Abstract: A method includes selecting a link voltage based on voltage efficiencies of components in an electric drive motor system, and applying the link voltage to an inverter electrically coupled to a drive motor to increase system efficiency.

**FIG. 1**

(Continued on next page)
Published:
— with international search report (Art. 21(3))
— before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))
SYSTEM AND METHOD FOR MOTOR SYSTEM CONTROL

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Application No. 62/067,218, filed October 22, 2014, entitled "SYSTEM AND METHODS FOR OPTIMIZING FUEL CONSUMPTION," which is hereby incorporated by reference in its entirety.

BACKGROUND

TECHNICAL FIELD

[0002] Embodiments of the invention relate generally to motor system control, such as in a vehicle.

DISCUSSION OF ART

[0003] In the mining industry, large off-highway vehicles, "OHVs", may employ electrically motorized wheels for propelling or retarding the vehicle. In particular, OHVs typically include a large horsepower diesel engine in conjunction with an alternator, a traction inverter, and wheel drive assemblies housed within the rear tires of the vehicle. In operation, the diesel engine drives the alternator, which powers the traction inverter. The traction inverter includes semiconductor power switches that commutate the alternator output current to provide electrical power to electric drive motors, e.g., AC motors, of the wheel drive assemblies.

[0004] Such systems also include controllers and software that set the voltage passed to the traction inverters. This voltage, referred to as a "link voltage" is the main system variable in determining the operating mode and efficiency of the alternator, traction inverter, and traction motor. Link voltages typically vary based solely on the OHV motor speed and do not take into consideration factors such as ambient conditions.

[0005] As will be appreciated, changing the link voltage, however, can alter the fuel consumption of the system. It may therefore be desirable to provide a system and method that differ from existing systems and methods, for motor system control to reduce fuel consumption.
BRIEF DESCRIPTION

[0006] In one embodiment, a method is provided (e.g., a method of motor system control). The method includes selecting a link voltage based on voltage efficiencies of components in an electric drive motor system, and applying the link voltage to an inverter electrically coupled to a drive motor to increase system efficiency (e.g., increase relative to using a link voltage that is not selected based on voltage efficiencies of components in the electric drive motor system). The method may be carried out by one or more electrical components of the electric drive motor system, such as a controller.

[0007] In an embodiment, a method includes selecting a link voltage based on one or more ambient conditions of an electric drive motor system and applying the link voltage to an inverter electrically coupled to a drive motor to increase system efficiency.

[0008] In an embodiment, a method includes selecting (e.g., periodically selecting) a link voltage based on one or more efficiency parameters of an electric drive motor system, applying the link voltage that is selected to an inverter of the system, and changing an operating mode of the inverter in response to the application of the selected link voltage.

[0009] In an embodiment, an electric drive motor system includes a controller configured to select (e.g., periodically select) a link voltage based on one or more efficiency parameters of the system. The system further includes an inverter electrically coupled to the controller and to a motor. The inverter is configured to receive the link voltage that is selected. At least one of the inverter or the controller is configured to change an operating mode of the inverter in response to application of the link voltage that is selected (e.g., the controller may control the inverter to change operating modes, or the inverter may itself change operating modes). For example, the inverter may be switched between pulse width modulation and square wave modulation to increase system efficiency.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The present invention will be better understood from reading the following description of non-limiting embodiments, with reference to the attached drawings, wherein below:

[0011] FIG. 1 is a simplified schematic diagram of a system, which may be used with embodiments of the present invention.
FIG. 2 is a chart depicting a typical link voltage curve.

FIG. 3 is a chart depicting a link voltage curve according to an embodiment of the present invention.

DETAILED DESCRIPTION

Reference will be made below in detail to exemplary embodiments of the invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference characters used throughout the drawings refer to the same or like parts. While embodiments of the invention are suitable for use with both mobile and stationary implementations, for ease of explanation a mobile implementation is described in detail herein. More specifically, an OHV has been selected for clarity of illustration for the disclosure of mobile embodiments. Other suitable vehicles include, for example, on-road vehicles, locomotives, construction equipment, industrial equipment, and marine vessels. As used herein, "operating mode" refers to power control modes of an inverter and includes, but is not limited to, pulse width and square wave modulations.

Referring now to FIG. 1, embodiments of a system are configured for use with a motive machine such as an OHV or other vehicle. In these embodiments, the system generally includes a primary DC link 10 and a secondary DC link 20. The links 10, 20 are electrically coupled to a converter 30, e.g., a DC/DC converter, which steps down voltage from the primary link 10 to the secondary link 20. As shown, the primary link 10 is connected to a power source 40, e.g., an engine- or other prime mover-driven alternator, which powers the system. The primary link 10 includes multiple traction inverters 50 that are coupled to one or more traction motors 60 (also referred to as drive motors) and a braking chopper 70.

As mentioned, the DC/DC converter 30 steps down the first link voltage V1. In an embodiment, the first link voltage V1 is from about 500V to about 2200V, e.g., the link-voltage may be a selected or pre-determined static value within that range, or may be controllable within that range. As further illustrated in FIG. 1, the system also includes a controller 100 that is configured to communicate with the power source, e.g., alternator 40, and traction inverters 50, through communication links, which may be Ethernet or fiber optic
based, although other communication protocols and cabling may be employed without departing from the broader aspects of the invention.

[00017] Referring now to FIG. 2, a chart shows a typical link voltage curve in which the link voltage VDC is fixed and based on motor speed. As shown, where the V-l-n curve crosses the 0.45* VDC curve, denoted by reference number 200, the fundamental operating mode of the system changes. That is, the inverters will switch from pulse width modulation (PWM) to square wave modulation. This is referred to herein as the operating mode "changeover point." The changeover reduces the losses in the inverter but increases the losses in the motors to a greater extent and by extension reduces overall system efficiency. Presently, this significant change from PWM to square wave happens at the same speed, i.e., is fixed, regardless of ambient conditions or other considerations such as individual system component voltage efficiencies, which are collectively referred to herein as "efficiency parameters." Voltage efficiency generally refers to efficiency of a component at a particular input voltage, e.g., link voltage, which may be determined empirically or based on sensor data and/or assessment of system performance in different operating modes over time.

[00018] Utilizing fixed voltages can be inefficient as most systems are designed to operate reliably in worst-case conditions. For example, the predetermined link voltages may be based on thermal limitations at hot ambient conditions, which may not be present. As a result, opportunities to save fuel (and increase system efficiency) may exist where vehicles are operating at lower temperatures. Indeed, in an embodiment, link voltage and the inverter changeover point may be adjusted based on ambient temperature and thermal margin. For example, on a cold day when inverters can handle it, the inverters can run in the more efficient PWM mode for extended periods instead of switching into square wave mode at higher motor speeds.

[00019] As shown in FIG. 3, in embodiments of the invention, the system can be run in a more efficient mode, when the inverter is not thermally limited, by varying the link voltage, e.g., increasing it, and remaining in PWM. In the depicted embodiment, the link voltage has increased and the operating mode changeover point 300 has correspondingly moved to from -750 rpm to 1000 rpm. By continuously varying the link voltage in real time, the inverter mode can be controlled at any speed within the acceptable limits for voltage and component temperature. As used herein, "real time" means the actual time during which something takes
place (e.g., the controller 100 may vary the link voltage as input data is received). Link voltage also affects alternator and inverter efficiency for a given operating mode so this may also be taken into consideration.

[00020] In an embodiment, the link voltage, and operating mode, can be varied/controlled in real time by assessing optimal voltages of system components. That is, the highest total system efficiency is determined by the operating mode/point of three major components, the alternator, the inverter, and the traction motor. With respect to the alternator, this component's efficiency is dependent on system voltage (e.g., the rated and/or maximum voltage of the system) and current. However, the alternator may have an intermediate voltage where its efficiency is highest, and always using the highest or lowest possible voltage is generally not optimal.

[00021] Inverter efficiency is dependent on system voltage, and the minimum voltage required to achieve desired output is generally optimal. Inverter efficiency is also highly dependent on inverter mode and switching frequency. Likewise, the traction motor efficiency is highly dependent on inverter mode and switching frequency. The optimal point, however, is the inverse of what is optimal for the inverter. The motor, however, generally is the larger portion of system losses. For example, the system may have a link voltage range of, for example, 1000-1200V, for a given load and speed. Individual components within the system may operate optimally at certain points within the range, e.g., the alternator may operate most efficiently at 1175 - 1200V.

[00022] By assessing the optimal component voltages, the system can be ran at the most efficient link voltage point while respecting thermal limits. As mentioned, for the alternator, in embodiments the alternator is operated at a voltage, such as an intermediate voltage, where its efficiency is highest, or at least higher than operation at other voltages. With respect to the inverter and traction motor, these components may be ran at the lowest voltage that supports PWM and the switching frequency that minimizes losses for as long as the inverter can thermally support operation in this mode. In embodiments, when the inverter is thermally challenged such that the ambient temperature approaches a threshold, switching frequency can be lowered or the inverter operating mode shifted, which increases total system losses but transfers the majority of losses to the motor instead of the inverter which increases system efficiency.
Certain embodiments of the invention relate to retarding a vehicle. In retard, the only power from the engine is the power used to cool the components. The engine is run at the lowest speed necessary to save fuel, but is increased when components become hot. Which components heat up and how fast is determined by the motor speed dependent link voltage schedule. In embodiments, the link voltage schedule could be altered in real time to minimize losses in a hot component or change the distribution of losses between components.

Additional!, switching frequency may be altered to balance losses between inverter and motor. This could be used to minimize the amount of time the engine speed needs to be elevated and therefore save fuel.

Referring again to FIG. 3, in certain embodiments of the invention, operating mode and link voltage may be varied to decrease losses at lower motor speeds. As shown therein, at lower speeds, e.g., 0 - 650 rpm, more power is generated than is needed which is graphically represented by area 310. In this region, 0.45*VDC, i.e., the voltage put out, is greater than the line voltage. In embodiments, by varying the link voltage and changing operating mode, system efficiency can be increased.

The above-described methods and control strategies may be effectuated by a controller, e.g., controller 100, which includes electronic components or other hardware for varying link voltage. The controller may additionally include one or more sets of instructions or other software, stored on a tangible non-transitory medium and accessible/readable by the hardware. In embodiments, the instructions include an algorithm that may be implemented in software running on a processor (e.g., RISC). In certain embodiments, the controller may be operative!} connected to sensors to detect ambient conditions, or other parameters, so that link voltage may be varied appropriately.

In an embodiment, a method is provided. The method includes the steps of selecting a link voltage based on voltage efficiencies of components in an electric drive motor system, and applying the link voltage to an inverter electrically coupled to a drive motor to increase system efficiency. In an embodiment, the components include at least an alternator, the inverter and the drive motor. In an embodiment, the step of selecting the link voltage may include assessing an optimal voltage for the alternator, inverter and drive motor. The optimal voltage for the drive motor and the inverter may be a lowest voltage that supports pulse width modulation. In an embodiment, the method may also include the step of
identifying a switching frequency for the inverter and the drive motor that minimizes losses for as long as the inverter can thermally support. Moreover, in an embodiment, the method may also include the steps monitoring an ambient temperature, and lowering the switching frequency of the inverter or shifting an operating mode of the inverter when the ambient temperature exceeds a threshold. In an embodiment, the steps of selecting and applying the link voltage are carried out by a controller of the electric motor drive system and are carried out in real time. The electric motor drive system may provide motive power for an off-highway vehicle.

[00027] In an embodiment, a method is provided. The method includes the steps of selecting a link voltage based on ambient conditions of an electric drive motor system and applying the link voltage to an inverter electrically coupled to a drive motor to increase system efficiency. In an embodiment, the step of selecting the link voltage may include assessing the voltage efficiencies of components in the electric drive motor system. The components may include at least an alternator, the inverter and the drive motor. In an embodiment, an optimal voltage for the traction motor and the inverter is a lowest voltage that supports pulse width modulation. In an embodiment, the method may also include the step of identifying a switching frequency for the inverter and the drive motor that minimizes losses for as long as the inverter can thermally support. In an embodiment, the method may also include the step of lowering the switching frequency of the inverter or shifting an operating mode of the inverter when the ambient conditions of the electric drive motor system exceed a threshold.

[00028] In yet another embodiment, a method is provided. The method includes the steps of periodically selecting a link voltage based on an efficiency parameter of an electric drive motor system, applying the link voltage to an inverter of the system, and changing an operating mode of the inverter in response to the application of a selected link voltage. In an embodiment, the efficiency parameter is an ambient condition of the electric drive motor system. In another embodiment, the efficiency parameter is a voltage efficiency of a component in the electric drive motor system. The component may be at least one of an alternator, a traction motor and the inverter.

[00029] In an embodiment, an electric drive motor system is provided. The system includes a controller configured to periodically select a link voltage based on at least one
efficiency parameter of the system and an inverter electrically coupled to the controller and to a motor. The inverter is configured to receive the selected link voltage. The inverter switches between pulse width modulation and square wave modulation to increase system efficiency, in response to receiving the selected link voltage. In an embodiment, the at least one efficiency parameter is an ambient condition of the electric drive motor system. In an embodiment, the at least one efficiency parameter is a voltage efficiency of a component in the electric drive motor system. In an embodiment, the component is at least one of an alternator, the motor and the inverter. In an embodiment, the system is configured to provide motive power for an off-highway vehicle.

[00030] In an embodiment, a method (e.g., a method of motor system control) includes selecting a link voltage based on voltage efficiencies of components in an electric drive motor system. The method further includes applying the link voltage to an inverter electrically coupled to a drive motor to increase system efficiency. For example, system efficiency may be increased relative to using a link voltage that is not selected based on voltage efficiencies of components in the electric drive motor system.

[00031] In an embodiment, an electric drive motor system includes a controller, an inverter, and a drive motor. The controller is configured to select a link voltage based on voltage efficiencies of components in the electric drive motor system. The controller is configured to apply the link voltage that is selected to the inverter, to increase system efficiency. The electric drive motor system may be part of an OHV or other vehicle, to provide motive power for the vehicle.

[00032] In an embodiment, a method (e.g., a method of motor system control) includes selecting a link voltage based on one or more ambient conditions of an electric drive motor system. The method further includes applying the link voltage to an inverter electrically coupled to a drive motor to increase system efficiency. For example, system efficiency may be increased relative to using a link voltage that is not selected based on voltage efficiencies of components in the electric drive motor system.

[00033] In an embodiment, an electric drive motor system includes a controller, an inverter, and a drive motor. The controller is configured to select a link voltage based on one or more ambient conditions the electric drive motor system. The controller is configured to apply the link voltage that is selected to the inverter, to increase system efficiency.
[0034] In an embodiment, a method (e.g., a method of motor system control) includes selecting (e.g., periodically selecting) a link voltage based on one or more efficiency parameters of an electric drive motor system. The method further includes applying the link voltage that is selected to an inverter of the system, and changing an operating mode of the inverter in response to the application of the link voltage that is selected. For example, changing the operating mode of the inverter may include switching the inverter between pulse width modulation and square wave modulation, b increase system efficiency.

[0035] In an embodiment, an electric drive motor system includes a controller, an inverter, and a drive motor. The controller is configured to select a link voltage based on one or more efficiency parameters of the system. The inverter is electrically coupled to the controller and to the motor, and is configured to receive the link voltage that is selected. At least one of the inverter or the controller is configured to change an operating mode of the inverter in response to application of the link voltage that is selected. For example, the system may be configured for the controller to control the inverter to change operating modes, and/or the inverter may be configured to automatically change operating modes responsive to link voltage. In an embodiment, change of operating modes of the inverter includes switching the inverter between pulse width modulation and square wave modulation, to increase system efficiency.

[0036] In any of the embodiments herein, a selected link voltage may be applied (e.g., to an electrical bus that connects to an inverter) by a controller controlling a power converter that is provided to generate the link voltage. For example, a system may include an engine or other prime mover, an alternator connected to the engine for generating electricity under operation of the engine, and a power converter connected to an output bus of the alternator for converting an electrical output of the alternator from one power format/waveform to another. The power converter may include plural transistors or other power switches, which are configured to be controlled by a controller to select a particular voltage output and/or waveform that is output by the converter.

[0037] It is to be understood that the above description is intended to be illustrative, and not restrictive. For example, the above-described embodiments (and/or aspects thereof) may be used in combination with each other. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing
from its scope. While the dimensions and types of materials described herein are intended to
define the parameters of the invention, they are by no means limiting and are exemplary
embodiments. Many other embodiments will be apparent to those of skill in the art upon
reviewing the above description. The scope of the invention should, therefore, be determined
with reference to the appended claims, along with the full scope of equivalents to which such
claims are entitled. In the appended claims, the terms "including" and "in which" are used as
the plain-English equivalents of the respective terms "comprising" and "wherein."
Moreover, in the following claims, terms such as "First," "second," "third," "upper," "lower,
"bottom," "top," etc. are used merely as labels, and are not intended to impose numerical or
positional requirements on their objects. Further, the limitations of the following claims are
not written in means-plus-function format and are not intended to be interpreted based on 35
U.S.C. § 122, sixth paragraph, unless and until such claim limitations expressly use the
phrase "means for" followed by a statement of function void of further structure.

This written description uses examples to disclose several embodiments of the
invention, including the best mode, and also to enable one of ordinary skill in the art to
practice the embodiments of invention, including making and using any devices or systems
and performing any incorporated methods. The patentable scope of the invention is defined
by the claims, and may include other examples that occur to one of ordinary skill in the art.
Such other examples are intended to be within the scope of the claims if they have structural
elements that do not differ from the literal language of the claims, or if they include
equivalent structural elements with insubstantial differences from the literal languages of the
claims.

As used herein, an element or step recited in the singular and proceeded with the
word "a" or "an" should be understood as not excluding plural of said elements or steps,
unless such exclusion is explicitly stated. Furthermore, references to "one embodiment" of
the present invention are not intended to be interpreted as excluding the existence of
additional embodiments that also incorporate the recited features. Moreover, unless
explicitly stated to the contrary, embodiments "comprising," "including," or "having" an
element or a plurality of elements having a particular property may include additional such
elements not having that property.
Since certain changes may be made in the above-described system and method, without departing from the spirit and scope of the invention herein involved, it is intended that all of the subject matter of the above description or shown in the accompanying drawings shall be interpreted merely as examples illustrating the inventive concept herein and shall not be construed as limiting the invention.
WHAT IS CLAIMED IS:

1. A method comprising:
   selecting a link voltage based on voltage efficiencies of components in an electric drive motor system; and
   applying the link voltage to an inverter electrically coupled to a drive motor to increase system efficiency.

2. The method according to claim 1, wherein:
   the components include at least an alternator, the inverter, and the drive motor.

3. The method according to claim 2, wherein:
   the step of selecting the link voltage includes assessing respective operating voltages for each of the alternator, inverter, and drive motor at which the alternator, inverter, and drive motor have respective peak efficiencies.

4. The method according to claim 3, wherein:
   the respective operating voltages for the drive motor and the inverter is a lowest voltage that supports pulse width modulation of the inverter.

5. The method according to claim 4, further comprising:
   identifying a switching frequency for the inverter and the drive motor that minimizes losses for as long as the inverter is not thermally limited.

6. The method according to claim 5, further comprising:
   monitoring an ambient temperature; and
   at least one of lowering the switching frequency of the inverter or shifting an operating mode of the inverter when the ambient temperature exceeds a threshold.

7. The method according to claim 1, wherein:
   the steps of selecting and applying the link voltage are carried out by a controller of the electric drive motor system and are carried out in real time.

8. The method according to claim 1, wherein:
the electric drive motor system provides motive power for a vehicle.

9. A method, comprising the steps of:

- selecting a link voltage based on one or more ambient conditions of an electric drive motor system; and
- applying the link voltage to an inverter electrically coupled to a drive motor to increase system efficiency.

10. The method according to claim 9, wherein:

- the step of selecting the link voltage includes assessing voltage efficiencies of components in the electric drive motor system.

11. The method according to claim 10, wherein:

- the components include at least an alternator, the inverter, and the drive motor.

12. The method according to claim 11, wherein:

- the link voltage is further selected based on a lowest voltage that supports pulse width modulation of the inverter.

13. The method according to claim 12, further comprising:

- identifying a switching frequency for the inverter and the drive motor that minimizes losses for as long as the inverter is not thermally limited.

14. The method according to claim 13, further comprising:

- lowering the switching frequency of the inverter or shifting an operating mode of the inverter when the one or more ambient conditions of the electric drive motor system exceed a threshold.

15. A method comprising:

- selecting a link voltage based on one or more efficiency parameters of an electric drive motor system;
- applying the link voltage that is selected to an inverter of the system; and
- changing an operating mode of the inverter in response to the application of the link voltage that is selected.
16. The method according to claim 15, wherein:
the one or more efficiency parameters comprises an ambient condition of the electric drive motor system.

17. The method according to claim 15, wherein:
the one or more efficiency parameters comprises a respective voltage efficiency of one or more components in the electric drive motor system.

18. The method according to claim 17, wherein:
the one or more components comprises at least one of an alternator, a drive motor, or the inverter.

19. The method according to claim 15, wherein changing the operating mode of the inverter comprises switching between pulse width modulation and square wave modulation, to increase system efficiency.

20. The method according to claim 15, wherein the link voltage is periodically selected based on one or more of the one or more efficiency parameters.

21. An electric drive motor system, comprising:
a controller configured to select a link voltage based on one or more efficiency parameters of the system; and
an inverter electrically coupled to the controller and to a motor, the inverter being configured to receive the link voltage that is selected;
wherein at least one of the inverter or the controller is configured to change an operating mode of the inverter in response to application of the link voltage that is selected.

22. The system of claim 22, wherein the at least one of the inverter or the controller is configured to change the operating mode by switching the inverter between pulse width modulation and square wave modulation, to increase system efficiency.

23. The system of claim 21, wherein:
the one or more efficiency parameters comprises an ambient condition of the electric drive motor system.

24. The system of claim 21, wherein:
the one or more efficiency parameters comprises a respective voltage
efficiency of one or more components in the electric drive motor system.

25. The system of claim 24, wherein:

the one or more components comprise at least one of an alternator, the
motor, or the inverter.

26. The system of claim 21, wherein the controller is configured to
periodically select the link voltage based on one or more of the one or more efficiency
parameters of the system.

27. The system of claim 21, wherein:

the system is configured to provide motive power for a vehicle.
FIG. 2
FIG. 3
A. CLASSIFICATION OF SUBJECT MATTER

H02P 5/68(2006.01)i, H02P 27/06(2006.01)i, B60L II/18(2006.01)i, B60W 10/08(2006.01)i, B60W 20/00(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H02P 5/68; B60K 6/445; B60K 1/00; B60L 22/00; H02M 3/155; H02P 9/04; B60L 15/20; H02F 7/16; B61C 3/00; H02P 27/06; B60L 11/18; B60W 10/08; B60W 20/00

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: motor, inverter, drive, vehicle, efficiency, voltage, temperature, frequency, PWM

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>US 2008-0296970 (FRANK DONNELLY et al.) 04 December 2008, See abstract, paragraphs [0029], [0051][0075], [0115] and figures 1-7.</td>
<td>1-2, 7-8</td>
</tr>
<tr>
<td>Y</td>
<td>US 2004-0238243 (ROBERT DEAN KING et al.) 02 December 2004, See abstract, paragraphs [0024]-[0037], and figures 1-5.</td>
<td>3-6, 9-27</td>
</tr>
<tr>
<td>A</td>
<td>US 5907194 (JOACHIM SCHENK et al.) 25 May 1999, See abstract, claims 1-8 and figure.</td>
<td>1-27</td>
</tr>
<tr>
<td>A</td>
<td>JP 2010-104139 (TOYOTA MOTOR CORP.) 06 May 2010, See abstract, paragraphs [0026]-[0111], and figures 1-6.</td>
<td>1-27</td>
</tr>
<tr>
<td>A</td>
<td>JP 2006-101587 (MAZDA MOTOR CORP.) 13 Apr i 1 2006, See abstract, paragraphs [0021]-[0040], and figures 1-3.</td>
<td>1-27</td>
</tr>
</tbody>
</table>

Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents:
  "A" document defining the general state of the art which is not considered to be of particular relevance
  "E" earlier application or patent but published on or after the international filing date
  "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
  "O" document referring to an oral disclosure, use, exhibition or other means
  "P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"S" document member of the same patent family

Date of the actual completion of the international search
29 February 2016 (29.02.2016)

Date of mailing of the international search report
29 February 2016 (29.02.2016)

Name and mailing address of the ISA/KR
International Application Division
Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea
Facsimile No. +82-42-472-7140

Authorized officer
COMMISSIONER
Telephone No. +82-42-481-81 16

Form PCT/ISA/210 (second sheet) (January 2015)
<table>
<thead>
<tr>
<th>Patent document cited in search report</th>
<th>Publication date</th>
<th>Patent family member(s)</th>
<th>Publication date</th>
</tr>
</thead>
<tbody>
<tr>
<td>US 2008-0296970 Al</td>
<td>04/12/2008</td>
<td>CA 2544910 Al</td>
<td>25/10/2006</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CA 2544910 C</td>
<td>09/07/2013</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EP 1878110 A2</td>
<td>16/01/2008</td>
</tr>
<tr>
<td></td>
<td></td>
<td>US 7514807 B2</td>
<td>07/04/2009</td>
</tr>
<tr>
<td></td>
<td></td>
<td>US 7518254 B2</td>
<td>14/04/2009</td>
</tr>
<tr>
<td></td>
<td></td>
<td>US 7906862 B2</td>
<td>15/03/2011</td>
</tr>
<tr>
<td>US 5907194 A</td>
<td>25/05/1999</td>
<td>DE 19628223 Al</td>
<td>22/01/1998</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DE 59708622 Dl</td>
<td>05/12/2002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EP 0869882 Al</td>
<td>13/02/2002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EP 0869882 Bl</td>
<td>30/10/2002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>JP 11-514838 A</td>
<td>14/12/1999</td>
</tr>
<tr>
<td></td>
<td></td>
<td>JP 3919821 B2</td>
<td>30/05/2007</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WO 98-02333 Al</td>
<td>22/01/1998</td>
</tr>
<tr>
<td>JP 2010-104139 A</td>
<td>06/05/2010</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>JP 2006-101587 A</td>
<td>13/04/2006</td>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>