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CA 2959324 C 2020/07/21

(11)(21) 2 959 324

(12) BREVET CANADIEN
CANADIAN PATENT

(13) C

(86) Date de dépôt PCT/PCT Filing Date: 2015/08/13
(87) Date publication PCT/PCT Publication Date: 2016/03/03
(45) Date de délivrance/Issue Date: 2020/07/21
(85) Entrée phase nationale/National Entry: 2017/02/24
(86) N° demande PCT/PCT Application No.: US 2015/044960
(87) N° publication PCT/PCT Publication No.: 2016/032757
(30) Priorité/Priority: 2014/08/29 (US14/473,075)

(51) Cl.Int./Int.Cl. *B60L 50/13* (2019.01), *B60L 1/00* (2006.01), *B60L 15/20* (2006.01)

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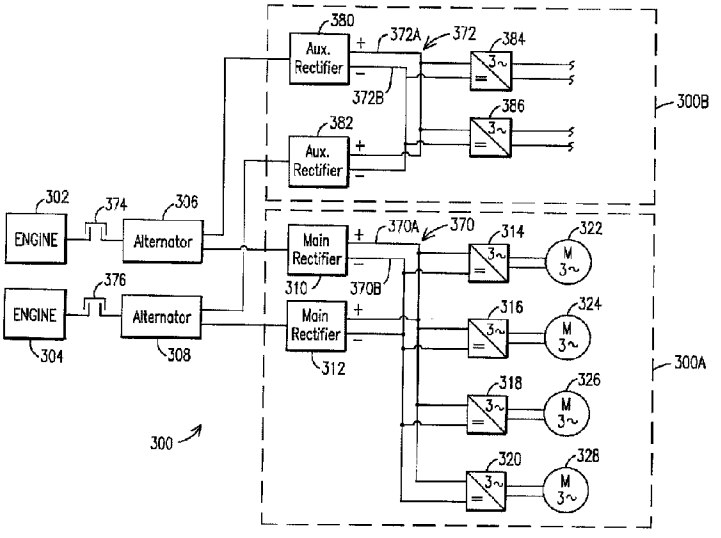
(54) Titre : SYSTEME D'ENTRAINEMENT ELECTRIQUE POUR CAMION DE ROULAGE DE MINE
(54) Title: ELECTRIC DRIVE SYSTEM FOR MINING HAUL TRUCK



(57) Abrégé/Abstract:
An electric drive system (300) for a vehicle (200) includes a first generator (306) in communication with a first engine (302), a second generator (308) in communication with a second engine (304), a first rectifier (310) and a second rectifier (312). Each generator (306, 308) has a main winding, each main winding being independently excitable and generating an alternating current (AC) output. A main AC output of the main winding of the first generator (306) is in communication with the first rectifier (310), and a main AC output of the main winding of the second generator (308) is in communication with the second rectifier (312). When in drive mode, the first engine (302) drives the first generator (306) and the second engine (304) drives the second generator (308), and the first and second generators (306, 308) supply power to a plurality of inverters (314, 316, 318, 320) coupled to the first and second rectifiers 310, 312), the plurality of inverters (314, 316, 318, 320) supplying power to a plurality of electric wheel motors (322, 324, 326, 328).

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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
3 March 2016 (03.03.2016)

WIPO | PCT

(10) International Publication Number
WO 2016/032757 A1

(51) International Patent Classification:
B60L 11/08 (2006.01) *B60L 15/20* (2006.01)
B60L 1/00 (2006.01)

(21) International Application Number:
PCT/US2015/044960

(22) International Filing Date:
13 August 2015 (13.08.2015)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
14/473,075 29 August 2014 (29.08.2014) US

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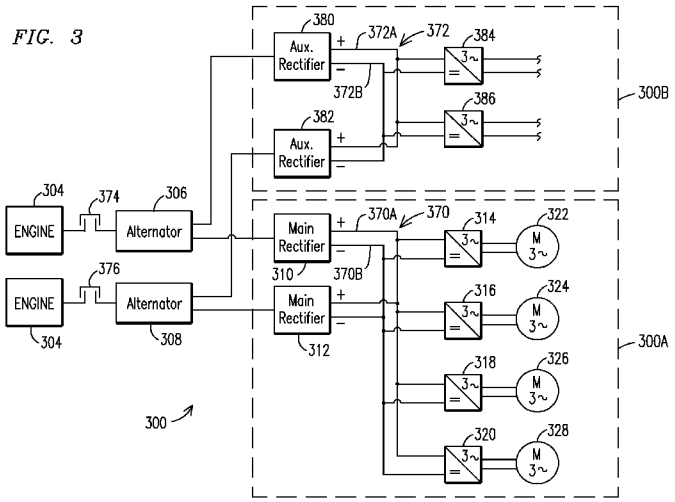
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*

(54) Title: ELECTRIC DRIVE SYSTEM FOR MINING HAUL TRUCK

FIG. 3



(57) Abstract: An electric drive system (300) for a vehicle (200) includes a first generator (306) in communication with a first engine (302), a second generator (308) in communication with a second engine (304), a first rectifier (310) and a second rectifier (312). Each generator (306, 308) has a main winding, each main winding being independently excitable and generating an alternating current (AC) output. A main AC output of the main winding of the first generator (306) is in communication with the first rectifier (310), and a main AC output of the main winding of the second generator (308) is in communication with the second rectifier (312). When in drive mode, the first engine (302) drives the first generator (306) and the second engine (304) drives the second generator (308), and the first and second generators (306, 308) supply power to a plurality of inverters (314, 316, 318, 320) coupled to the first and second rectifiers 310, 312), the plurality of inverters (314, 316, 318, 320) supplying power to a plurality of electric wheel motors (322, 324, 326, 328).

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ELECTRIC DRIVE SYSTEM FOR MINING HAUL TRUCK

BACKGROUND

[0001] 1. Field

[0002] Aspects of the present invention relate to power systems for a vehicle, and more particularly to electric drive systems for a vehicle, for example a mining haul truck, and a method for providing electrical power for a vehicle, for example a mining haul truck.

2. Description of the Related Art

[0003] Vehicles used in the mining industry such as for example mining haul trucks, electric shovels, and draglines are often driven by high-powered electrical motors. In some applications, electrical power is supplied to the electrical motors from an external power station via a feed cable or trolley line. In other applications, electrical power is supplied to the electrical motors from a generator on board the vehicle; the generator can be driven, for example, by a diesel engine.

[0004] Traditionally, mining truck applications only use one diesel engine and one generator or alternator. But one engine and one generator may not be capable to produce enough power required for certain applications. An improved electric drive system for off–highway vehicles is desired.

SUMMARY

[0005] Briefly described, aspects of the present invention relate to electric drive systems for a vehicle, for example an off-highway vehicle and methods of providing electric power for an off-highway vehicle, the vehicle being for example a mining haul truck, in particular a dump truck.

[0006] A first aspect of the present invention provides an electric drive system for a

vehicle comprising a first generator in communication with a first engine, a second generator in communication with a second engine, and a first rectifier and a second rectifier. Each generator comprises a main winding, and each main winding is independently excitable and generating an alternating current (AC) output. A main AC output of the main winding of the first generator is in communication with the first rectifier, and a main AC output of the main winding of the second generator is in communication with the second rectifier. When in drive mode, the first engine drives the first generator and the second engine drives the second generator, and the first and second generators supply power to a plurality of inverters coupled to the first and second rectifiers, the plurality of inverts supplying power to a plurality of electric wheel motors.

[0007] A second aspect of the present invention provides a method for providing electric power for a vehicle. Electric power is supplied by at least two generators to at least four electric wheel motors, the at least two generators being in communication with at least two engines, wherein the electric power is supplied from a plurality of inverters for at least four electric wheel motors via at least two rectifiers, the at least two rectifiers being operably connected to the at least two generators.

[0008] A third aspect of the present invention provides an electric drive system comprising a first engine coupled to a first alternator, wherein the first alternator generates a first output and a second output, a second engine coupled to a second alternator, wherein the second alternator generates a third output and a fourth output, a first main rectifier operably connected to the first output of the first alternator, a first auxiliary rectifier operably connected to the second output of the first alternator, a second main rectifier operably connected to the third output of the second alternator, and a second auxiliary rectifier operably connected to the fourth output of the second alternator. The first and second main rectifiers each generate a direct current (DC) output, and both DC outputs of the main rectifiers are connected to a main DC bus. The first and second auxiliary rectifiers each generate a direct current (DC) output, and both DC outputs of the auxiliary rectifiers are connected to an auxiliary DC bus providing an auxiliary output for auxiliary devices. The main DC bus provides electric power for a plurality of inverters in

operable connection with wheel motors for driving wheels of a vehicle during drive mode.

[0008a] According to one aspect of the present invention, there is provided an electric drive system for a vehicle comprising: a first generator in communication with a first engine; a second generator in communication with a second engine; a primary power system comprising a first main rectifier and a second main rectifier; wherein each generator comprises a main field coil, each main field coil independently excitable, each main field coil generating an alternating current (AC) output, a main AC output of the main field coil of the first generator in communication with the first main rectifier, and a main AC output of the main field coil of the second generator in communication with the second main rectifier, wherein, when in drive mode, the first engine drives the first generator and the second engine drives the second generator, and the first and second generators supply power to a plurality of inverters coupled to the first and second main rectifiers, the plurality of inverts supplying power to a plurality of electric wheel motors, and wherein the first and second main rectifiers each comprise a direct current (DC) output, both DC outputs of the first and second main rectifiers being connected to a common main DC bus; and an auxiliary power system comprising a first auxiliary rectifier and a second auxiliary rectifier; wherein each generator comprises an auxiliary field coil, each auxiliary field coil independently excitable, each auxiliary field coil generating an AC output, an auxiliary AC output of the auxiliary field coil of the first generator connected to the first auxiliary rectifier, and an auxiliary AC output of the auxiliary field coil of the second generator connected to the second auxiliary rectifier, and wherein the first and second auxiliary rectifiers each comprise a DC output, both DC outputs of the first and second auxiliary rectifiers connected to an auxiliary DC bus providing an auxiliary output for auxiliary devices including cooling assemblies.

[0008b] According to another aspect of the present invention, there is provided a method for providing electric power for a vehicle, the method comprising: supplying electric power by at least two generators to at least four electric wheel motors, the at least two generators being in communication with at least two engines, wherein the electric power is supplied from a plurality of inverters for the at least four electric wheel motors via at least two

rectifiers, the at least two rectifiers being operably connected to the at least two generators, wherein outputs of the at least two generators are operably connected to the at least two rectifiers, the at least two rectifiers each comprising a direct current (DC) output, the DC output being connected to a common main DC bus, and wherein the outputs of the at least two generators are further operably connected to at least two auxiliary rectifiers, the at least two auxiliary rectifiers each comprising a direct current (DC) output, the DC output being connected to an auxiliary DC bus, the common main DC bus and the auxiliary DC bus being operable in parallel, wherein the auxiliary DC bus provides an auxiliary output for auxiliary devices including cooling assemblies.

[0008c] According to another aspect of the present invention, there is provided an electric drive system comprising: a first engine coupled to a first alternator, wherein the first alternator comprises a mainfield coil generating a first output and an auxiliary field coil generating a second output; a second engine coupled to a second alternator, wherein the second alternator comprises a main field coil generating a third output and an auxiliary field coil generating a fourth output, each main field coil and each auxiliary field coil being independently excitable; a first main rectifier operably connected to the first output of the first alternator; a first auxiliary rectifier operably connected to the second output of the first alternator; a second main rectifier operably connected to the third output of the second alternator; a second auxiliary rectifier operably connected to the fourth output of the second alternator; wherein the first and second main rectifiers each generate a direct current (DC) output, and both DC outputs of the main rectifiers are connected to a main DC bus, and wherein the first and second auxiliary rectifiers each generate a direct current (DC) output, and both DC outputs of the auxiliary rectifiers are connected to an auxiliary DC bus providing an auxiliary output for auxiliary devices including cooling assemblies, wherein the main DC bus provides electric power for a plurality of inverters in operable connection with wheel motors for driving wheels of a vehicle during drive mode.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Fig. 1 shows a single-line diagram of a prior-art diesel-powered electrical system for a mining haul truck.

[0010] Fig. 2 shows a side view of a vehicle, for example a mining haul truck or a dump truck, in accordance with an exemplary embodiment of the present invention.

[0011] Fig. 3 shows a single-line diagram of a diesel-powered electrical system for a vehicle, in accordance with an exemplary embodiment of the present invention.

DETAILED DESCRIPTION

[0012] To facilitate an understanding of embodiments, principles, and features of the present invention, they are explained hereinafter with reference to implementation in illustrative embodiments. In particular, they are described in the context of being electric drive systems and methods for mining applications. Embodiments of the present invention, however, are not limited to use in the described systems or methods.

[0013] The components and materials described hereinafter as making up the various embodiments are intended to be illustrative and not restrictive. Many suitable components and materials that would perform the same or a similar function as the materials described herein are intended to be embraced within the scope of embodiments of the present invention.

[0014] In the description below, a vehicle, for example a mining haul truck or a dump truck is used as an example of electrically powered mining equipment. One skilled in the art, however, can develop embodiments of the invention for other electrically powered mining vehicles, such as front loaders, and for non-mobile electrically powered mining equipment, such as mills and conveyor systems.

[0015] **Fig. 1** shows a single-line diagram of prior-art a mining haul truck power system **100**. The mining haul truck has two drive wheels. In the drive mode, also referred to as the propel mode, each wheel is driven by a 3-phase alternating-current (AC) wheel motor (M). The wheel motors are referenced as a first wheel motor **110** and a second wheel motor **114**. Electrical power is supplied by the diesel engine **102** driving the 3-phase AC generator **104**, also referred to as an alternator. The diesel engine **102** and the generator **104** are connected via the coupling **124**. Other types of engines can be used, but diesel engines are typical in mining operations. The diesel engine **102** and the generator **104** are mounted on the mining haul truck.

[0016] The AC output of the generator **104** is connected to the rectifiers **106**. The direct current (DC) output of the rectifiers **106** is then connected to a single DC bus **126** with a positive rail **126A** and a negative rail **126B**. The inverter(s) **108** draw DC power from the DC bus **126** and supply 3-phase AC power to the wheel motor **110**. Similarly, the inverter(s) **112** draw power from the DC bus **126** and supply 3-phase AC power to the wheel motor **114**.

[0017] To slow down a moving mining haul truck, the mining haul truck drive system operates in the retard mode, also referred to as the braking mode. Under normal operation, an electrical motor converts electrical energy into mechanical energy. An electrical motor can also be operated in reverse as a generator to convert mechanical energy into electrical energy. The electrical energy is then fed into inverters. Braking choppers, connected to the inverters, channel the power into a power resistor grid that continuously dissipates the energy until the mining haul truck reaches standstill. Braking is smooth, without mechanical brake wear.

[0018] Referring to **Fig. 1**, the braking chopper **116** and the power resistor grid **118** dissipate energy from the wheel motor **110** during braking action, i.e. provide the braking action for the wheel motor **110**. Similarly, the chopper **120** and the power resistor grid **122** dissipate energy from the wheel motor **114** during braking action. The mining haul truck can also be outfitted with a mechanical braking system as a backup to the electrical braking system.

[0019] In the power system shown in **Fig. 1**, the entire power requirements for the wheel motor **110** and the wheel motor **114** are supplied by the diesel engine **102**. Performance, as determined, for example, by acceleration and speed, of the mining haul truck is limited by the power capacity of the diesel engine **102**.

[0020] **Fig. 2** shows a schematic representation of a side view of a vehicle, for example a mining haul truck or a dump truck, including components of a power system, in accordance with an exemplary embodiment of the present invention.

[0021] The vehicle **200**, which can be for example a mining haul truck and in some embodiments, more specifically a dump truck, has at least two axles and up to four drive wheels, and can have, for example and not limiting, approximately a 450-metric ton payload capacity (those skilled in the art would appreciate different payload capacities are available). In the drive mode, each wheel is driven by a 3-phase alternating-current wheel motor, each motor coupled to a wheel of the mining haul truck. **Fig. 2** shows electric wheel motors **222** and **224**. The other two electric wheel motors are opposite the wheel motors **222** and **224** on the other side of the truck **200** (not shown in **Fig. 2**). Electrical power is supplied by two diesel engines **202, 204** driving two 3-phase AC generators, also referred to as alternators . The first diesel engine **202** is coupled to a first alternator, and the second diesel engine **204** is coupled to a second alternator. The diesel engines **202, 204** and the alternators are mounted on the mining haul truck **200**.

[0022] **Fig. 3** shows a single-line diagram of a diesel-powered electrical system for a vehicle **300**, in accordance with an exemplary embodiment of the present invention.

[0023] The drive system **300** comprises two diesel engines **302** and **304**. Other types of engines may be used; diesel engines are typical in mining applications. Each diesel engine drives a 3-phase AC generator, also referred to as alternator. As illustrated in **Fig. 3**, the diesel engine **302** drives alternator **306**, and the diesel engine **304** drives alternator **308**. Each diesel engine **302, 304** is coupled to an alternator **306** and **308** via couplings **374** and **376**. The diesel engines **302** and **304** and the alternators **306** and **308**

are carried by the vehicle **200** (see **Fig. 2**), which can be for example a mining haul truck.

[0024] The alternators **306** and **308** can operate alone or in parallel. In an exemplary embodiment, each of the alternators **306** and **308** comprises a main winding and an auxiliary winding, also referred to as main field coil and auxiliary field coil. Each alternator field coil of each alternator **306** and **308** can be independently excited. Each AC output of the alternators **306** and **308** is connected to a rectifier. The AC output of the main winding of the alternator **306** is connected to main rectifier **310** and the AC output of the main winding of alternator **308** is connected to main rectifier **312**. Both outputs of rectifiers **310**, **312** are connected to a common DC bus **370**. The DC bus **370** comprises a positive rail **370A** and a negative rail **370B**. Many types of rectifiers can be used. The rectifiers can comprise for example IGBTs or diodes. In an alternative embodiment, the common DC bus can comprise separate DC buses for each rectifier.

[0025] The drive system **300** comprises a plurality of inverters, for example four inverters **314**, **316**, **318** and **320** which draw DC power from the DC bus **370** and supply 3-phase AC power for up to four wheel motors **322**, **324**, **326**, **328**. This means that all four wheels of the mining haul truck have independent traction electric motors driven by two alternators **306** and **308** with two diesel engines **302** and **304**. The inverters **314**, **316**, **318** and **320** can be for example IGBT inverters which provide a variable AC voltage to control the wheel motors **322**, **324**, **326**, **328**. The IGBT inverters feed the wheel motors **322**, **324**, **326**, **328**, and the speed of the mining haul truck varies in proportion to the IGBT inverter output frequency. Many other known types of inverters can be used for the described arrangement.

[0026] **Fig. 3** shows the primary power system **300A** and the auxiliary power system **300B** using dotted lines. The rectifiers **310**, **312**, inverters **314**, **316**, **318**, **320**, and wheel motors **322**, **324**, **326**, **328** are components of the primary power system **300A**. The primary power system **300A** can have many other components, for example braking choppers and resistors. Both engines **302**, **304** and both alternators **306**, **308** provide power to the paralleled DC links **370** and **372** of the primary system **300A** and the auxiliary system **300B**.

[0027] The auxiliary power system **300B** as embodied according to **Fig. 3** shows that each AC output of the auxiliary windings of the alternators **306** and **308** is connected to auxiliary rectifiers **380** and **382**. For example, the AC output of the auxiliary winding of the alternator **306** is connected to auxiliary rectifier **380**. The AC output of the auxiliary winding of alternator **308** is connected to auxiliary rectifier **382**. Both rectifier outputs of auxiliary rectifiers **380** and **382** are connected to an auxiliary DC bus **372** comprising a positive rail **372A** and a negative rail **372B**.

[0028] The auxiliary power system **300B** comprises a plurality of inverters for supplying power to auxiliary devices, for example cooling assemblies and retard functionality. In this example, the plurality of inverters comprises at least two inverters **384** and **386**. The auxiliary power system **300B** can comprise many components.

[0029] The drive system comprises four wheel motors, which allows front wheel and rear wheel drive. The drive system provides the ability to switch between front wheel and rear wheel drive, for example when the mining haul truck is not fully loaded. The use of the all-wheel gear has opened up new possibilities of distributing tractive effort to both axles of the mining truck. Also, having more than one power source allows partial machine operation in the event that one of the power sources fail. Further, in case of failure of one of the driving gears, an emergency mode can be activated, which would enable the truck to get to the service station without being towed.

[0030] While embodiments of the present invention have been disclosed in exemplary forms, it will be apparent to those skilled in the art that many modifications, additions, and deletions can be made therein without departing from the spirit and scope of the invention and its equivalents, as set forth in the following claims.

CLAIMS:

1. An electric drive system for a vehicle comprising:

a first generator in communication with a first engine;

a second generator in communication with a second engine;

a primary power system comprising a first main rectifier and a second main rectifier;

wherein each generator comprises a main field coil, each main field coil independently excitable, each main field coil generating an alternating current (AC) output, a main AC output of the main field coil of the first generator in communication with the first main rectifier, and a main AC output of the main field coil of the second generator in communication with the second main rectifier,

wherein, when in drive mode, the first engine drives the first generator and the second engine drives the second generator, and the first and second generators supply power to a plurality of inverters coupled to the first and second main rectifiers, the plurality of inverts supplying power to a plurality of electric wheel motors, and

wherein the first and second main rectifiers each comprise a direct current (DC) output, both DC outputs of the first and second main rectifiers being connected to a common main DC bus; and

an auxiliary power system comprising a first auxiliary rectifier and a second auxiliary rectifier;

wherein each generator comprises an auxiliary field coil, each auxiliary field coil independently excitable, each auxiliary field coil generating an AC output, an auxiliary AC output of the auxiliary field coil of the first generator connected to the first auxiliary rectifier, and an auxiliary AC output of the auxiliary field coil of the second generator connected to the second auxiliary rectifier, and

wherein the first and second auxiliary rectifiers each comprise a DC output, both DC outputs of the first and second auxiliary rectifiers connected to an auxiliary DC bus providing an auxiliary output for auxiliary devices including cooling assemblies.

2. The electric drive system of claim 1, wherein the plurality of inverters draws DC power from the main DC bus and supplies AC power to the plurality of electric wheel motors when in the drive mode.

3. The electric drive system of claim 1, wherein the main DC bus comprises separate DC busses for the first and second rectifiers.

4. The electric drive system of claim 1 configured to power a mining haul truck.

5. An electric drive system comprising:

a first engine coupled to a first alternator, wherein the first alternator comprises a main field coil generating a first output and an auxiliary field coil generating a second output;

a second engine coupled to a second alternator, wherein the second alternator comprises a main field coil generating a third output and an auxiliary field coil generating a fourth output, each main field coil and each auxiliary field coil being independently excitable;

a first main rectifier operably connected to the first output of the first alternator;

a first auxiliary rectifier operably connected to the second output of the first alternator;

a second main rectifier operably connected to the third output of the second alternator;

a second auxiliary rectifier operably connected to the fourth output of the second alternator;

wherein the first and second main rectifiers each generate a direct current (DC) output, and both DC outputs of the main rectifiers are connected to a main DC bus, and

wherein the first and second auxiliary rectifiers each generate a direct current (DC) output, and both DC outputs of the auxiliary rectifiers are connected to an auxiliary DC bus providing an auxiliary output for auxiliary devices including cooling assemblies,

wherein the main DC bus provides electric power for a plurality of inverters in operable connection with wheel motors for driving wheels of a vehicle during drive mode.

6. The electric drive system of claim 5, wherein the main DC bus and the auxiliary DC bus are operable in parallel.

7. The electric drive system of claim 5, the plurality of inverters comprising a first inverter, a second inverter, a third inverter, and a fourth inverter,

wherein each inverter draws DC power from the main DC bus and generates an alternating current (AC) output for the wheel motors.

8. The electric drive system of claim 5 configured to power a mining haul truck.

9. The electric drive system of claim 8, wherein the first and second engines, the first and second alternators and the wheel motors are mounted on the mining haul truck.

10. The electric drive system of claim 5, wherein the wheel motors are independently operable.

11. The electric drive system of claim 5, wherein the first and second alternators are operated in parallel

FIG. 1
PRIOR ART

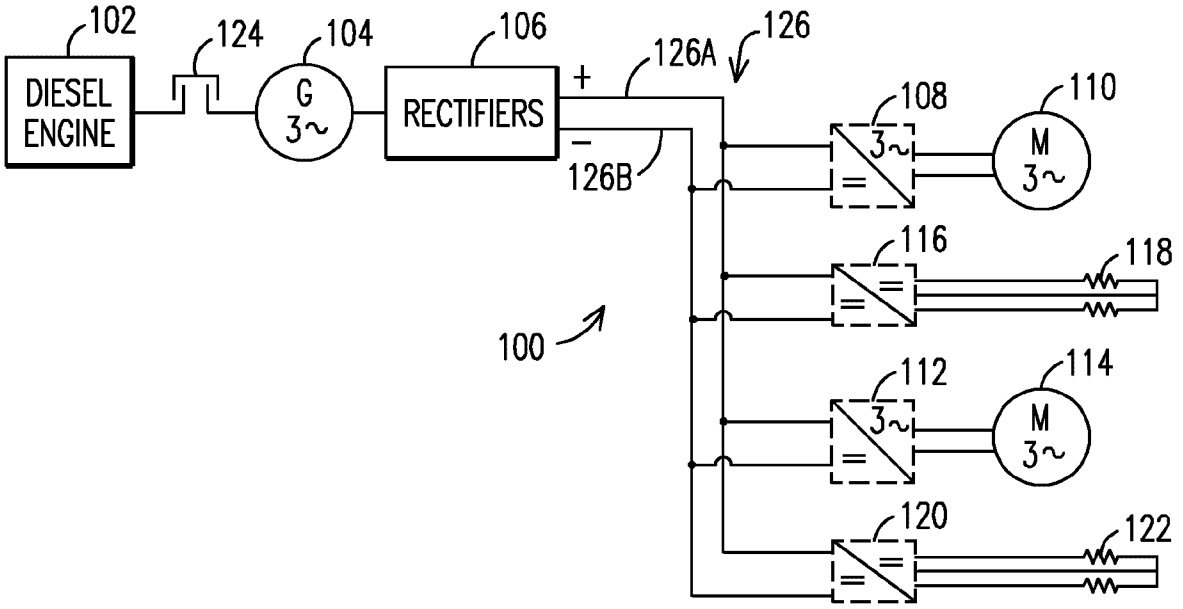
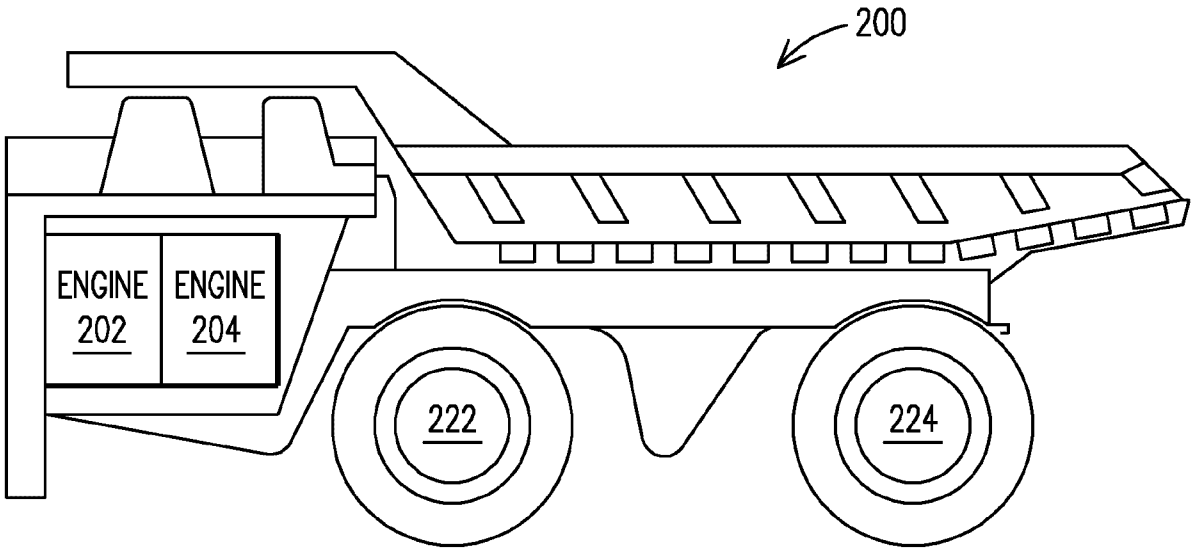


FIG. 2



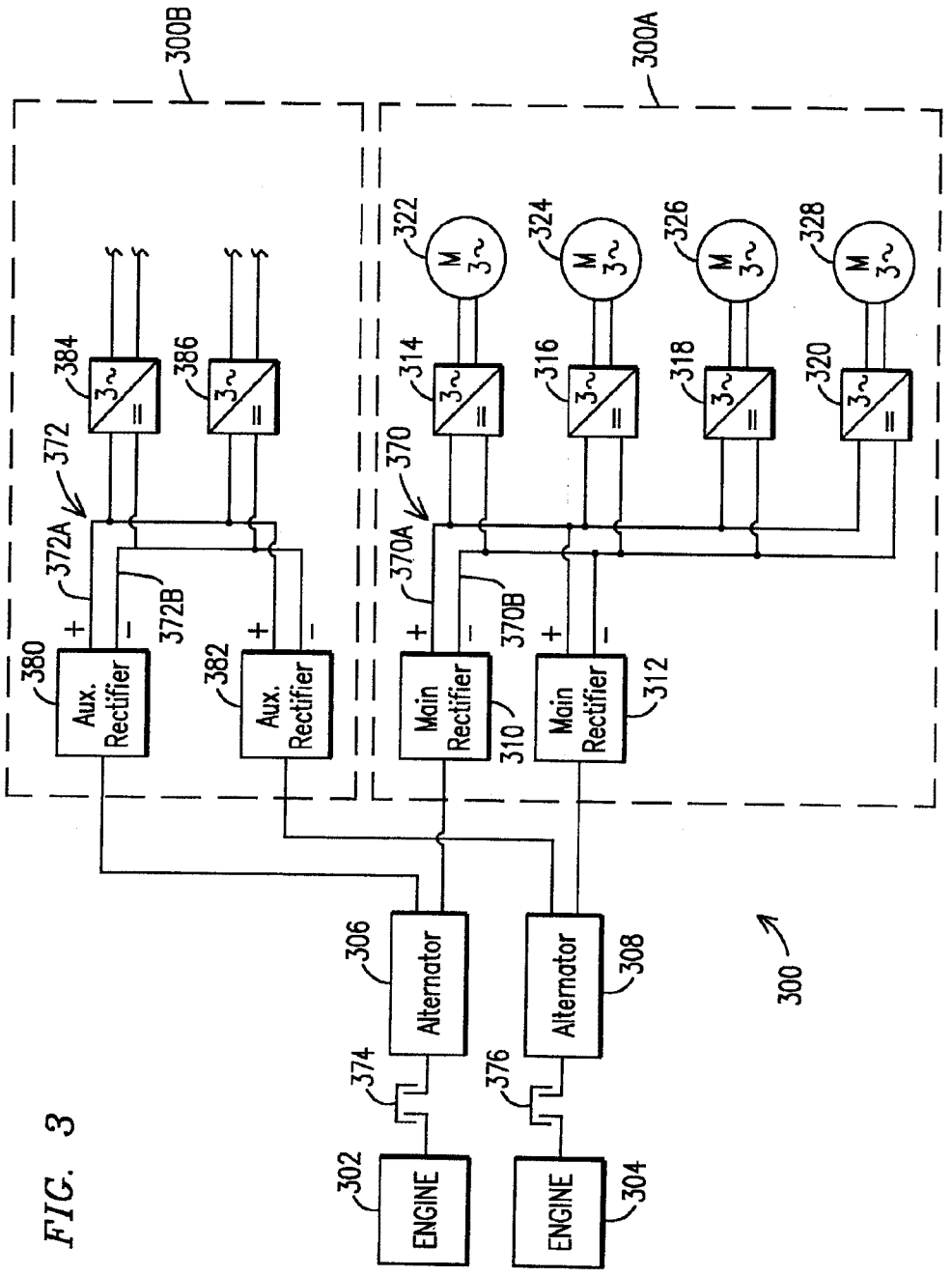
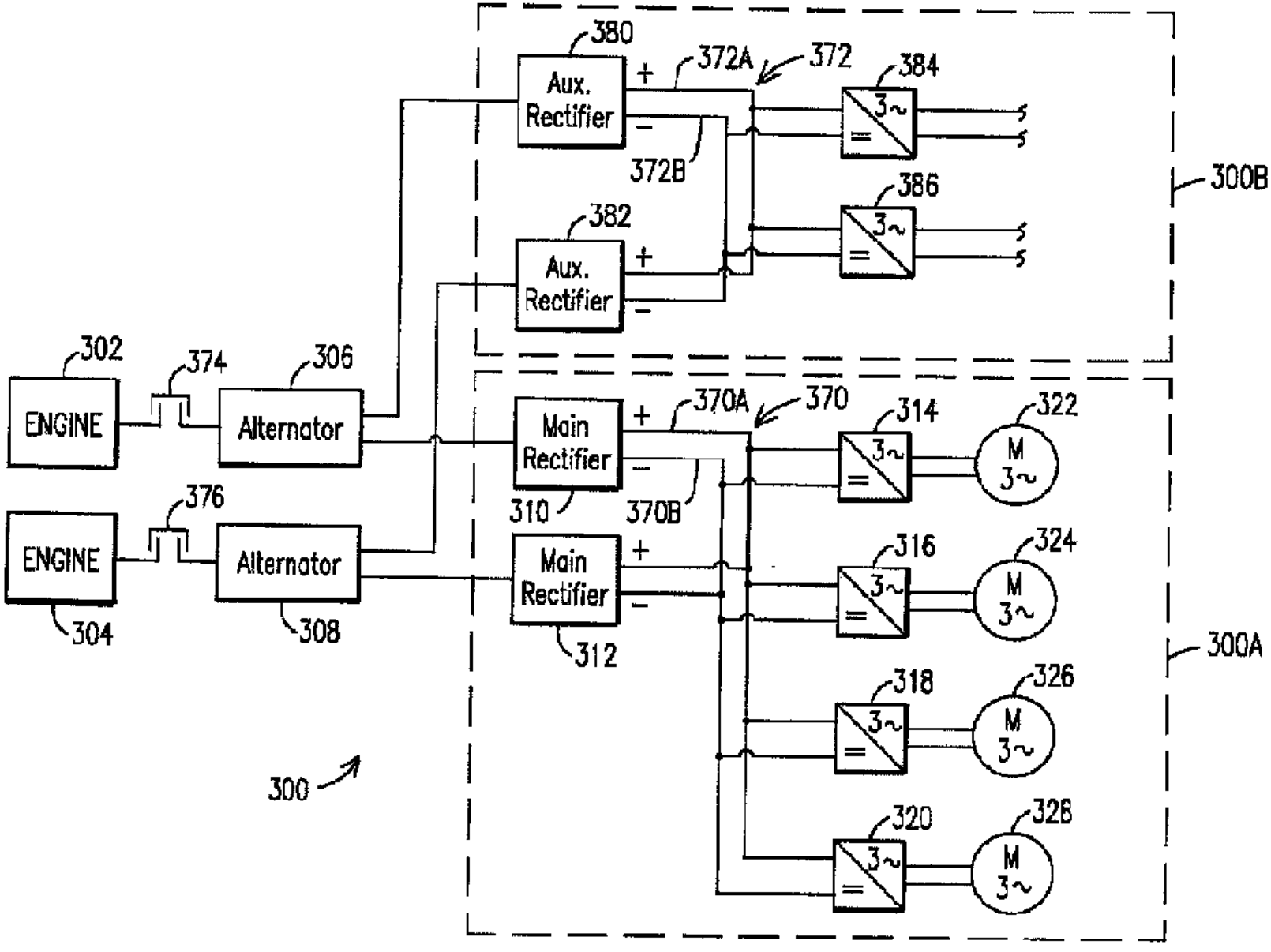

300B
300A
384
386
372
372A
372B
380
Aux. Rectifier
382
Aux. Rectifier
322
324
326
328
314
316
318
320
370
370A
370B
Main Rectifier
310
Main Rectifier
312
306
Alternator
308
Alternator
374
376
302
ENGINE
304
ENGINE
300

FIG. 3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370B
376
ENGINE
Alternator
Main Rectifier
316
324
304
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300A
318
326
300
320
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