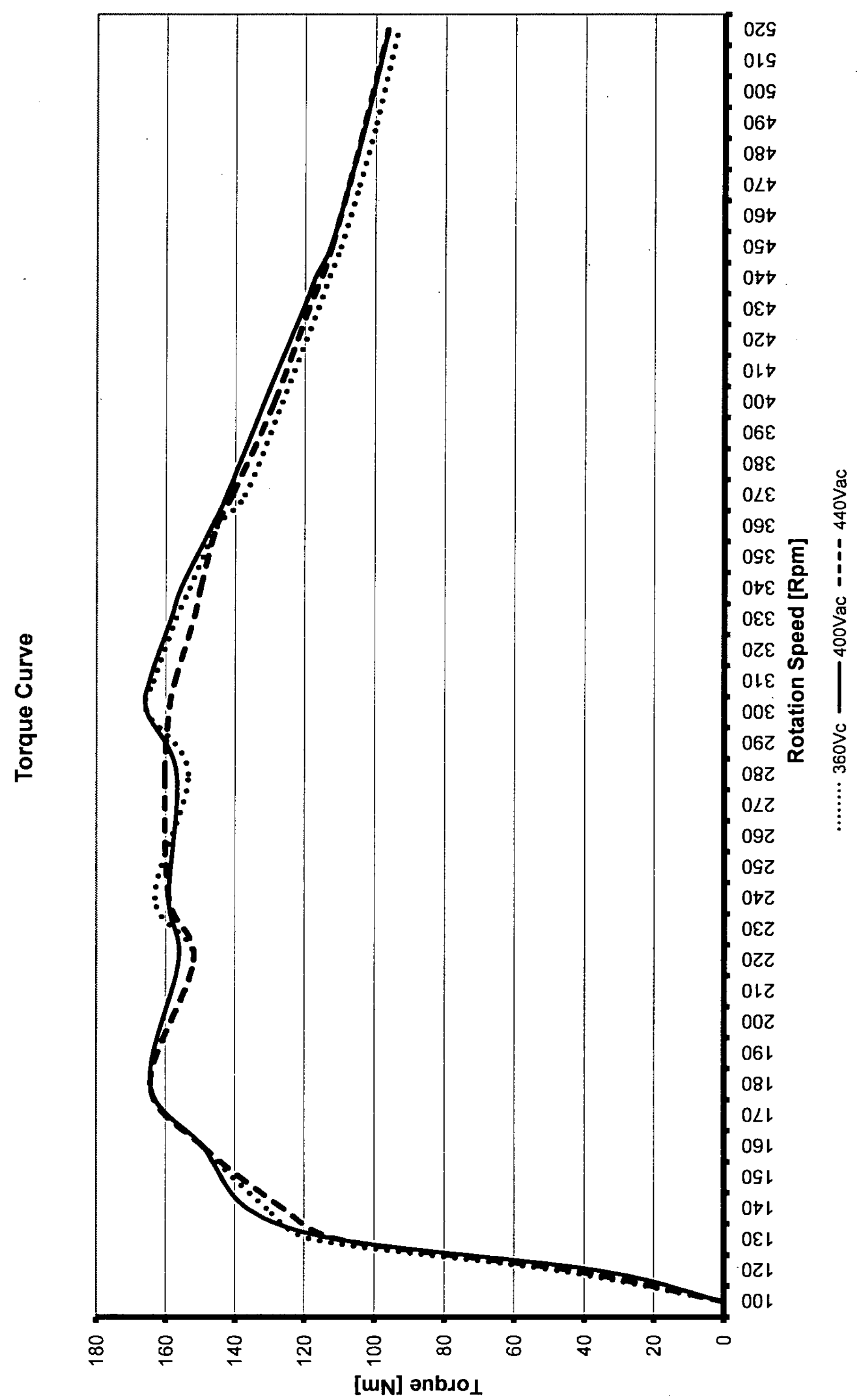

Torque Curve
Torque [Nm]
0
20
40
60
80
100
120
140
160
180
Rotation Speed [Rpm]
100
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
410
420
430
440
450
460
470
480
490
500
510
520
360Vc
400Vac
440Vac

Figure 12A

Figure 12B

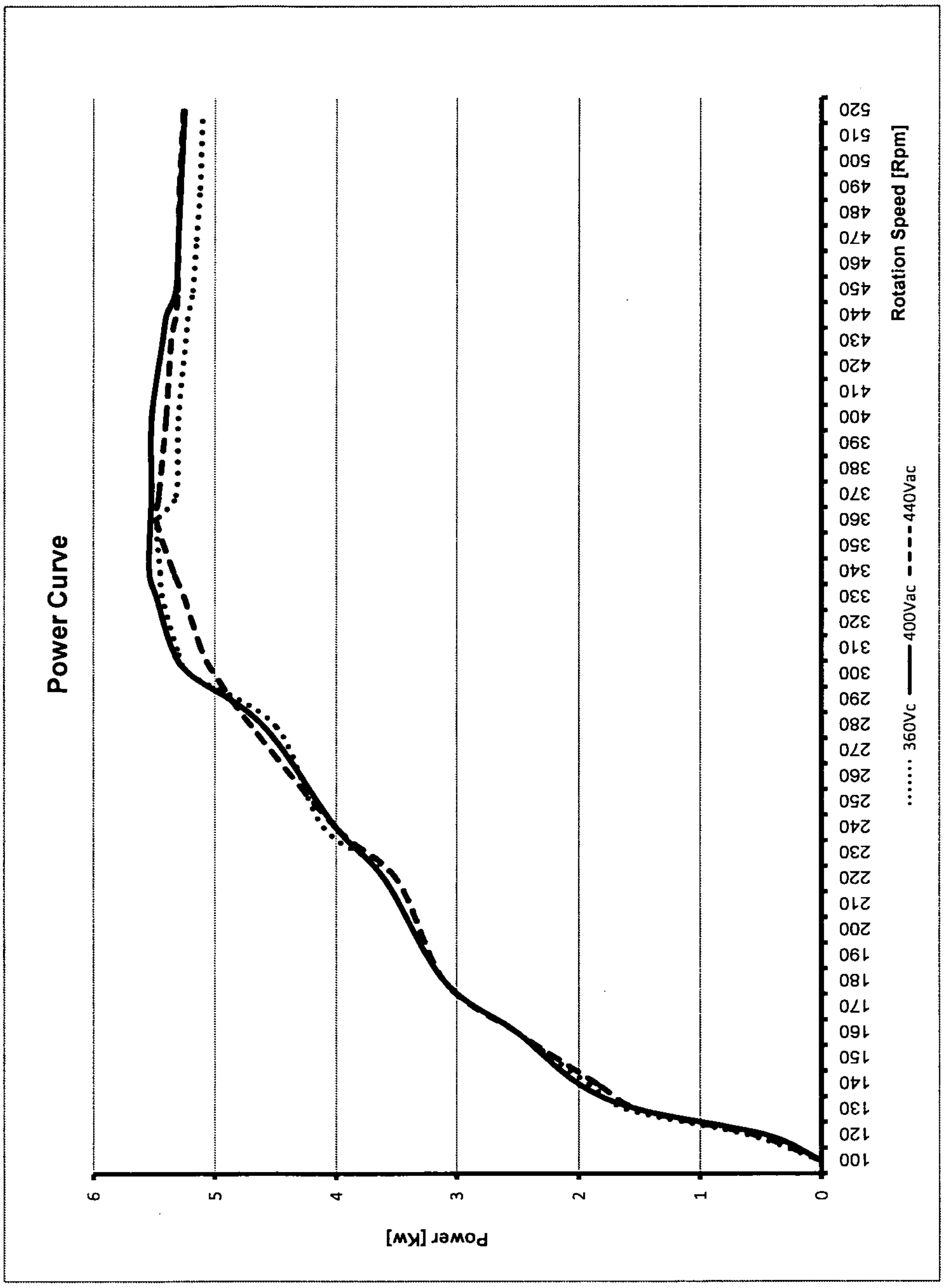
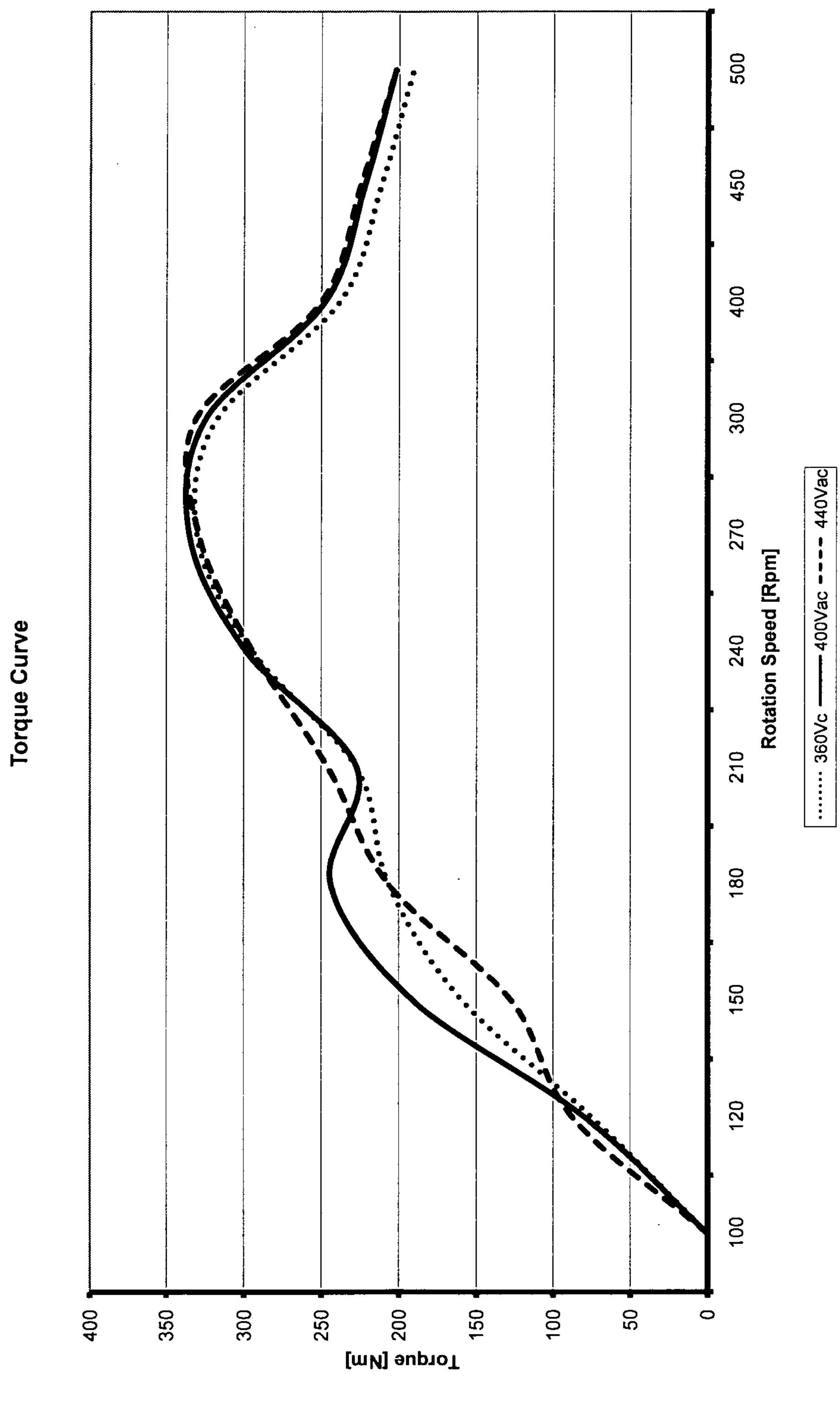

Power Curve
Power [Kw]
0
1
2
3
4
5
6
100 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310 320 330 340 350 360 370 380 390 400 410 420 430 440 450 460 470 480 490 500 510 520
Rotation Speed [Rpm]
360Vc
400Vac
440Vac

Figure 13A


Torque Curve
Torque [Nm]
400
350
300
250
200
150
100
50
0
100
120
150
180
210
240
270
300
400
450
500
Rotation Speed [Rpm]
360Vc
400Vac
440Vac

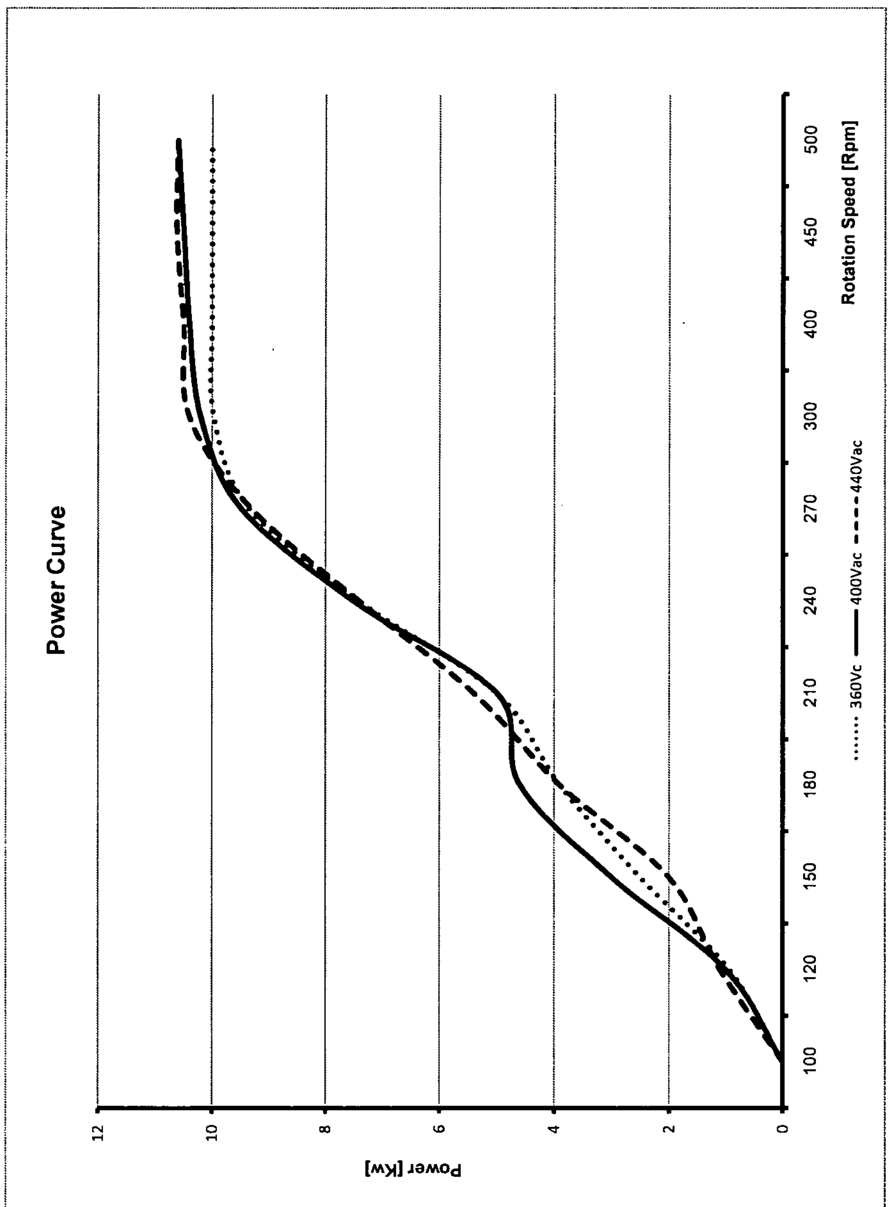

Power Curve
Power [Kw]
0
2
4
6
8
10
12
100
120
150
180
210
240
270
300
400
450
500
Rotation Speed [Rpm]
360Vc
400Vac
440Vac

Figure 13B