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(54) Title: AN AUTONOMOUS EXCITATION CONTROL SYSTEM FOR AN INTERNAL COMBUSTION DRIVEN ELECTRIC GENERATOR AND A METHOD THEREOF

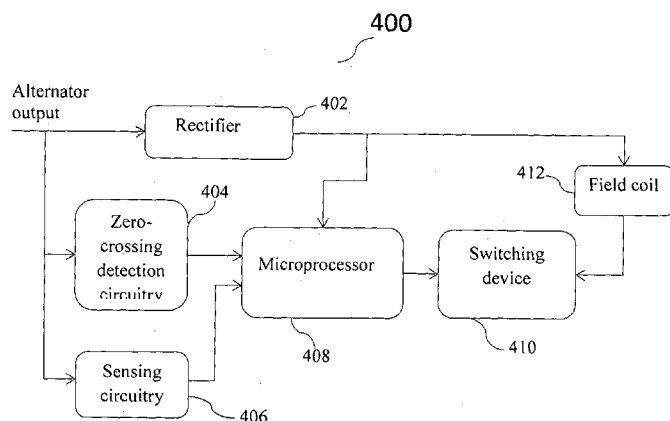


Fig. 4

(57) Abstract: An autonomous excitation control system for an internal combustion driven electric generator comprising: a rectifier circuitry coupled to alternator output to convert AC waveform from alternator output to a DC waveform; a zero crossing detection circuitry coupled to alternator output and generating an output pulse when the generator output crosses zero value; a sensing circuitry for sensing generator output voltage and converting said output voltage to low-power electric signals; a microprocessor receiving power from said rectifier circuit and having first input from said zero crossing detection circuitry and second input from said sensing circuitry; and an electronic switching device having input from said microprocessor is coupled to field coil of said electric generator; wherein based on the output of said sensing circuitry and said zero crossing detection circuitry, said microprocessor determines a first modulation index and based on the output of said zero crossing detection circuitry said microprocessor determines a second modulation index wherein based on said first modulation index and said second modulation index said microprocessor generates a modulation command for said electronic switching device thereby regulating power flow by said electronic switching device.



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TITLE OF THE INVENTION

**An Autonomous Excitation Control System for an Internal Combustion
Driven Electric Generator and a Method Thereof**

FIELD OF THE INVENTION

10 [001] The present invention relates generally to an excitation control system for an electric generator driven by an internal combustion engine. More particularly it relates to an autonomous excitation control system for an internal combustion engine driven electrically-excited electric generator and method thereof.

15 DESCRIPTION OF THE BACKGROUND OF THE INVENTION

[002] Electric generators driven by internal combustion engines have long been used as a source of electricity for backup power as well as for primary power applications. Such generators consist of an internal combustion engine, output shaft of which is connected to the rotating part of an electric generator. The generator converts the mechanical energy supplied by internal combustion engine into electricity, which is used to power electrical loads such as lighting equipment, electric motors and heating coils.

[003] In most applications of internal combustion engine driven electric generators, an electrically-excited type electric generator is used. The existing excitation control system for an internal combustion engine driven electrically

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5 excited type electric generator is described schematically in Fig. 1 wherein the same numerals indicate the same parts. The existing excitation control system 100 consists of an internal combustion engine 102, an alternator 104, AVR 106 and a field coil 108 of the alternator. The alternator 104 is an electromechanical device that converts mechanical energy to electrical energy in the form of alternating
10 current. The output of the alternator 104 i.e. the voltage is supplied to the AVR 106 and output of the AVR is supplied to the field coil 108 of the generator. In an electrically-excited type electric generator, a magnetic field is created in the electric generator using an externally applied electric current. This magnetic field is necessary for conversion of mechanical energy supplied by engine to electrical
15 energy, and has a strong influence on the characteristics of the electrical output. Figure 2 shows a graph representing variation of alternator output (voltage) with field coil current. Specifically, by varying the strength of the magnetic field, it is possible to vary the electric voltage generated at the generator output terminals.

20 [004] To ensure that the output of electric generator is compatible with the equipment with which it is connected, it needs to be ensured that certain characteristics of the generator output are within allowable tolerance limits. For example, for normal operation, most electric equipment requires that the supply voltage amplitude and frequency should be within certain permissible range.

5 While the frequency of the supply voltage is determined by operating speed of the internal combustion engine that is driving the generator, the voltage amplitude is a complex function of a number of operating parameters such as engine speed, load current and temperature. To ensure that in presence of varying operating parameters the voltage amplitude is maintained within permissible tolerance, an
10 excitation control system is used in electrically-excited generators. The excitation control system varies the current in field coil of the electric generator in response to change in amplitude of generator output voltage caused by variation in operating parameters, such that the generator output voltage amplitude is maintained within a tolerance band.

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[005] In an internal combustion engine, the power is generated in a non-uniform manner. Specifically, operation of an engine typically consists of four strokes: an intake stroke, a compression stroke, a power stroke and an exhaust stroke. Each stroke lasts for a specific crank angle duration, and the cycle of these four strokes
20 is repeated indefinitely. Out of these four strokes, the power is generated only during one of the strokes, namely the power stroke. Due to this phenomenon, the crank-shaft speed of an internal combustion engine exhibits periodic fluctuations. Figure 3 shows a graph representing how fluctuations in engine speed lead to fluctuations in alternator voltage. Since the crank-shaft of the engine is directly

5 coupled to the electric generator, speed of the electric generator also exhibits periodic fluctuations. Since the amplitude of the generator output voltage is a function of generator speed, such fluctuations in engine speed tends to cause fluctuations in output voltage amplitude. While the generator excitation control system corrects for slow variations in output voltage amplitude arising due to
10 factors such as change in load current, it cannot account for the fast fluctuations in voltage amplitude. Thus, output voltage amplitude of an electric generator driven by an internal combustion engine exhibits periodic fluctuations.

[006] Such fluctuation in voltage amplitude is, in general, undesirable. For
15 example, in presence of such fluctuations, a lighting load exhibits annoying flickering. While the extent of crank-shaft speed fluctuations can be reduced by increasing the weight of the flywheel connected to the engine, it increases the cost of flywheel and of other related mechanisms such as bearings and starter mechanism.

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[007] Considering the above there is need to provide an autonomous excitation control system and method for an internal combustion engine driven electrically-excited electric generator to regulate the output voltage value at a pre-determined value while reducing the fluctuations arising due to crank-shaft speed fluctuations.

- 5 [008] Further, there is need to provide an excitation correction system and method for an internal combustion engine driven electrically-excited electric generator that reduces voltage fluctuations arising in an engine driven electric generator equipped with an excitation control system, due to crank-shaft speed fluctuations.

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SUMMARY OF THE INVENTION

- [009] Disclosed herein is an autonomous excitation control system for an internal combustion driven electric generator comprising: a rectifier circuitry coupled to alternator output converts AC waveform from alternator output to a
- 15 DC waveform; a zero crossing detection circuitry coupled to alternator output and generating an output pulse when the generator output crosses zero value; a sensing circuitry for sensing generator output voltage and converting said output voltage to low-power electric signals; a microprocessor receiving power from output of said rectifier circuit and having first input from said zero crossing detection
- 20 circuitry and second input from said sensing circuitry; and an electronic switching device having input from said microprocessor is coupled to field coil of said electric generator; wherein based on the output of said sensing circuitry and said zero crossing circuitry, the microprocessor determines a first modulation index and based on the output of said zero crossing circuitry the microprocessor

5 determines a second modulation index wherein based on said first modulation index and said second modulation index the microprocessor generates a modulation command for said electronic switching device thereby regulating power flow by said electronic switching device.

10 [010] In some embodiments, excitation control system comprises a data storage circuitry.

[011] In some embodiments, excitation control system comprises an excitation control system.

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[012] In some embodiments, the electronic switching device is connected in series between the excitation control system and field coil.

[013] Also disclosed herein a method for autonomous excitation control system
20 for an internal combustion driven electric generator comprising the steps of: generating a DC power from the generator output power; supplying said DC power to a microprocessor and field coil of generator; sensing the generator output signal and converting it to low power electric signals; generating an output pulse when the generator output waveform crosses zero value; determining a

- 5 modulation index; and generating a modulation command, based on modulation index, for electronic switching device thereby regulating power flow by the electronic switching device.

BRIEF DESCRIPTION OF THE ACCOMPANYING DRAWINGS

- 10 [014] The above-mentioned and other features and advantages of the various embodiments of the invention, and the manner of attaining them, will become more apparent and will be better understood by reference to the accompanying drawings, wherein:

- [015] Fig. 4 is a schematic representation of an autonomous excitation control
15 system for an internal combustion engine driven electrically-excited electric generator according to the present invention; and

- [016] Fig. 5 is a schematic representation of an excitation correction system for an internal combustion engine driven electrically-excited electric generator according to the present invention.

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DESCRIPTION OF THE INVENTION

- [017] In order to achieve the aforesaid and other objectives, according to the invention, an autonomous excitation control system and method for an internal combustion engine driven electrically-excited electric generator and an excitation

5 correction system and method for an internal combustion engine driven electrically-excited electric generator is disclosed.

[018] Figure 4 shows a schematic representation of an autonomous excitation control system for an internal combustion engine driven electrically-excited electric generator. The autonomous excitation control system 400 for an internal combustion engine driven electrically-excited electric generator comprises a rectifier circuitry 402, a zero crossing detection circuitry 404, a sensing circuitry 406, a microprocessor 408, a data storage circuitry, an electronic switching device 410 and a field coil 412 of the generator. The rectifier circuitry 402 generates a direct current (DC) power source from generator output power. The zero crossing detection circuitry 404 generates an output pulse when the generator output waveform crosses zero value. The sensing circuitry 406 senses electric generator output voltage. The electronic switching device 410 regulates power flow. The microprocessor 408 determines a modulation index and a data storage circuitry that interfaces with the microprocessor.

[019] The rectifier circuitry 402 converts the alternating waveform from alternator output into a DC waveform. This DC waveform serves as the power source both for excitation energy to be supplied to the field coil 412 of the electric

5 generator as well as for the microprocessor 408 and other electronic circuitry. The sensing circuitry 406 converts the generator output signal to low-power electric signals that can be interfaced with the microprocessor 408. The microprocessor 408 processes the output of sensing circuitry and generates a command to modulate the electronic switching device 410. The DC waveform output of the
10 rectifier circuitry 402 is applied across the field coil 412 of the electric generator through the switching device 410. By suitable modulation of the switching device 410, the amount of excitation energy to the field coil 412 is controlled, which in effect controls the strength of magnetic field.

15 [020] The output of the zero-crossing detection circuitry and that of the sensing circuitry serve as an input to the microprocessor. Based on these inputs, the microprocessor 408 determines a modulation index, which is the fraction of time for which the switching device is to be kept in “on” state. The modulation index is directly related to the amount of energy supplied to the field coil, and hence to the
20 strength of the magnetic field created in the generator.

[021] Based on the output of the sensing circuitry and the zero-crossing detection circuitry, the microprocessor determines a first modulation index as follows: the output of the sensing circuitry is converted into a digital value inside

5 the microprocessor 408. Based on the output of zero-crossing detection circuitry, where each zero-crossing event corresponds to a cycle of generator output waveform, an average of this digital value over a certain number of generator output cycles is computed. The number of cycles for which to determine this average value is determined as the integer number of generator output cycles that
10 correspond to an engine thermal cycle, where an engine thermal cycle comprises two mechanical revolutions of engine. Thus, this value is effectively equal to number of poles of the generator.

[022] The digital value so computed is compared with a reference digital value.
15 The difference between the two values is acted upon by a proportional-integral-derivative (PID) method which is a well-known method in control systems literature. The output of the PID method is interpreted as the first modulation index.

20 [023] Further, the microprocessor determines a second modulation index as follows: based on the output of the zero-crossing detection circuitry, the microprocessor determines the time corresponding to a cycle of generator output waveform. By suitably updating the memory element at every zero-crossing event, the value of time taken for each generator output cycle for cycles corresponding to

5 last engine thermal cycle is stored in the memory element. From such stored values, a value corresponding to average time taken per cycle for cycles corresponding to the last engine thermal cycle is computed. The second modulation index is computed as the difference between the average time per cycle over duration of last engine thermal cycle and the time taken for the latest
10 cycle, multiplied by a constant.

[024] The microprocessor 408 adds the first modulation index with the second modulation index to compute the total modulation index. Based on value of total modulation index, the microprocessor 408 generates a modulation command for
15 the switching device 410.

[025] The effect of first modulation index and the second modulation index are explained herein below. The first modulation index generates a field excitation value to regulate the generator output voltage at a pre-determined value in
20 presence of factors such as internal resistance of generator windings, variations in load current, variations in temperature and part-to-part variability. This is achieved due to feedback control action, where the field excitation amount is varied according to error between the desired output voltage value and measured output voltage value. Further, since an average value of time taken per cycle over

5 duration of an engine thermal cycle is used for the feedback control computations, the first modulation index is not affected by cyclic crank-shaft speed fluctuations.

[026] The second modulation index reduces effect of cyclic crank-shaft speed fluctuations on generator output. This is achieved by varying the excitation
10 amount in accordance with crank-shaft speed fluctuations in such as manner as to negate the effect of later on generator output voltage. Specifically, within the duration of an engine thermal cycle, in generator output cycles where the engine crank-shaft speed is expected to be more than the average engine speed over an engine thermal cycle, the excitation amount is decreased. Similarly, in generator
15 output cycles where engine crank-shaft speed is expected to be less than the average engine speed over an engine thermal cycle, the excitation amount is increased. Further, this increase/decrease in excitation amount is done in proportion to fluctuations in engine crank-shaft speed. This ensures that effect of engine speed fluctuations on generator output voltage is substantially reduced.

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[027] A method of autonomous excitation control system for an internal combustion engine driven electrically-excited electric generator is also disclosed. The method comprises the steps of: generating a direct current (DC) power source from the generator output power, supplying the DC power source to the

5 microprocessor and the field coil of the generator, sensing the generator output signal and converting it to low power electric signals, generating an output pulse when the generator output waveform crosses zero value, determining a modulation index, generating a modulation command for the electronic switching device and regulating power flow by the electronic switching device.

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[028] Figure 5 shows a schematic representation of an excitation correction system for an internal combustion engine driven electrically-excited electric generator. The excitation correction system 500 reduces voltage fluctuations arising in an engine driven electric generator equipped with an excitation control
15 system, due to crank-shaft speed fluctuations. The excitation correction system 500 adds a correction value to amount of field excitation generated by an already-existing excitation control system to counter the voltage fluctuations arising due to crank-shaft speed fluctuations.

20 [029] The excitation correction system 500 comprises a rectifier circuitry 502, a zero crossing detection circuitry 504, a sensing circuitry 506, a microprocessor 508, an electronic switching device 510 and a field coil 512 of the generator. The rectifier circuitry 502 converts the alternating waveform from alternator output into a DC waveform. This DC waveform serves as the power source for the

5 microprocessor 508. The sensing circuitry 506 senses electric generator output voltage. The zero-crossing detection circuitry 504 generates an output pulse when the generator output waveform crosses zero value. The microprocessor 508 determines a modulation index and a data storage circuitry that interfaces with the microprocessor 508. The electronic switching device 510 regulates power flow.

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[030] In the excitation correction system, the sensing circuitry 506 converts the generator output signal to low-power electric signals that can be interfaced with the microprocessor 508. The electric generator output voltage is supplied to the existing excitation system and further the output of the existing excitation system
15 is supplied to the field coil 512 of the generator. The microprocessor 508 processes the output of sensing circuitry and generates a command to modulate the electronic switching device 510. The switching device 510 is connected in series between the excitation control system and the field coil. Specifically, the switching device is connected between one terminal of excitation control system
20 and the corresponding field coil terminal. By suitable modulation of the switching device, the amount of excitation energy to the field coil provided by the excitation control system can be modified, which in effect results in modification in the strength of magnetic field.

5 **[031]** The extent to which the excitation provided by the excitation control system is to be modified is decided by the microprocessor 508 through computation of a modulation index. The modulation index corresponds to the fraction of time for which the switching device is “on”. The modulation index is directly proportional to the amount of modification made in the excitation
10 provided by the excitation control system.

[032] The modulation index is determined by the microprocessor 508 based on the output of the sensing circuitry and the zero-crossing detection circuitry in a manner similar to the one described in this invention for the case of autonomous
15 excitation control system. Specifically, only the second modulation index described in the case of autonomous excitation control system is determined.. Based on value of the modulation index so determined, the microprocessor generates a modulation command for the switching device.

20 **[033]** Since the second modulation index addresses only the voltage fluctuations arising due to crank-shaft speed fluctuations, the excitation correction system only addresses those voltage fluctuations, without affecting other performance of the excitation control system.

5 [034] A method of excitation correction system for an internal combustion engine driven electrically-excited electric generator is also disclosed. The method comprises the steps of: generating a direct current (DC) power source from generator output power, supplying the DC power source to the microprocessor and the field coil of the generator, sensing the generator output signal and
10 converting it to low power electric signals, generating an output pulse when the generator output waveform crosses zero value, determining a modulation index, adding a correction value to the amount of field excitation, generating a modulation command for the electronic switching device and regulating the power flow by the electronic switching device.

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[035] It will be apparent to those skilled in the art that various modifications and variations can be made to the present invention without departing from the spirit and scope of the invention. Thus it is intended that the present invention cover the modifications and variations of this invention provided they come within the
20 scope of the appended claims and their equivalents.

5 We claim:

1. An autonomous excitation control system for an internal combustion driven electric generator comprising:
 - a rectifier circuitry coupled to alternator output to convert AC waveform from alternator output to a DC waveform;
 - 10 a zero crossing detection circuitry coupled to alternator output and generating an output pulse when the generator output crosses zero value;
 - a sensing circuitry for sensing generator output voltage and converting said output voltage to low-power electric signals;
 - a microprocessor receiving power from said rectifier circuit and having first
 - 15 input from said zero crossing detection circuitry and second input from said sensing circuitry; and
 - an electronic switching device having input from said microprocessor is coupled to field coil of said electric generator; wherein
 - based on the output of said sensing circuitry and said zero crossing detection
 - 20 circuitry, said microprocessor determines a first modulation index and based on the output of said zero crossing detection circuitry said microprocessor determines a second modulation index wherein based on said first modulation index and said second modulation index said microprocessor generates a

- 5 modulation command for said electronic switching device thereby regulating power flow by said electronic switching device.
2. An autonomous excitation control system for an internal combustion driven electric generator as claimed in claim 1, comprising a data storage circuitry.
- 10 3. An autonomous excitation control system for an internal combustion driven electric generator as claimed in claim 1, comprising an excitation control system.
- 15 4. An autonomous excitation control system for an internal combustion driven electric generator as claimed in claim 3, wherein said electronic switching device is connected in series between the excitation control system and field coil.
- 20 5. A method for autonomous excitation control system for an internal combustion driven electric generator comprising the steps of:
generating a DC power from the generator output power;
supplying said DC power to a microprocessor and field coil of generator;

- 5 sensing the generator output signal and converting it to low power electric signals;
generating an output pulse when the generator output waveform crosses zero value;
determining a modulation index; and
10 generating a modulation command, based on modulation index, for electronic switching device thereby regulating power flow by the electronic switching device.
6. A method for autonomous excitation control system for an internal
15 combustion driven electric generator as claimed in claim 5, wherein said modulation index is a sum of first modulation index and a second modulation index.
7. A method for autonomous excitation control system for an internal
20 combustion driven electric generator as claimed in claim 6, wherein method for determining first modulation index comprises the steps of:
converting said low power electric signals to a digital value inside the microprocessor;

5 based on said output pulse an average of said digital value is computed over a
certain number of generator output cycles;
comparing said digital value with a reference digital value and generating a
difference signal; and
performing a proportional-integral-derivative (PID) on the difference signal to
10 obtain first modulation index.

8. An autonomous excitation control system for an internal combustion driven
electric generator as claimed in claim 6, wherein method for determining
second modulation index comprises the steps of:
15 determining the time corresponding to a cycle of generator output waveform;
storing value of time taken for each generator output cycle for cycles
corresponding to last engine thermal cycle;
computing average time taken per cycle for cycles corresponding to the last
engine thermal cycle;
20 computing difference between the average time per cycle over duration of last
engine thermal cycle and the time taken for the latest cycle;
obtaining second modulation index by multiplying said computed difference
by a constant.

- 5 9. An autonomous excitation control system for an internal combustion driven electric generator as claimed in claim 6, wherein first modulation index generates a field excitation value to regulate the generator output voltage at a pre-determined value.
- 10 10. An autonomous excitation control system for an internal combustion driven electric generator as claimed in claim 6, wherein second modulation index reduces effect of cyclic crank-shaft speed fluctuations on generator output.

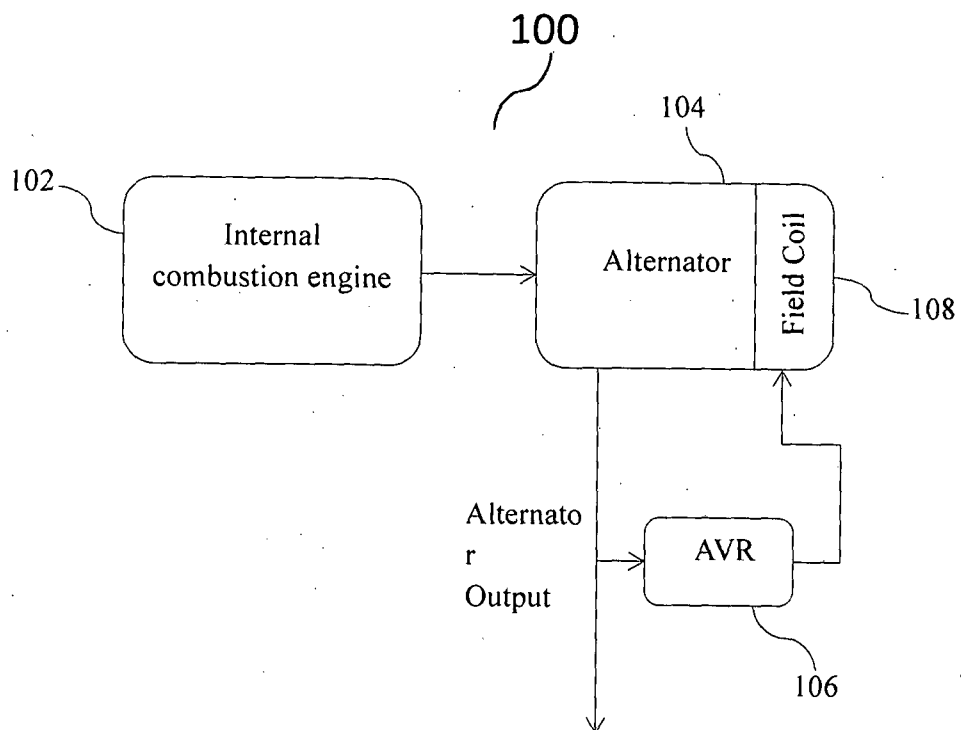


Fig. 1

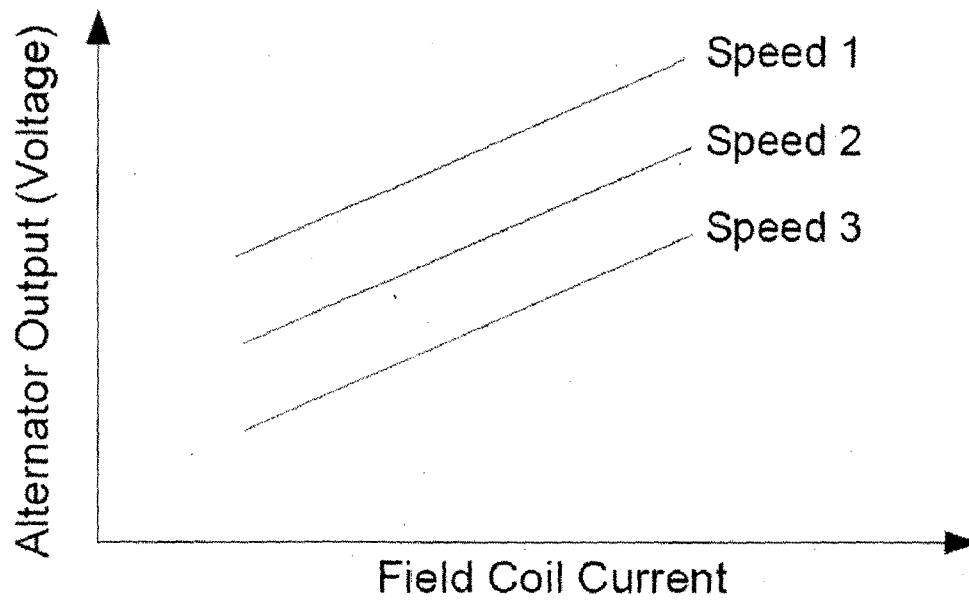


Fig 2

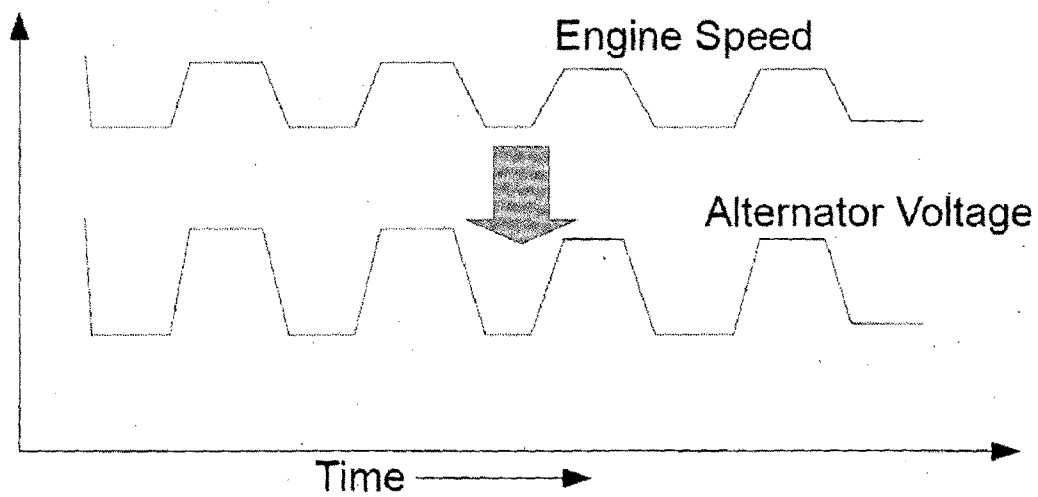


Fig 3

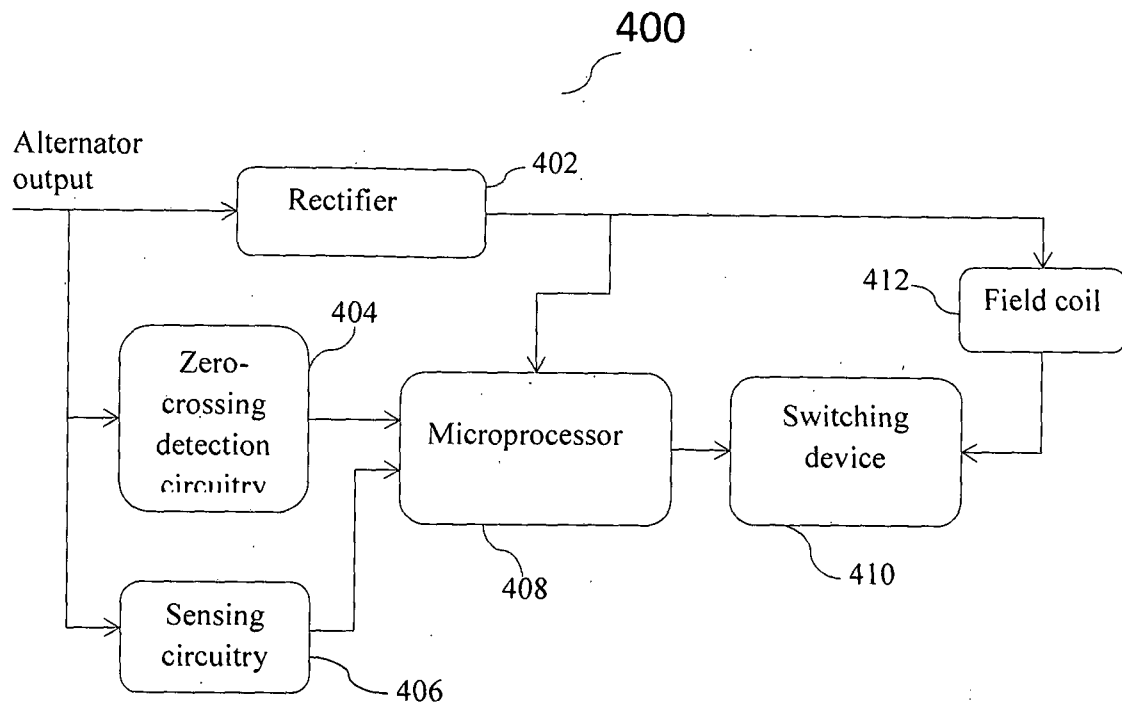


Fig. 4

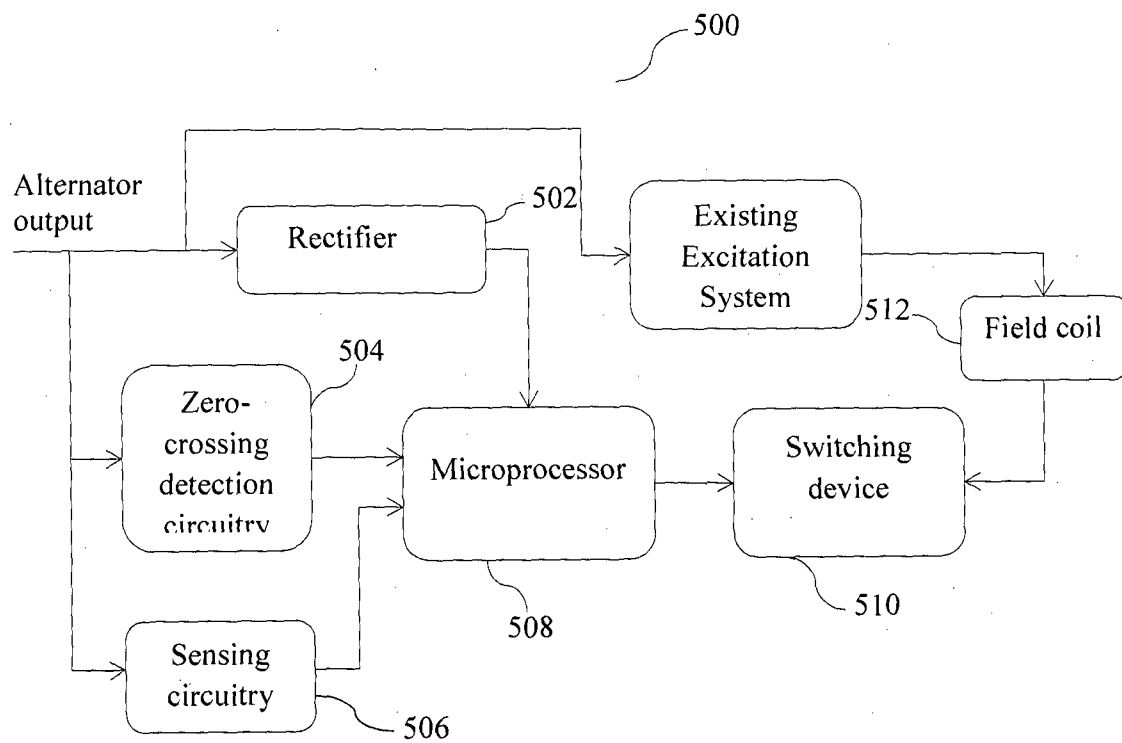


Fig. 5