US 20250144995A1

(19) United States

(12) Patent Application Publication

Olason

(10) Pub. No.: US 2025/0144995 A1

(43) Pub. Date: May 8, 2025

(54) **ELECTRICALLY VARIABLE TRANSMISSIONS FOR OFF-ROAD VEHICLES**

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(21) Appl. No.: **18/408,985**

(22) Filed: **Jan. 10, 2024**

Related U.S. Application Data

(60) Provisional application No. 63/596,478, filed on Nov. 6, 2023.

Publication Classification

(51) **Int. Cl.**

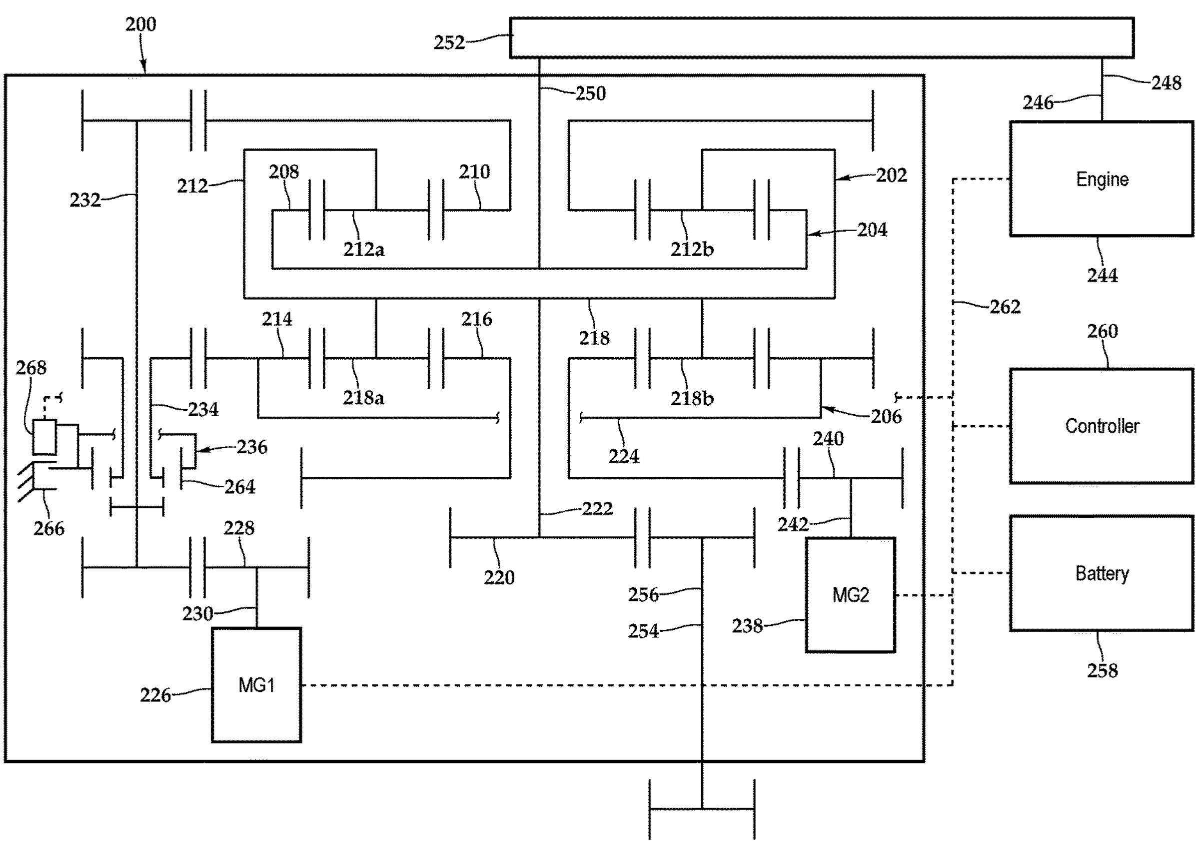
B60K 6/543	(2007.10)
B60K 6/365	(2007.10)
B60K 6/40	(2007.10)
B60K 6/442	(2007.10)
B62M 27/02	(2006.01)
F16H 3/72	(2006.01)
F16H 61/66	(2006.01)

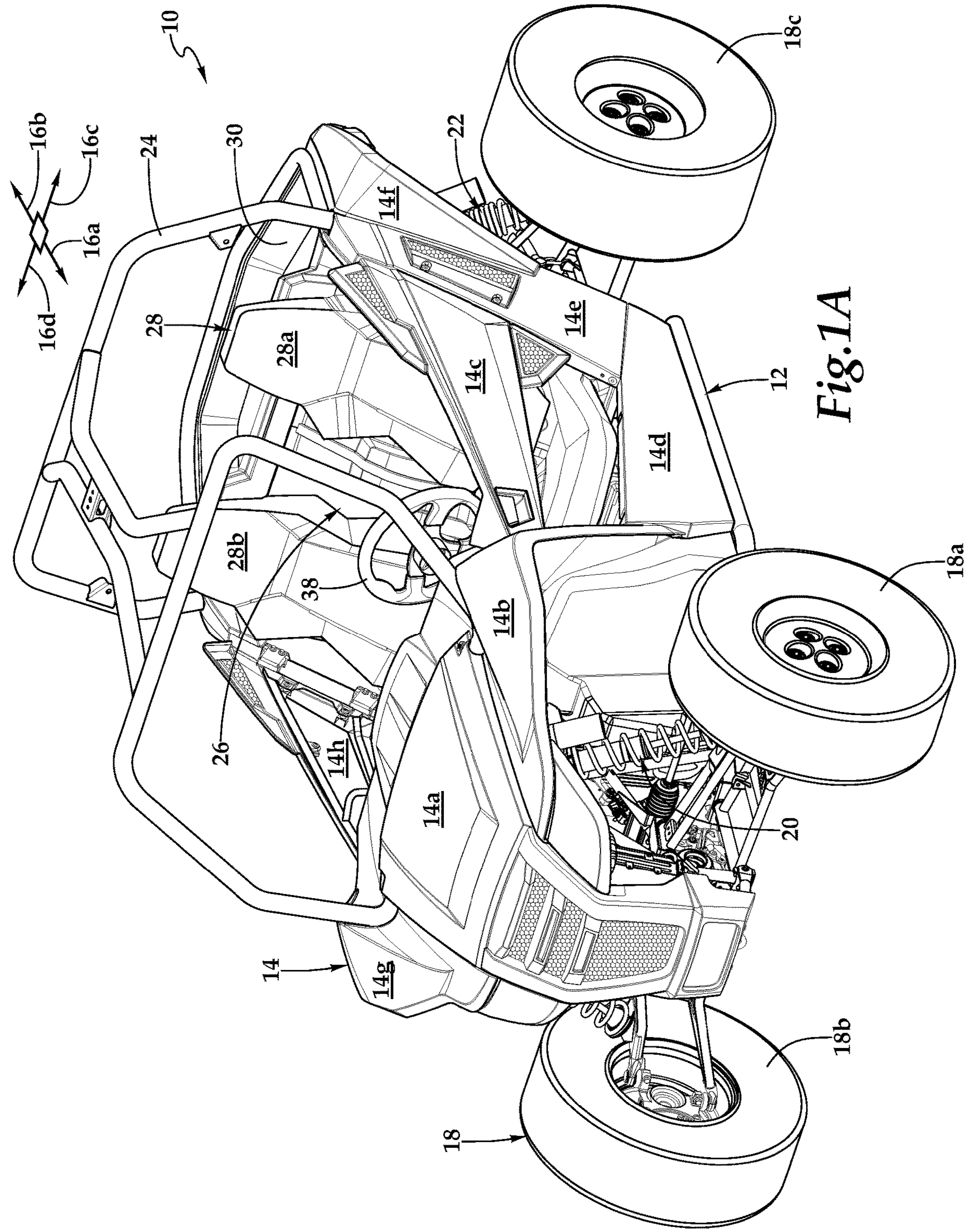
(52) **U.S. Cl.**

CPC ***B60K 6/543*** (2013.01); ***B60K 6/365*** (2013.01); ***B60K 6/40*** (2013.01); ***B60K 6/442*** (2013.01); ***F16H 3/728*** (2013.01); ***F16H 61/66*** (2013.01); *B60Y 2200/92* (2013.01); *B62M 27/02* (2013.01); *F16H 2061/6603* (2013.01); *F16H 2200/2007* (2013.01)

(57) **ABSTRACT**

An electrically variable transmission for an off-road vehicle including an internal combustion engine with a crankshaft. The electrically variable transmission includes a compound planetary gear assembly having a first planetary gear set with a first ring gear, a first sun gear and a first planet carrier and a second planetary gear set with a second ring gear, a second sun gear and a second planet carrier. The planet carriers are coupled together for common rotation and are coupled to an output gear for common rotation therewith. The first ring gear is in torque transferring communication with the crankshaft. The first sun gear is in torque transferring communication with a first motor generator. The second sun gear is in torque transferring communication with a second motor generator. The rotational axes of the compound planetary gear assembly and each of the motor generators are parallel rotational axes.

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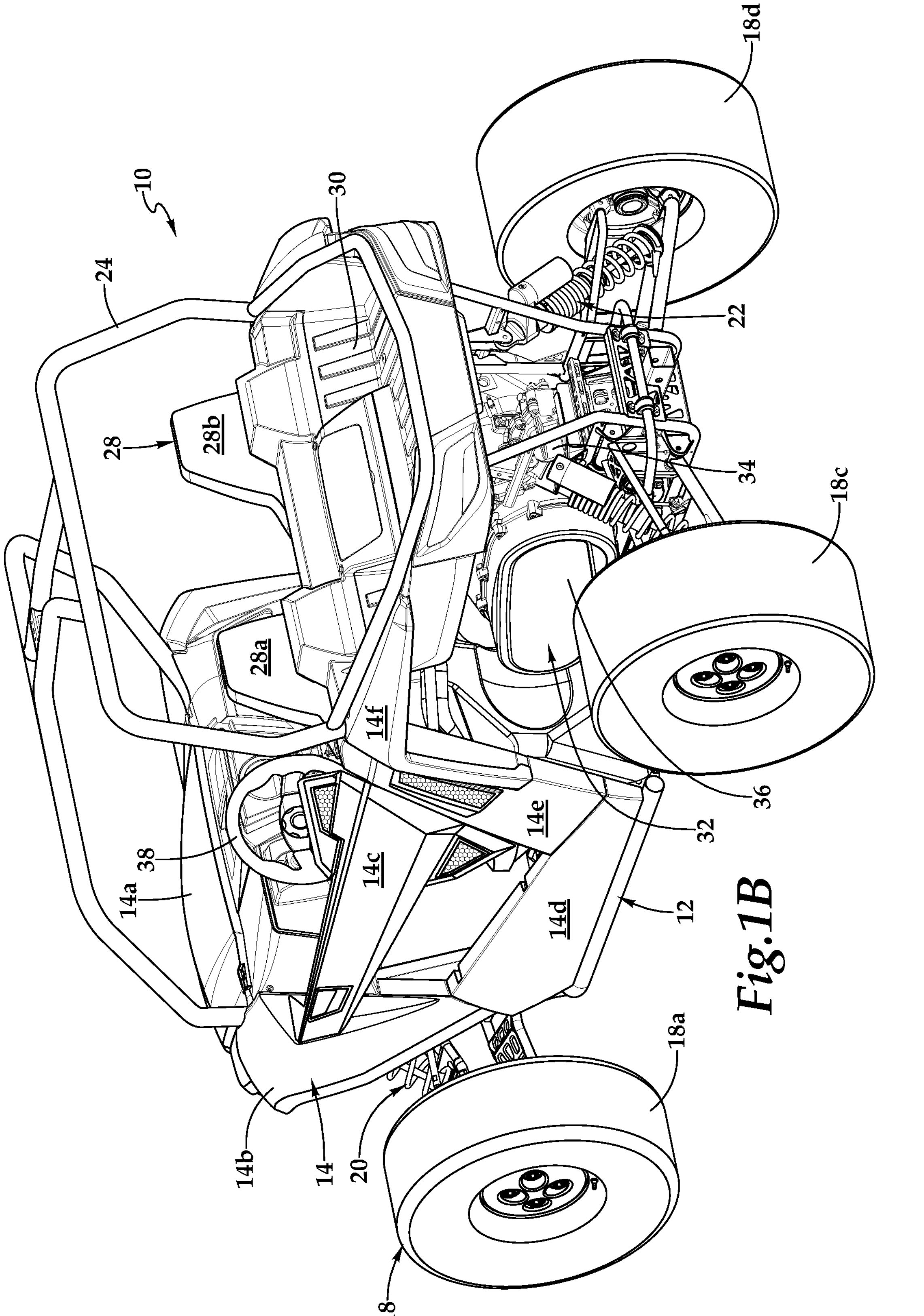
16a
16b
16c
16d
24
30
28
28a
22
14f
14e
14c
12
14d
18c
28b
38
26
14b
14h
14a
18a
20
14
14g
18b
18

Fig.1A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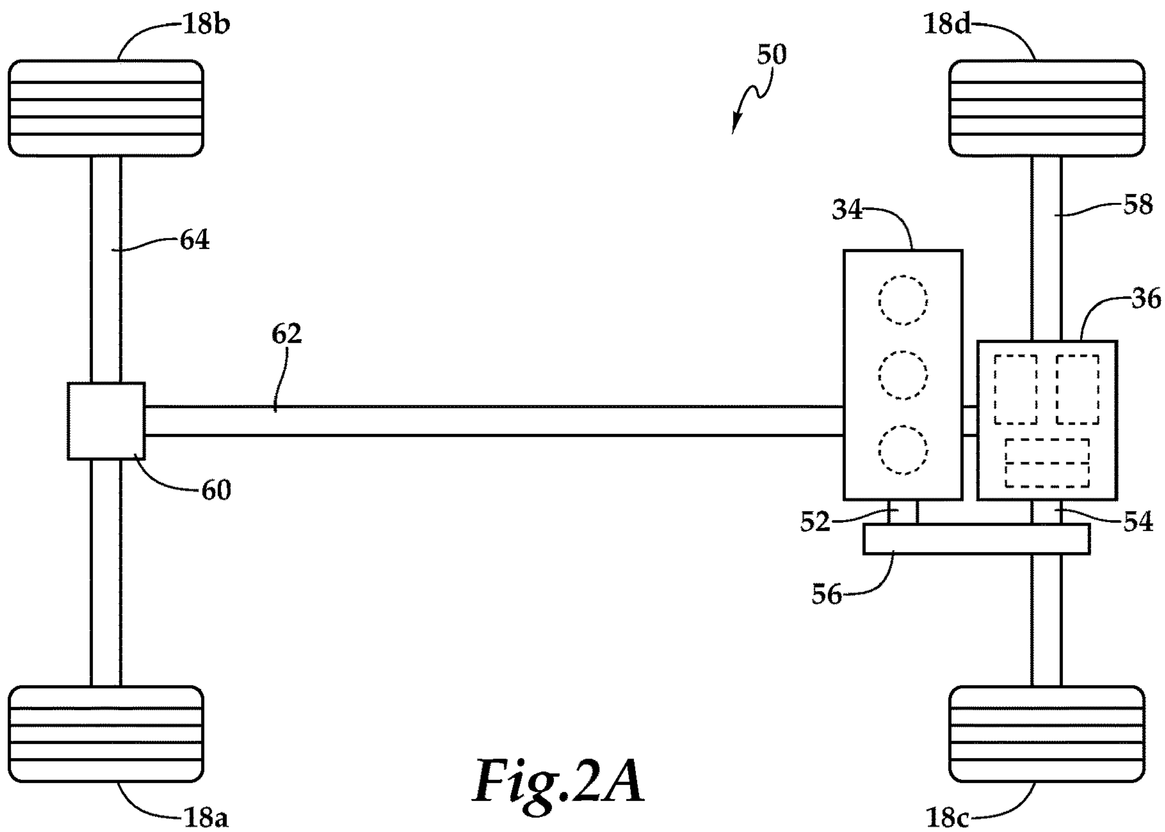
22
28
28b
34
18c
28a
14f
36
32
14e
38
14a
14c
14d
12
18a
20
14
14b
18

Fig.1B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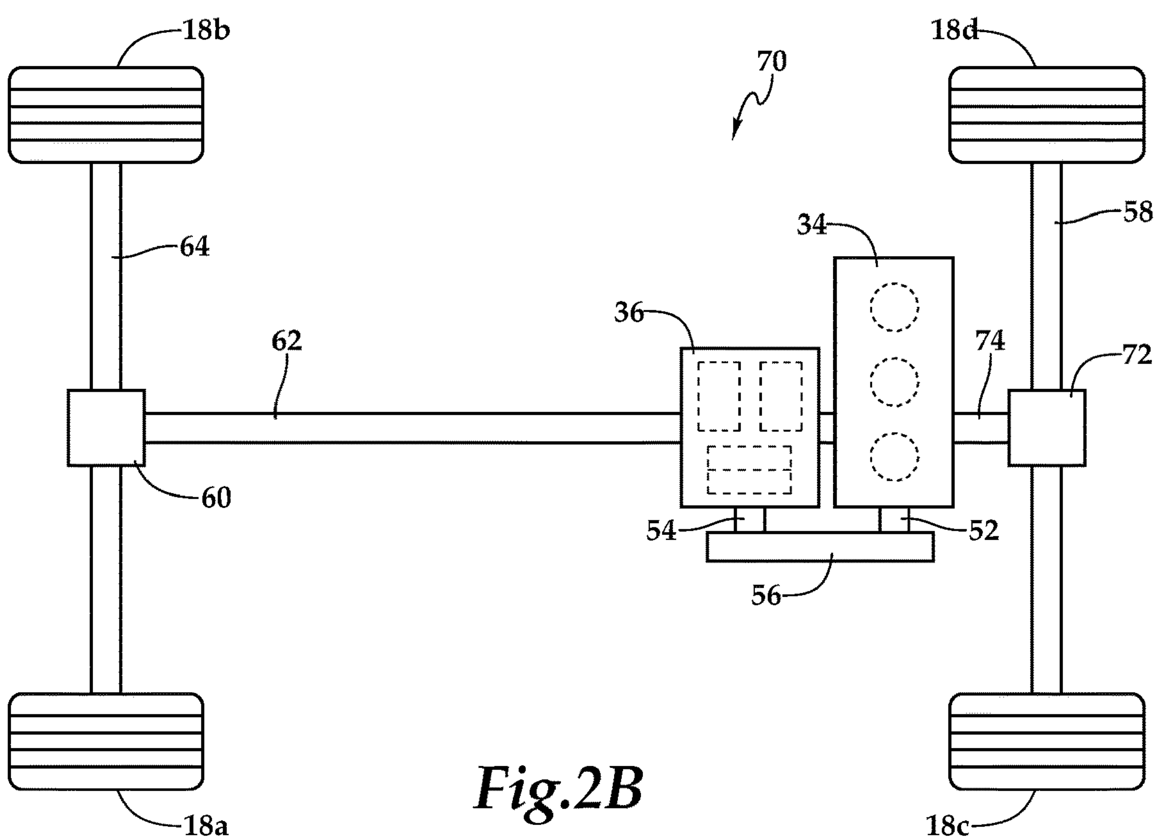
50
18d
58
64
34
36
62
60
52
54
56
18a
18c

Fig.2A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18d
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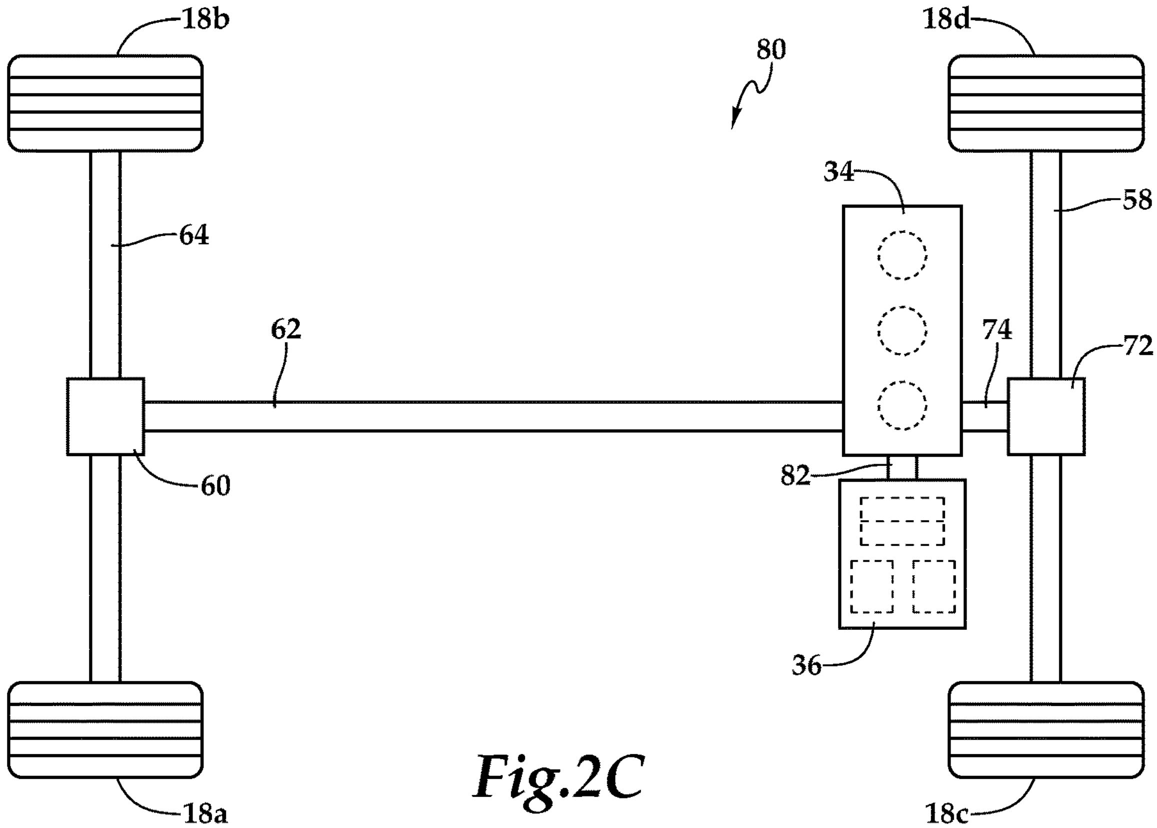
64
34
36
62
74
72
60
54
52
56
18a
18c

Fig.2B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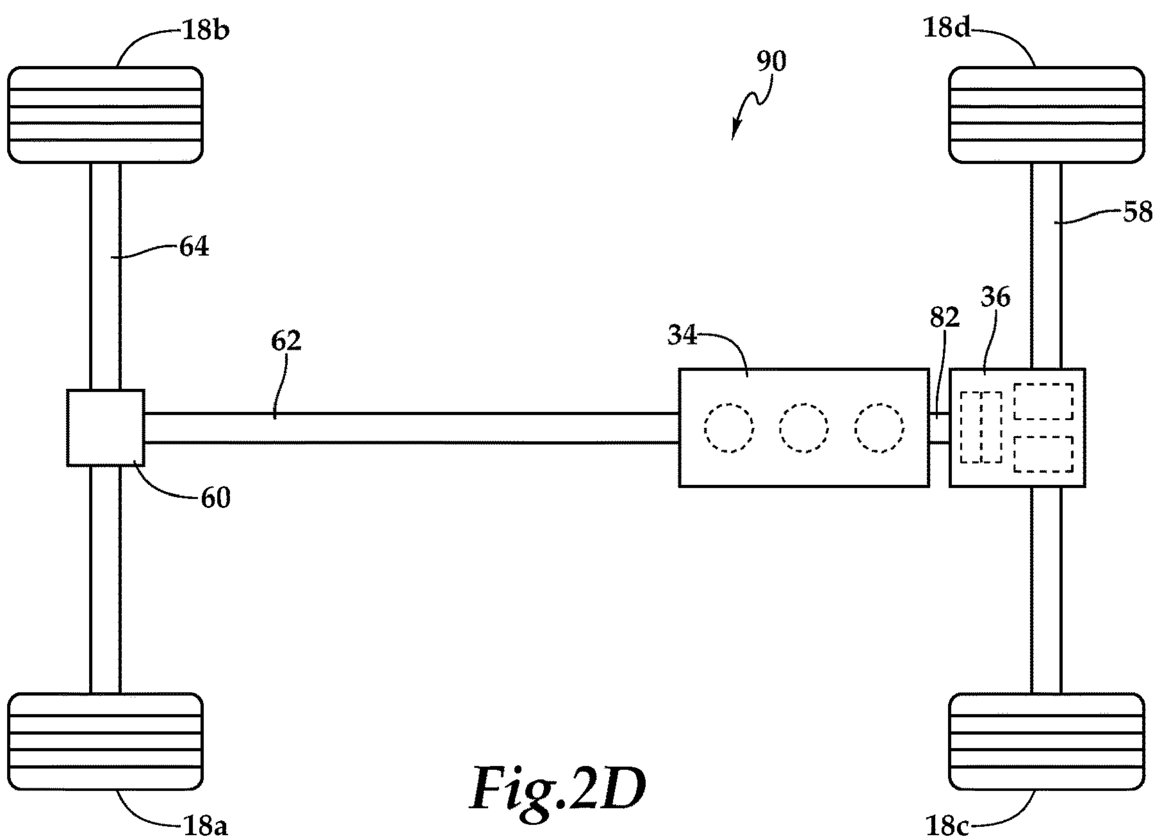
18d
80
34
58
64
62
74
72
60
82
36
18a
18c

Fig.2C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18d
90
58
64
36
82
62
34
60
18a
18c

Fig.2D

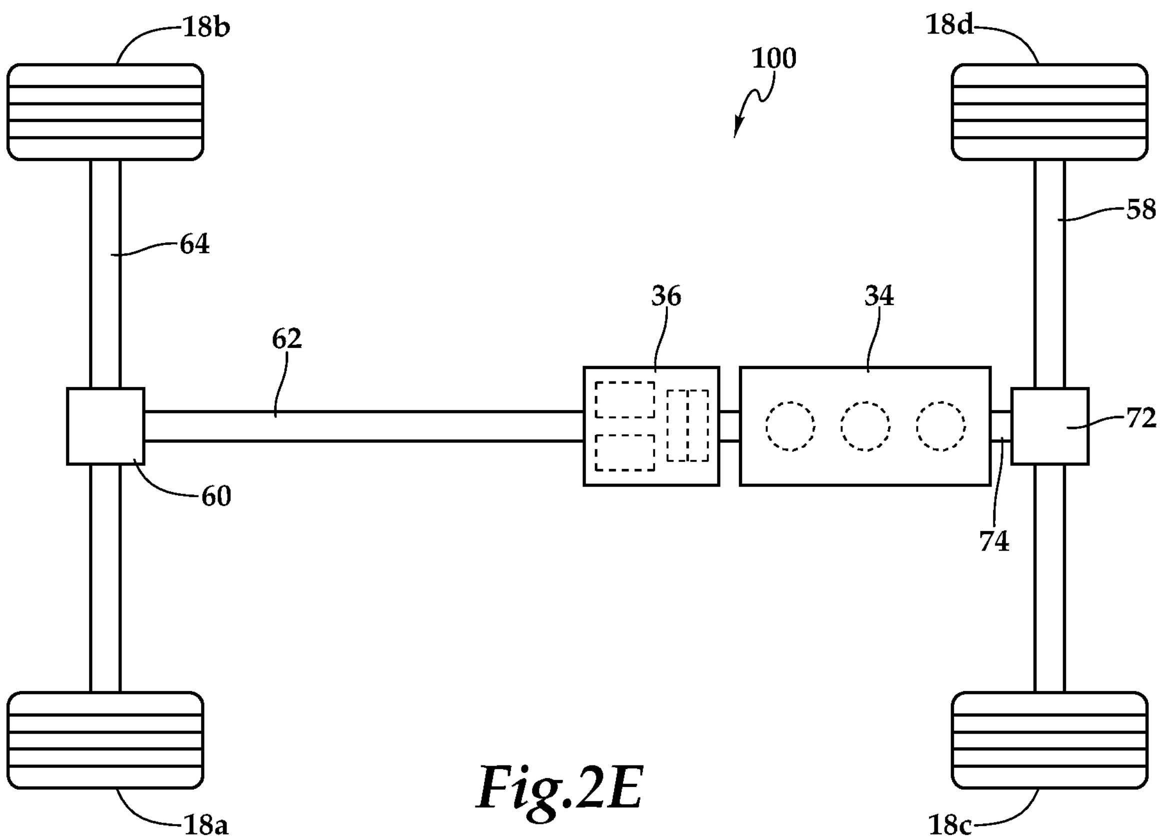


Fig.2E

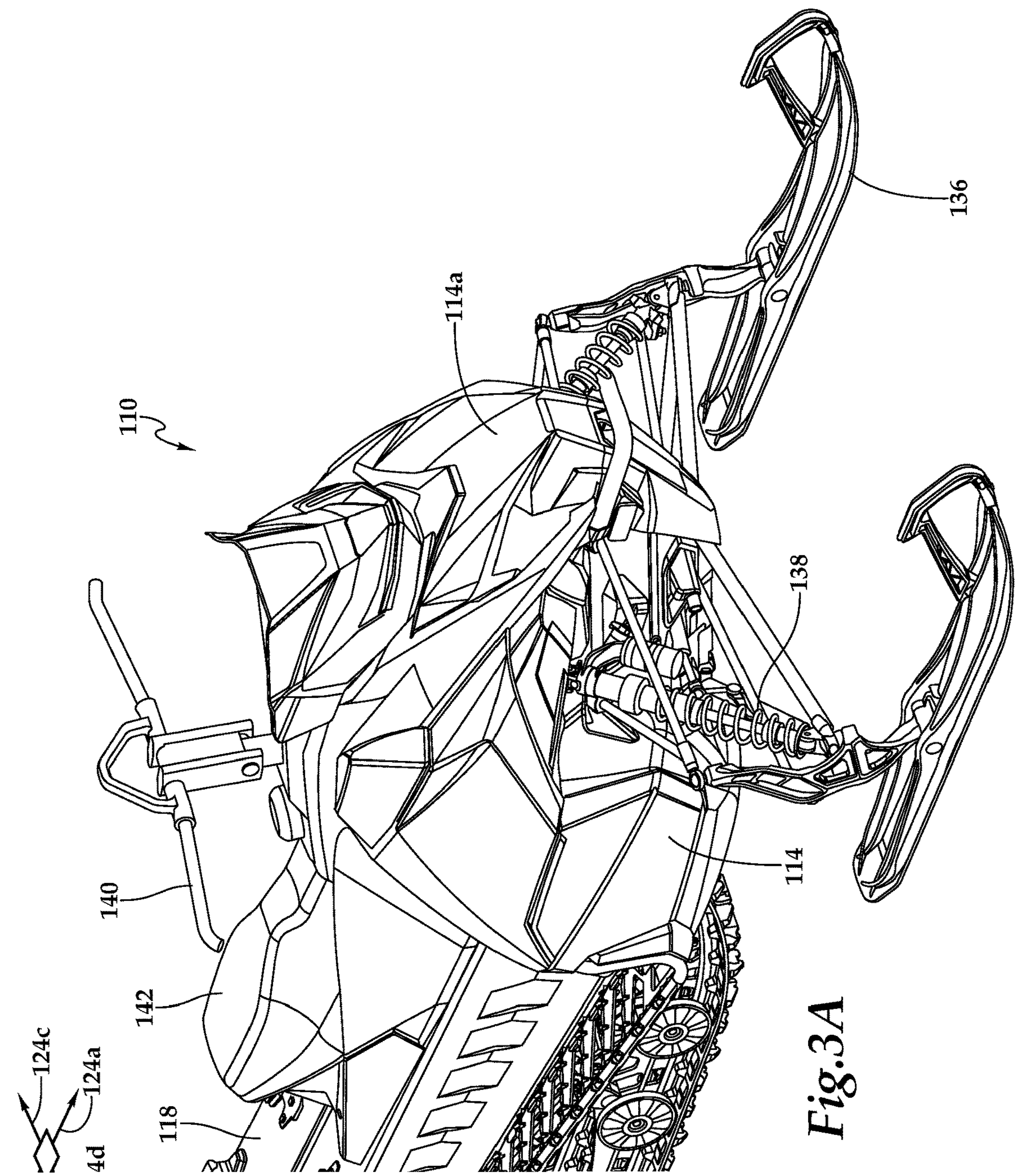


Fig.3A

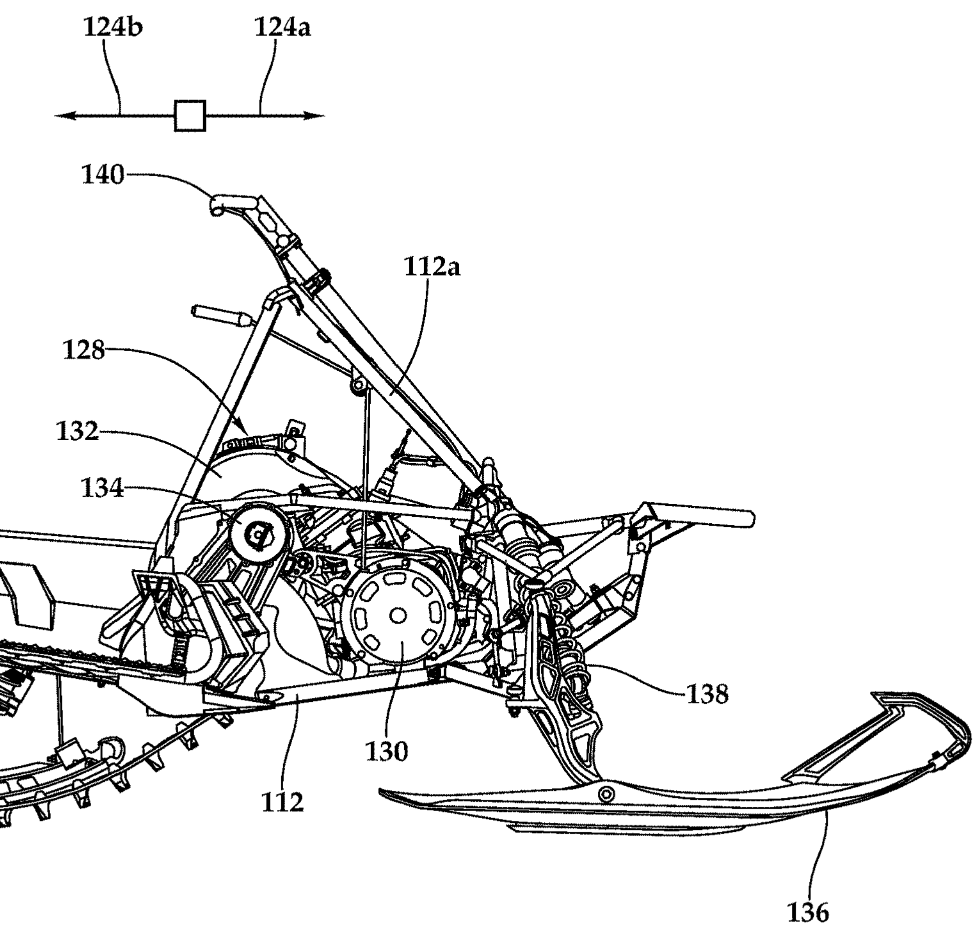
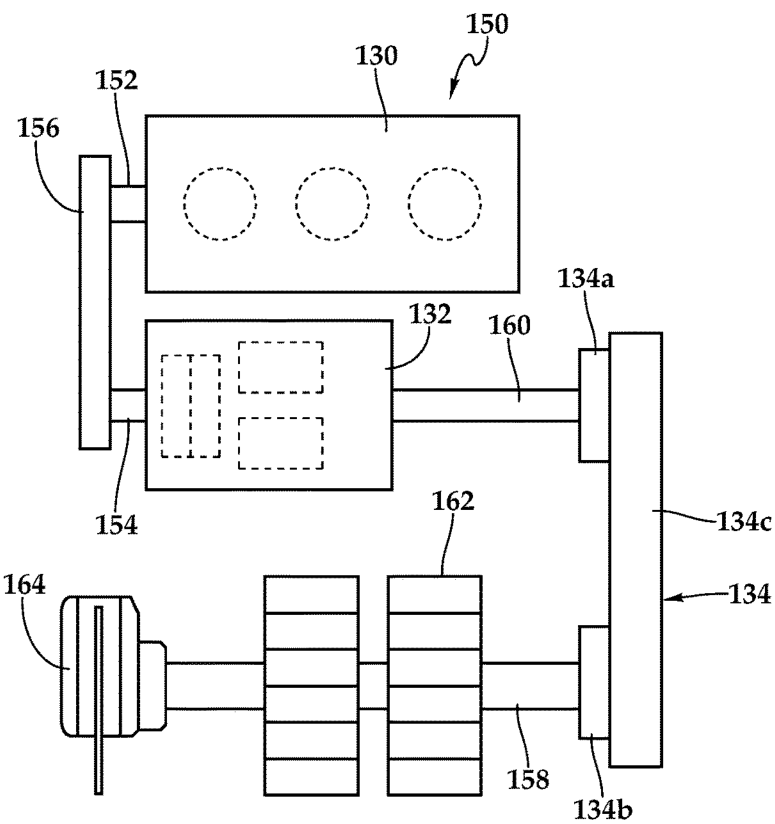


Fig.3B

Fig.4A



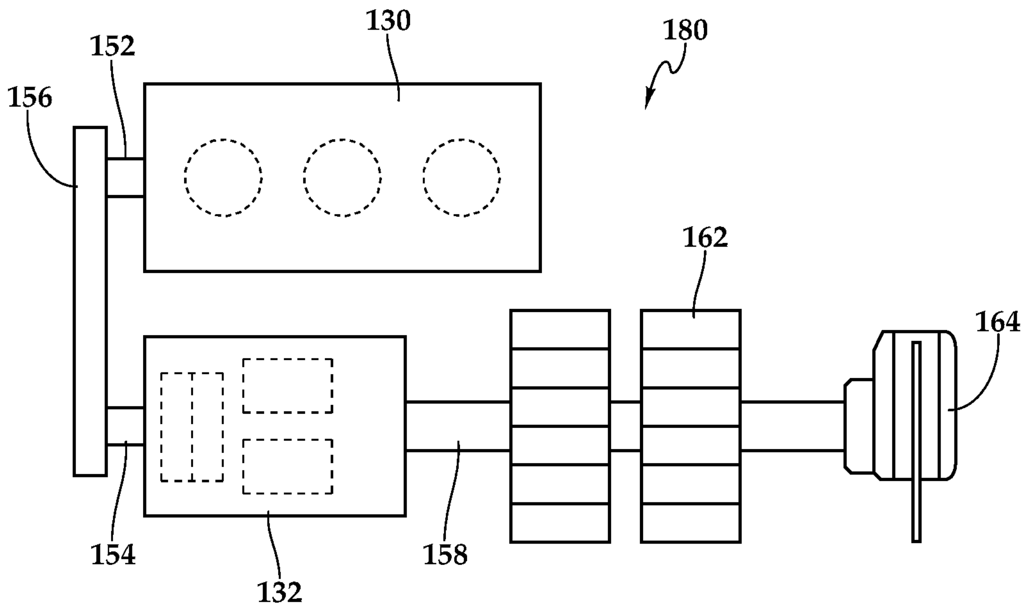


Fig.4C

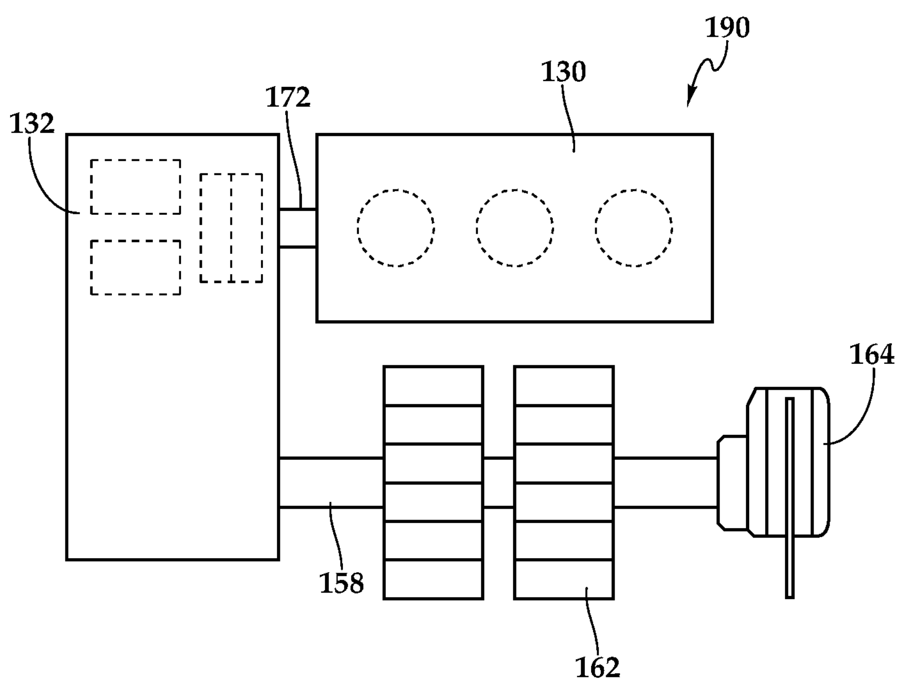
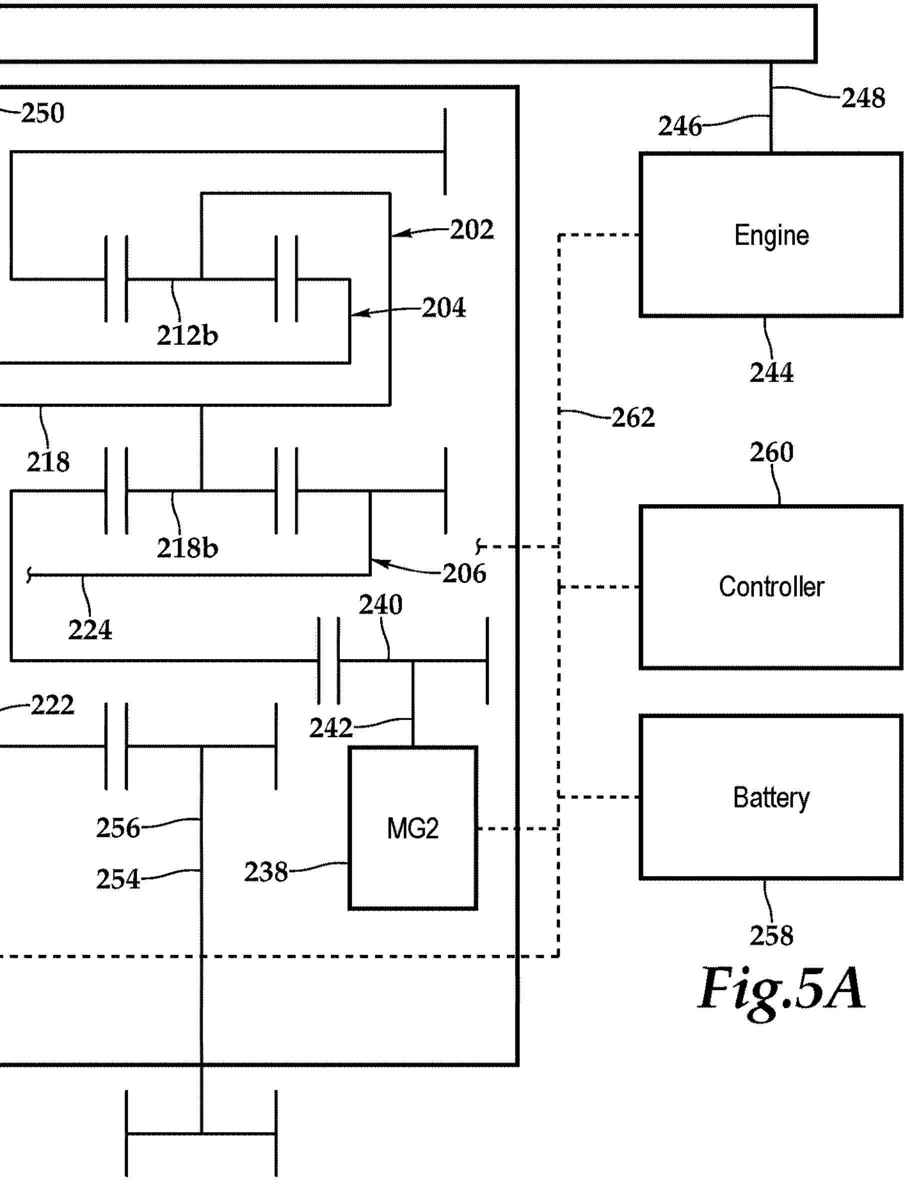


Fig.4D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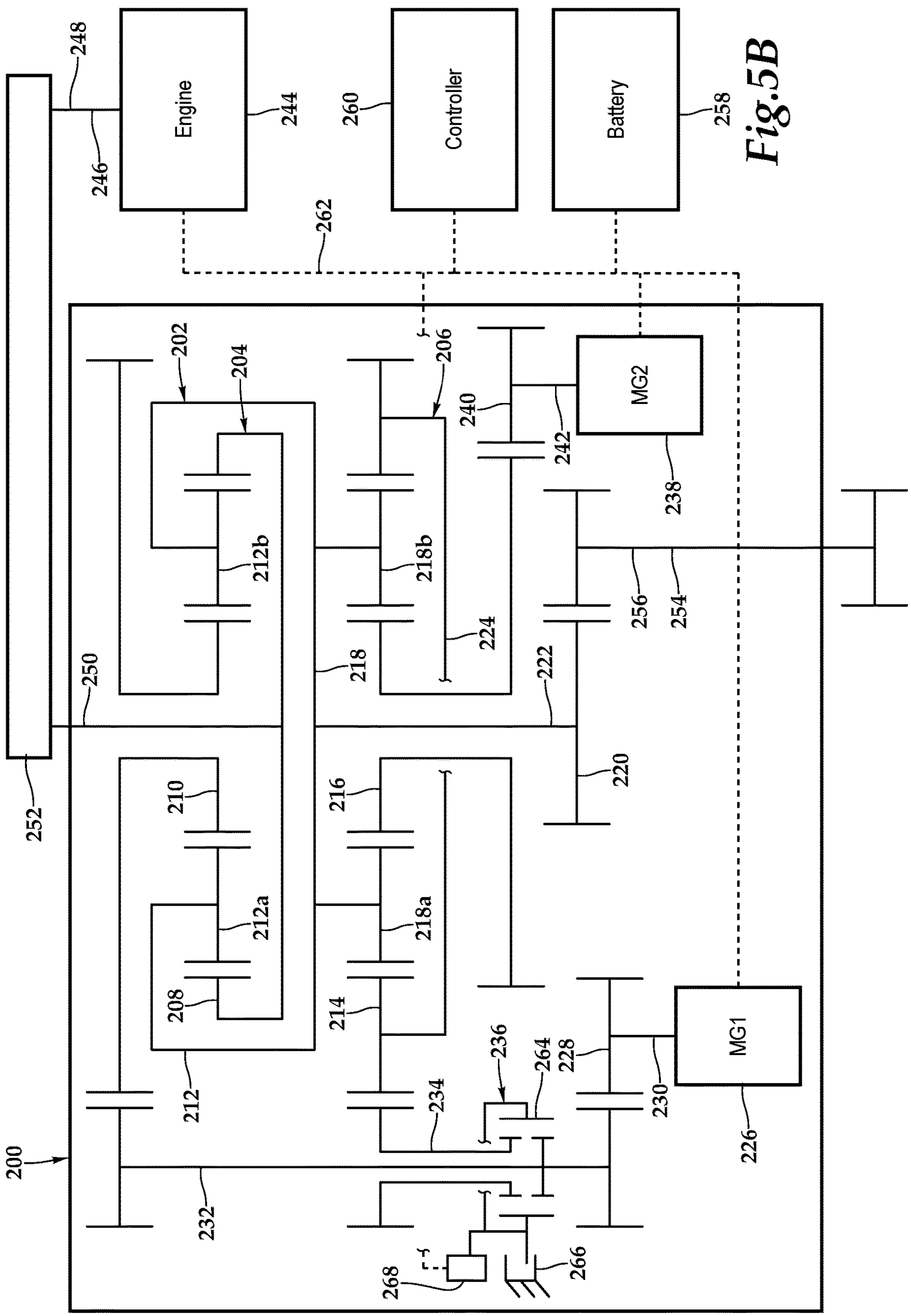
246
Engine
244
250
202
204
212b
262
260
Controller
218
218b
206
224
240
222
242
Battery
256
MG2
254
238
258

Fig.5A


Engine
Controller
Battery
MG2
MG1
200
202
204
206
208
210
212
212a
212b
214
216
218
218a
218b
220
222
224
226
228
230
232
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264
266
268

Fig.5B

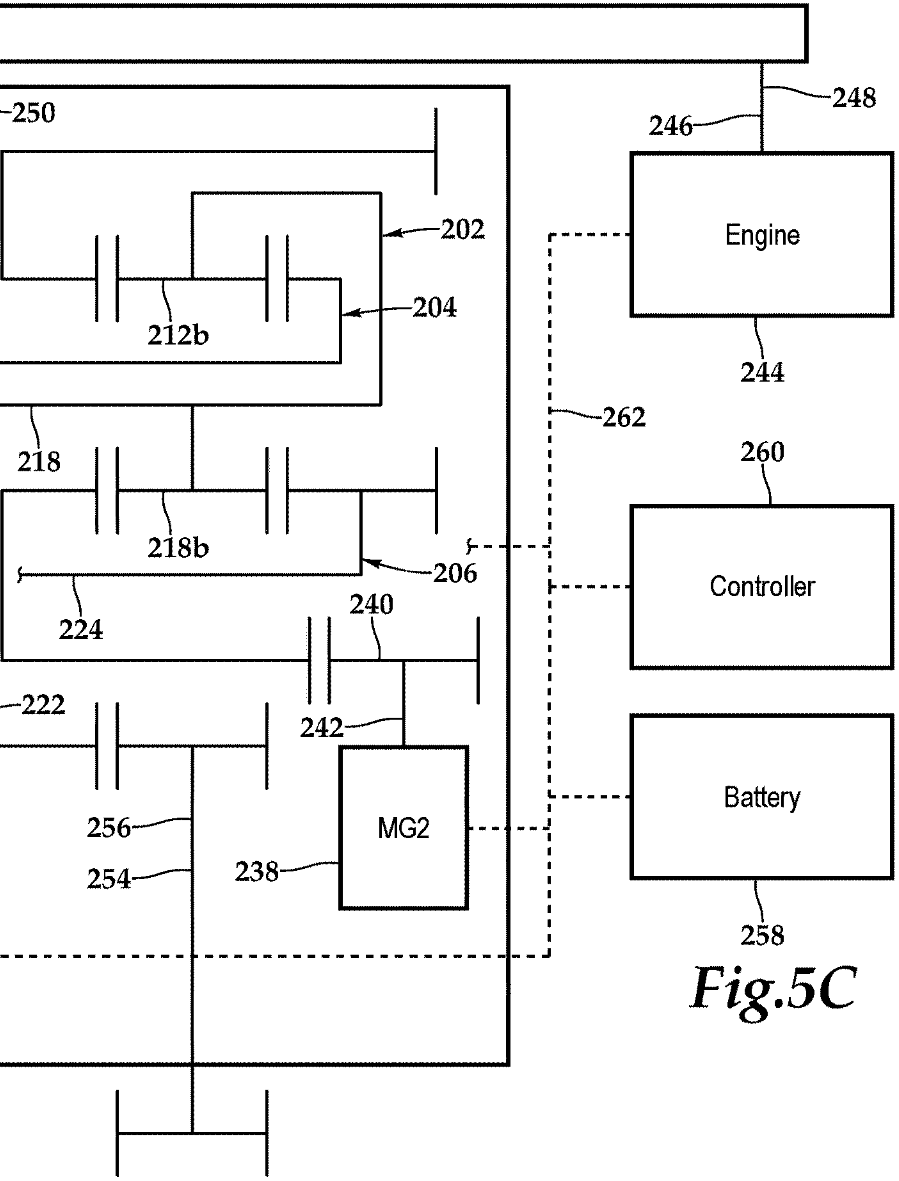

250
202
204
212b
218
218b
206
224
240
222
242
256
254
238
MG2
262
248
246
Engine
244
260
Controller
Battery
258

Fig.5C

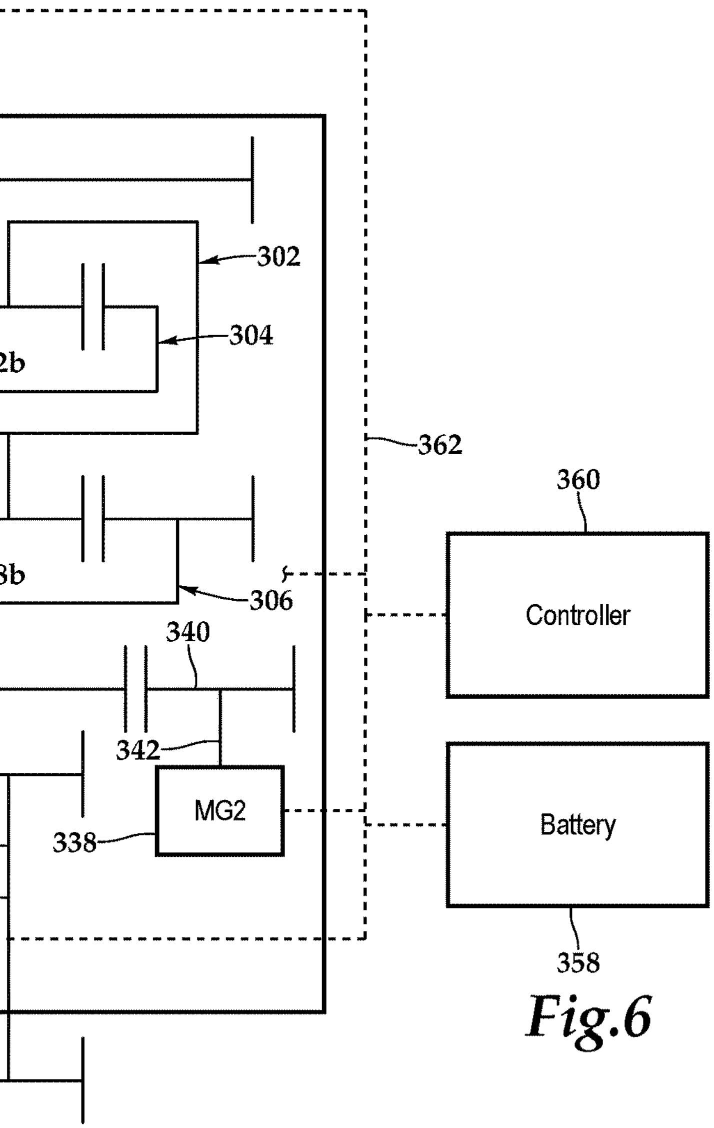


Fig.6

ELECTRICALLY VARIABLE TRANSMISSIONS FOR OFF-ROAD VEHICLES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims the benefit of U.S. Provisional Application No. 63/596,478, filed Nov. 6, 2023, the entire contents of which is hereby incorporated by reference.

TECHNICAL FIELD OF THE DISCLOSURE

[0002] The present disclosure relates, in general, to transmissions used in off-road vehicles and, in particular, to electrically variable transmissions that have a compound planetary gear assembly and two motor generators each operating on a parallel rotational axis to provide variator functionality with a compact footprint for off-road vehicles.

BACKGROUND

[0003] Off-road vehicles are popular land vehicles used for transportation, recreation and utility purposes. Certain off-road vehicles, such as side-by-side vehicles (SxS) and recreational off-highway vehicles (ROV), have ground-engaging wheels. Some off-road vehicles, such as snowmobiles, have a ground-engaging track. Other off-road vehicles, such as all-terrain vehicles (ATV) and utility task vehicles (UTV), may have either ground-engaging wheels or ground-engaging tracks. Wheeled off-road vehicles that are primarily designed for utility applications may offer high ground clearance, low gear ratios for towing, racks for hauling large loads, large dump boxes and/or high payload capacity. Wheeled off-road vehicles that are primarily designed for recreational applications may offer high performance engines as well as safety features including rollover protection, hard tops, windshields and/or cab enclosure features such as body panels. Tracked off-road vehicles may be used in snowy or icy environments and may be designed for specific applications such as trail, utility, mountain, race and crossover, to name a few.

[0004] Both wheeled and tracked off-road vehicles typically utilize a gasoline powered engine that provides torque to the ground-engaging members via a transmission, such as a continuously variable transmission, that helps to provide speed control for the vehicle. It has been found, however, that the belts utilized in continuously variable transmissions tend to experience belt slippage and excessive belt wear during extreme off-road conditions such as in heavy mud or during water crossings in wheeled off-road vehicles and in

a first planet carrier. The second planetary gear set includes a second ring gear, a second sun gear and a second planet carrier. The first and second planet carriers are coupled together for common rotation. The first ring gear is in torque transferring communication with the crankshaft. The compound planetary gear assembly has a first rotational axis. A first motor generator has a first input gear that is in torque transferring communication with the first sun gear. The first input gear has a second rotational axis. A second motor generator has a second input gear that is in torque transferring communication with the second sun gear. The second input gear has a third rotational axis. An output gear is coupled to the first and second planet carriers for common rotation therewith. The first, second and third rotational axes are parallel rotational axes.

[0006] In certain embodiments, the crankshaft may have a fourth rotational axis such that the first, second, third and fourth rotational axes are parallel rotational axes. In such embodiments, an output driveshaft in torque transferring communication with the output gear may have a fifth rotational axis such that the first, second, third, fourth and fifth rotational axes are parallel rotational axes. In other embodiments, the crankshaft may have a fourth rotational axis such that the first and fourth rotational axes are common rotational axes. In such embodiments, an output driveshaft in torque transferring communication with the output gear may have a fifth rotational axis such that the first, second, third and fifth rotational axes are parallel rotational axes. In some embodiments, an output driveshaft in torque transferring communication with the output gear may have a fourth rotational axis such that the first, second, third and fourth rotational axes are parallel rotational axes.

[0007] In certain embodiments, in a low speed mode of the vehicle, the second ring gear may be stationary and each of the engine, the first motor generator and the second motor generator may be configurable as an input to the compound planetary gear assembly. In such embodiments, an output torque and an output speed of the compound planetary gear assembly may be controlled by varying at least one of an engine speed, a first motor generator speed and a second motor generator speed. In some embodiments, in an intermediate speed mode of the vehicle, the first sun gear, the second ring gear and the first motor generator may be stationary and each of the engine and the second motor generator may be configurable as an input to the compound planetary gear assembly. In such embodiments, an output torque and an output speed of the compound planetary gear assembly may be controlled by varying at least one of an engine speed and a second motor generator speed. Also, in second motor generator may be configurable as an output of the compound planetary gear assembly operable to charge a battery.

[0008] In a second aspect, the present disclosure is directed to an off-road vehicle including an internal combustion engine with a crankshaft. A compound planetary gear assembly has first and second planetary gear sets. The first planetary gear set includes a first ring gear, a first sun gear and a first planet carrier. The second planetary gear set includes a second ring gear, a second sun gear and a second planet carrier. The first and second planet carriers are coupled together for common rotation. The first ring gear is in torque transferring communication with the crankshaft. The compound planetary gear assembly has a first rotational axis. A first motor generator has a first input gear that is in torque transferring communication with the first sun gear. The first input gear has a second rotational axis. A second motor generator has a second input gear that is in torque transferring communication with the second sun gear. The second input gear has a third rotational axis. An output gear is coupled to the first and second planet carriers for common rotation therewith. At least one ground-engaging member is in torque transferring communication with the output gear.

[0016] FIG. **6** is a schematic illustration of a powertrain for an off-road vehicle having an electrically variable transmission in accordance with embodiments of the present disclosure.

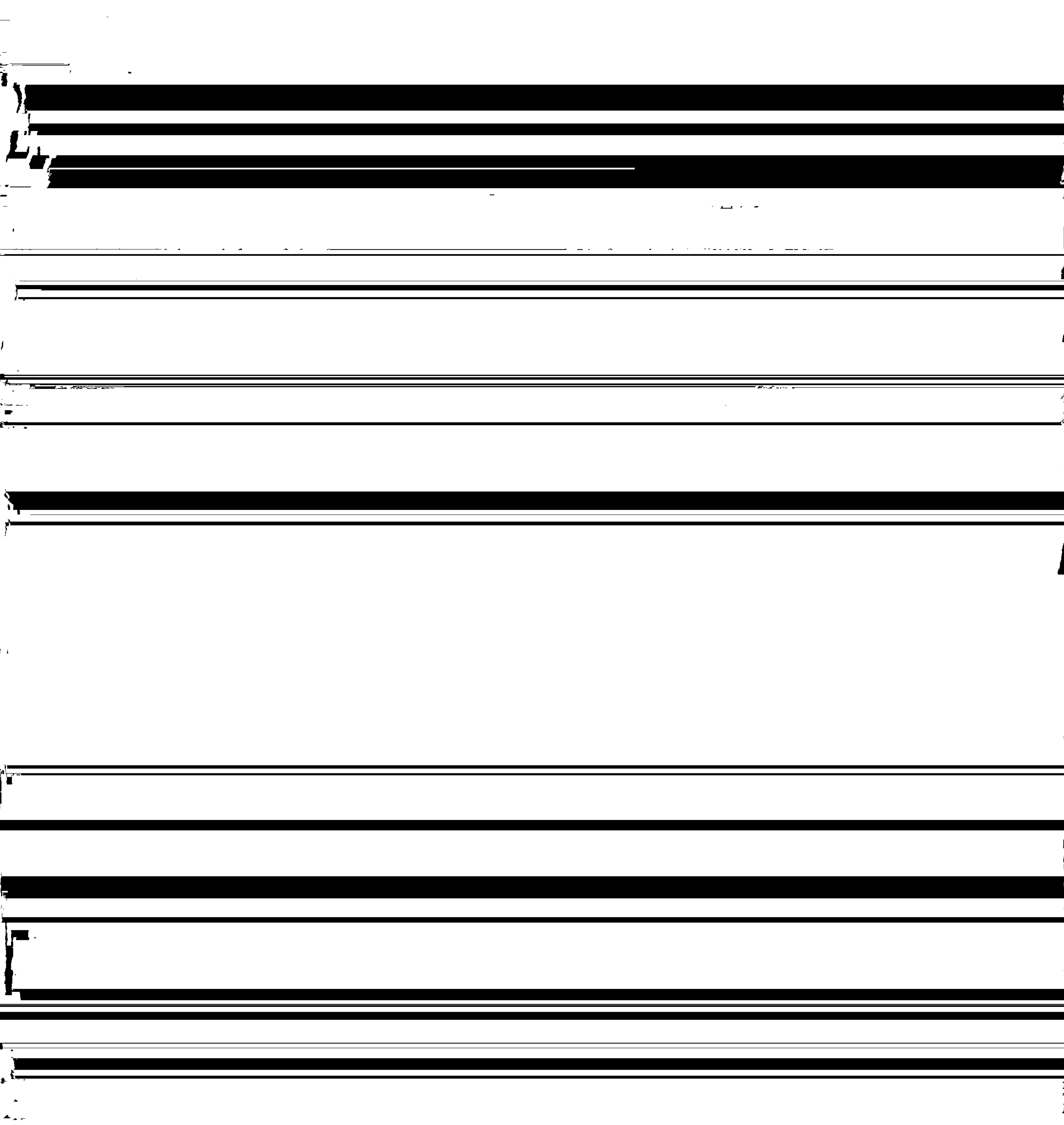
DETAILED DESCRIPTION

[0017] While the making and using of various embodiments of the present disclosure are discussed in detail below, it should be appreciated that the present disclosure provides many applicable inventive concepts, which can be embodied in a wide variety of specific contexts. The specific embodiments discussed herein are merely illustrative and do not delimit the scope of the present disclosure. In the interest of clarity, all features of an actual implementation may not be described in this specification. It will of course be appreciated that in the development of any such actual embodiment, numerous implementation-specific decisions must be made to achieve the developer's specific goals, such as compliance with system-related and business-related constraints, which will vary from one implementation to another. Moreover, it will be appreciated that such a development effort might be complex and time-consuming but would neverthewheeled off-road vehicle **10** such as a hood panel **14**_a_, a left front fender panel **14**_b_, a left door panel **14**_c_, a left side panel **14**_d_, a left rear panel **14**_e_ and a left rear fender panel **14**_f_. It should be understood by those having ordinary skill in the art that wheeled off-road vehicle **10** has similar body panels on the right side of the vehicle including a right front fender panel **14**_g_, a right door panel **14**_h_, a right side panel (not visible), a right rear panel (not visible) and a right rear fender panel (not visible) with these and other body panels of wheeled off-road vehicle **10** being collectively referred to herein as body panels **14**. Body panels **14** may be formed from sheet metal or metal alloy, such as steel or aluminum, and/or polymeric materials such as fiber reinforced polymer composites. In addition, it should be understood by those having ordinary skill in the art that the right side and the left side of wheeled off-road vehicle **10** will be with reference to a forward-facing occupant of wheeled off-road vehicle **10** with the right side of wheeled off-road vehicle **10** corresponding to the right side of the occupant and the left side of wheeled off-road vehicle **10** corresponding to the left side of the occupant. The forward direction of wheeled off-road vehicle **10** is indicated by forward arrow **16**_a_ and the backward direction of wheeled off-road vehicle **10** is indicated by backwards arrow **16**_b_. The forward and backward directions also represent the longitudinal direction of wheeled off-road vehicle **10** with the lateral direction of wheeled off-road vehicle **10** being normal thereto and represented by a leftward arrow **16**_c_ and a rightward arrow **16**_d_. The backward direction may also be referred to herein as the aftward direction.

[0021] Wheeled off-road vehicle **10** includes a plurality of ground-engaging members depicted as four wheels **18** including front wheels **18**_a_, **18**_b_ that are coupled to frame assembly **12** by a front suspension **20** and rear wheels **18**_c_, **18**_d_ that are coupled to frame assembly **12** by a rear suspension **22**. Frame assembly **12** includes a rollover protection structure **24** that at least partially defines an occupant space **26** within wheeled off-road vehicle **10**. In the electrically variable transmissions, electrically variable transmission **36** has a compact footprint making it suitable for use on wheeled off-road vehicles. In the illustrated embodiment, wheeled off-road vehicle **10** is a four-wheel drive vehicle in which powertrain **32** is operatively coupled to front wheels **18**_a_, **18**_b_ via a front differential and to rear wheels **18**_c_, **18**_d_ via a transaxle or rear differential. In other embodiments, wheeled off-road vehicle **10** may be a two-wheel drive vehicle such as a rear-wheel drive vehicle in which the powertrain is coupled to only the rear wheels or a front-wheel drive vehicle in which the powertrain is coupled to only the front wheels.

[0023] Positioned within occupant space **26**, wheeled off-road vehicle **10** includes a steering wheel **38** that is coupled to front wheels **18**_a_, **18**_b_ via a steering linkage. Wheeled off-road vehicle **10** may having a power steering system such as an electric power steering system coupled to the steering linkage, a hydraulically assisted power steering system, an electric power steering system without a mechanical linkage such as a drive-by-wire system, an electric assisted power steering system or other suitable steering system. Wheeled off-road vehicle **10** may also include a gear shift selector that is coupled to transmission **36** that enables the driver to shift wheeled off-road vehicle **10** between various diving modes including forward and reverse driving modes.

[0024] Referring next to FIGS. **2**A-**2**E in the drawings, various powertrain configurations suitable for use in a wheeled off-road vehicle such as wheeled off-road vehicle **10** will now be disclosed. In FIG. **2**A, a powertrain **50** for a wheeled off-road vehicle includes engine **34** and electrically variable transmission **36**. Engine **34** is depicted as a three cylinder, four-stroke engine and electrically variable transmission **36** is depicted as including a compound planetary gear assembly and two motor generators each operating on a parallel rotational axis. The crankshaft **52** of engine **34** is in torque transferring communication with an input shaft **54** of electrically variable transmission **36** via a belt or chain



cally variable transmission **36** via drive mechanism **56**. In the illustrated embodiment, electrically variable transmission **36** is coupled to a rear differential **72** via a drive shaft **74**. Rear differential **72** provides torque to rear axle **58** which rotates rear wheels **18***c*, **18***d*. Electrically variable transmission **36** is also coupled to a front differential **60** via a drive shaft **62**. Front differential **60** provides torque to front axle **64** which rotates front wheels **18***a*, **18***b*. In the illustrated embodiment, electrically variable transmission **36** including the compound planetary gear assembly is positioned forward of engine **34** and is configured such that the rotational axis

vehicle includes engine **34** and electrically variable transmission **36**. Engine **34** is depicted as a three cylinder, four-stroke engine and electrically variable transmission **36** is depicted as including a compound planetary gear assembly and two motor generators each operating on a parallel rotational axis. The crankshaft of engine **34** is in torque transferring communication with the input shaft of electrically variable transmission **36** via a shaft coupling **82**. In the illustrated embodiment, electrically variable transmission **36** is coupled to a rear differential **72** via a drive shaft **74**. Rear differential **72** provides torque to rear axle **58** which rotates rear wheels **18***c*, **18***d*. Electrically variable transmission **36** is supercharger or a turbocharger. In the illustrated embodiment, electrically variable transmission **132** includes a compound planetary gear assembly and two motor generators each operating on a parallel rotational axis for varying the ratio of the engine output speed to the input speed to drive track **116**. By configuring the operative components of electrically variable transmission **132** on three parallel rotational axes instead of a single common rotational axis typically found in electrically variable transmissions, electrically variable transmission **132** has a compact footprint making it suitable for use on tracked off-road vehicles. In the illustrated embodiment, powertrain **128** also includes a belt drive assembly **134** that is positioned in torque transferring communication between electrically variable transmission **132** and drive track **116**. Belt drive assembly **134** may be used to switch snowmobile **110** between forward and reverse modes. Alternatively, the forward and reverse modes of snowmobile **110** may be controlled directly by electrically variable transmission **132**. Snowmobile **110** includes skis **136** and a front suspension assembly **138** that provide front end support for snowmobile **110**. Skis **136** are interconnected to handlebar **140** that is used by an operator to steer snowmobile **110**. The operator controls snowmobile **110** from a seat **142** positioned atop tunnel **118** and behind handlebar **140**.

[0031] Referring to FIGS. **4**A-**4**D in the drawings, various powertrain configurations suitable for use in a tracked off-road vehicle such as snowmobile **110** will now be disclosed. In FIG. **4**A, a powertrain **150** for a tracked off-road vehicle includes engine **130** and electrically variable transmission **132**. Engine **130** is depicted as a three cylinder, four-stroke engine and electrically variable transmission **132** is depicted as including a compound planetary gear assembly and two motor generators each operating on a parallel rotational axis. The crankshaft **152** of engine **130** is in torque transferring communication with an input shaft **154** of electrically variable transmission **132** via a belt or chain drive mechanism **156**. Torque is provided from electrically variable transmission **132** to the final drive, depicted as track driveshaft **158**, via a jack shaft **160** and belt drive assembly **134** that includes a top pulley **134***a*, a bottom pulley **134***b* and a drive belt **134***c*. As illustrated, track driveshaft **158** transfer torque from bottom pulley **134***b* to drive track sprockets **162**, which engage the inside of drive track **116** to provide torque and rotational energy thereto and thus to propel the tracked off-road vehicle. A disc-and-caliper braking system **164** is located at the end of track driveshaft **158** opposite of belt drive assembly **134**. Braking

transferring communication with the input shaft of electrically variable transmission **132** via a shaft coupling **172**. Torque is provided from electrically variable transmission **132** to track driveshaft **158** via jack shaft **160** and belt drive assembly **134** that includes top pulley **134***a*, bottom pulley **134***b* and drive belt **134***c*. As illustrated, track driveshaft **158** transfers torque from bottom pulley **134***b* to drive track sprockets **162**, which engage the inside of drive track **116** to provide torque and rotational energy thereto and thus to propel the tracked off-road vehicle. A disc-and-caliper braking system **164** is located at the end of track driveshaft **158** opposite of belt drive assembly **134**. Braking system **164** is used to slow or stop track driveshaft **158**, thereby slowing or stopping the tracked off-road vehicle. In the illustrated embodiment, electrically variable transmission **132** including the compound planetary gear assembly is positioned lateral of engine **130** and is configured such that the rotational axis of the crankshaft is common with the rotational axis of the compound planetary gear assembly and parallel to the rotational axes of the two motor generators with each of the rotational axes extending substantially in the lateral direction of the vehicle.

[0033] In FIG. **4**C, a powertrain **180** for a tracked off-road vehicle includes engine **130** and electrically variable transmission **132**. Engine **130** is depicted as a three cylinder, four-stroke engine and electrically variable transmission **132** is depicted as including a compound planetary gear assembly and two motor generators each operating on a parallel rotational axis. The crankshaft **152** of engine **130** is in torque transferring communication with an input shaft **154** of electrically variable transmission **132** via a belt or chain drive mechanism **156**. Torque is provided from electrically variable transmission **132** directly to the final drive by track driveshaft **158**. As illustrated, track driveshaft **158** transfer torque to drive track sprockets **162**, which engage the inside of the drive track to provide torque and rotational energy thereto and thus to propel the tracked off-road vehicle. A disc-and-caliper braking system **164** is located at the end of track driveshaft **158**. Braking system **164** is used to slow or stop track driveshaft **158**, thereby slowing or stopping the tracked off-road vehicle. In the illustrated embodiment, electrically variable transmission **132** including the compound planetary gear assembly is positioned aft of engine **130** and is configured such that the rotational axis of crankshaft **152** is parallel to each of the rotational axes of the compound planetary gear assembly and the two motor generators with each of the rotational axes extending substantially in the lateral direction of the vehicle.

164 is used to slow or stop track driveshaft **158**, thereby slowing or stopping the tracked off-road vehicle. In the illustrated embodiment, electrically variable transmission **132** including the compound planetary gear assembly is positioned lateral of engine **130** and is configured such that the rotational axis of the crankshaft is common with the rotational axis of the compound planetary gear assembly and parallel to the rotational axes of the two motor generators with each of the rotational axes extending substantially in the lateral direction of the vehicle.

[0035] Referring next to FIGS. **5A-5C** in the drawings, additional details regarding an electrically variable transmission **200**, which is representative of electrically variable transmissions **36**, **130**, will now be discussed. Electrically variable transmission **200** is presented in a symbolic representation to aid in the clarity of the description. Electrically variable transmission **200** includes a compound planetary gear assembly **202** formed from a first planetary gear set **204** and a second planetary gear set **206**. First planetary gear set **204** include a first ring gear **208**, a first sun gear **210** and a first planet carrier **212** that includes a plurality of first planet gears, such as first planet gears **212***a*, **212***b*. Second planetary gear set **206** include a second ring gear **214**, a second sun gear **216** and a second planet carrier **218** that includes a plurality of second planet gears, such as second planet gears **218***a*, **218***b*. In compound planetary gear assembly **202**, first planet carrier **212** and second planet carrier **218** are coupled together for common rotation and are coupled to an output gear **220**. Each of first ring gear **208**, first sun gear **210**, first planet carrier **212**, second ring gear **214**, second sun gear **216**, second planet carrier **218** and output gear **220** share a common rotational axis indicated at **222**, which is considered to be the rotational axis of compound planetary gear assembly **202**. For convenience of illustration, second ring gear **214** is shown with a broken line **224** to prevent the overlapping of lines in the figure, however, those having ordinary skill in the art will understand the symbolic representation of second ring gear **214**.

[0036] Electrically variable transmission **200** includes a first motor generator **226** that is operable to rotate an input gear **228** about a rotational axis **230** thereof. Input gear **228** is in torque transferring communication with first sun gear **210** of first planetary gear set **204** via a gear train including a gear system **232**. As explained in greater detail herein, input gear **228** is in selective torque transferring communication with second ring gear **214** of second planetary gear set **206** via a gear train including gear system **232**, a gear system **234** and a mode selector assembly **236**. Electrically variable transmission **200** also includes a second motor generator **238** that is operable to rotate an input gear **240** about a rotational axis **242** thereof. Input gear **240** is in torque transferring communication with second sun gear **216** of second planetary gear set **206**. In the illustrated embodiment, each of rotational axis **222** of compound planetary gear assembly **202**, rotational axis **230** of first motor generator **226** and rotational axis **242** of second motor generator **238** is parallel to each of the other rotational axes of electrically variable Rotational axis **242** of second motor generator **238** is parallel to each of rotational axis **222** of compound planetary gear assembly **202** and rotational axis **230** of first motor generator **226**.

[0037] By parallelly offsetting rotational axes **222**, **230**, **242** instead of having compound planetary gear assembly **202**, first motor generator **226** and second motor generator **238** share a common rotational axis as in conventional electrically variable transmissions, the footprint of electrically variable transmission **200** may be greatly reduced such that electrically variable transmission **200** can be assembled in a sufficiently compact package to fit within the tight space requirements of an off-road vehicle. In addition, it should be understood by those having ordinary skill in the art that even though the symbolic representation of electrically variable transmission **200** depicts rotational axes **222**, **230**, **242** in a single plane, the symbolic representation is a two-dimensional representation of a three-dimensional system in which rotational axes **222**, **230**, **242** reside in three-dimensional space. As such, a proper interpretation of the term "parallel rotational axes" refers to non-intersecting and non-coincident rotational axes with no requirement for the recited rotational axes to be coplanar.

[0038] The primary input to electrically variable transmission **200** is provided by engine **244**, which is representative of engines **34**, **130**. In the illustrated embodiment, engine **244** includes a crankshaft **246** that is operable to rotate about a rotational axis **248**. Engine **244** is in torque transferring communication with first ring gear **208** of first planetary gear set **204** via an input shaft **250** and a belt or chain drive mechanism **252**. In the illustrated arrangement, rotational axis **248** of crankshaft **246** is parallel to each of rotational axis **222** of compound planetary gear assembly **202**, rotational axis **230** of first motor generator **226** and rotational axis **242** of second motor generator **238**. The primary output from electrically variable transmission **200** is to the final drive of the off-road vehicle such as the rear axis of a wheeled off-road vehicle or the track driveshaft of a tracked off-road vehicle. In the illustrated embodiment, output gear **220** of compound planetary gear assembly **202** is in torque transferring communication with the final drive via a gear train including an output driveshaft **254** that is operable to rotate about a rotational axis **256**. In the illustrated arrangement, rotational axis **256** of output driveshaft **254** is parallel to each of rotational axis **248** of crankshaft **246**, rotational axis **222** of compound planetary gear assembly **202**, rotational axis **230** of first motor generator **226** and rotational axis **242** of second motor generator **238**.

[0039] The operation of electrically variable transmission **200** will now be described. FIG. **5A** depicts electrically variable transmission **200** in a configuration particularly useful while operating in a low speed mode of the vehicle. As used herein, the term low speed refers to a vehicle speed ranging, for example, between zero percent and forty percent of the maximum vehicle speed. A battery **258** provides electrical power to first motor generator **226**, second motor generator **238**, engine **244**, mode selector assembly **236**, battery **258**, controller **260**, first motor generator **226**, second motor generator **238**, engine **244**, mode selector assembly **236** and other electrical components of the off-road vehicle is enabled by a wired communication system depicted as dashed lines **262** including a broken section of dashed line extending to mode selector assembly **236**. Even though a single battery **258** has been depicted and described, it should be understood by those having ordinary skill in the art that battery **258** represents any number of batteries which may be arranged in a single array or may be distributed in multiple locations including multiple batteries that may operate at different voltages. For example, one battery may be operably associated with engine **244**, while another battery may be operably associated with first motor generator **226** and/or second motor generator **238**.

[0040] Prior to starting the vehicle, electrically variable transmission **200** is configured in the low speed mode with first motor generator **226** in torque transferring communication with first sun gear **210** of first planetary gear set **204** and disengaged from torque transferring communication with second ring gear **214** of second planetary gear set **206**. Specifically, mode selector assembly **236** is positioned such that the inner splines of selector sleeve **264** are out of mesh with the outer splines of gear system **232** and in mesh with the outer splines of gear system **234**. Rotation of selector sleeve **264** is prevented by engagement with lock **266** which in turn prevents rotation of gear system **234** and thus second ring gear **214**. As gear system **232** is disengaged from selector sleeve **264**, first motor generator **226** is operable to rotate first sun gear **210** via gear system **232**. Engine **244** may be started responsive to power from battery **258**. Alternatively, responsive to power from battery **258** and commands from controller **260**, first motor generator **226** may be used to cause first sun gear **210** to rotate which causes first ring gear **208** to rotate with first planet carrier **212** being held stationary. The rotation of first ring gear **208** is coupled to engine **244** via input shaft **250**, drive mechanism **252** and crankshaft **246** such that engine **244** may be started. In an idle mode of engine **244**, first motor generator **226** and/or second motor generator **238** may be used prevent rotation of output gear **220** by providing a torque balance with engine **244**. Alternatively or additionally, a brake may be used to prevent rotation of the final drive, such that input from engine **244** into electrically variable transmission **200** is output by first motor generator **226** and/or second motor generator **238** acting in generator mode to, for example, charge battery **258**.

[0041] During operation of the vehicle in the low speed mode, engine **244** may be operated within a desired speed range (desired revolutions per minute) with first motor generator **226** and second motor generator **238** being used to vary the ratio between the engine input speed and the transmission output speed. Specifically, by changing the input from first motor generator **226** to first sun gear **210** and by changing the input from second motor generator **238** to second sun gear **216**, the gear ratio of electrically variable transmission **200** may be adjusted. In this manner, the output torque and the output speed at output gear **220** of compound planetary gear assembly **202** is controlled by varying the speed of engine **244**, the speed of first motor generator **226**, the speed of a second motor generator **238** or combinations either or both of first motor generator **226** and second motor generator **238** may have a positive speed, a zero speed or a negative speed when providing input to electrically variable transmission **200**. Engine **244** will generally only have a positive speed with backward rotation of crankshaft **246** prevented by a clutch or other suitable mechanism particularly when engine **244** is a four-stroke engine. It is noted that with a two-stroke engine, forward and backward rotation of the crankshaft may be allowed.

[0042] FIG. **5**B depicts electrically variable transmission **200** in a configuration particularly useful while operating in an intermediate speed mode of the vehicle. As used herein, the term intermediate speed refers to a vehicle speed ranging, for example, between thirty percent and seventy percent of the maximum vehicle speed. When the vehicle approaches or has entered the intermediate speed range from below, controller **260** sends commands to actuator **268** of mode selector assembly **236** and to first motor generator **226**. Specifically, rotation first motor generator **226** is stopped such that the relative rotation between the outer splines of gear system **232** and the outer splines of gear system **234** is stopped, noting that the outer splines of gear system **234** are stationary due to being coupled with locked selector sleeve **264**. Once relative rotation has ceased, actuator **268** may shift selector sleeve **264** such that the inner splines of selector sleeve **264** are in mesh with the outer splines of gear system **232** and in mesh with the outer splines of gear system **234**. Rotation of selector sleeve **264** is still prevented by engagement with lock **266** which now prevents rotation of gear system **232** and gear system **234** and thus of first sun gear **210** and second ring gear **214**. First motor generator **226** is now disengage as an input to electrically variable transmission **200**. In this configuration, engine **244** may be operated within a desired speed range with second motor generator **238** being used to vary the ratio between the engine input speed and the transmission output speed. Specifically, by changing the input from second motor generator **238** to second sun gear **216**, the gear ratio of electrically variable transmission **200** may be adjusted. In this manner, the output torque and the output speed at output gear **220** of compound planetary gear assembly **202** is controlled by varying the speed of engine **244**, the speed of second motor generator **238** or combinations thereof. In addition, engine **244** may function as the sole input to electrically variable transmission **200** in a direct drive mode or may be used to rotate second motor generator **238**, which may function as an output from electrically variable transmission **200** in a generator mode to, for example, charge battery **258**.

[0043] FIG. **5**C depicts electrically variable transmission **200** in a configuration particularly useful while operating in a high speed mode of the vehicle. As used herein, the term high speed refers to a vehicle speed ranging, for example, between sixty percent and one hundred percent of the maximum vehicle speed. When the vehicle approaches or has entered the high speed range from below, controller **260** sends a command to actuator **268** of mode selector assembly **236** to shift selector sleeve **264** into disengagement with lock **266** while maintaining the inner splines of selector sleeve **264** in mesh with the outer splines of gear system **232** and in mesh with the outer splines of gear system **234**. With gear system **232** and gear system **234** coupled together and within a desired speed range with first motor generator **226** and second motor generator **238** being used to vary the ratio between the engine input speed and the transmission output speed. Specifically, by changing the input from first motor generator **226** to first sun gear **210** and second ring gear **214** and/or by changing the input from second motor generator **238** to second sun gear **216**, the gear ratio of electrically variable transmission **200** may be adjusted. In this manner, the output torque and the output speed at output gear **220** of compound planetary gear assembly **202** is controlled by varying the speed of engine **244**, the speed of first motor generator **226**, the speed of second motor generator **238** or combinations thereof. In addition, either first motor generator **226** or second motor generator **238** may be driven by engine **244** to function as an output from electrically variable transmission **200** in a generator mode to, for example, charge battery **258**.

[0044] When it is desired to reduce vehicle speed and the vehicle approaches or has entered the intermediate speed range from above, controller **260** sends commands to actuator **268** of mode selector assembly **236** and to first motor generator **226**. Specifically, rotation first motor generator **226** is stopped such that the relative rotation between selector sleeve **264** and lock **266** is stopped. Once relative rotation has ceased, actuator **268** may shift selector sleeve **264** into engagement with lock **266** while maintaining the inner splines of selector sleeve **264** in mesh with the outer splines of gear system **232** and in mesh with the outer splines of gear system **234**. Rotation of selector sleeve **264** is now prevented by engagement with lock **266** which also prevents rotation of gear system **232** and gear system **234** and thus of first sun gear **210** and second ring gear **214**. Electrically variable transmission **200** is now in the configuration depicted in and described with reference to FIG. **5**B, which is particularly useful for operating in the intermediate speed mode of the vehicle.

[0045] When it is desired to further reduce vehicle speed and the vehicle approaches or has entered the low speed range from above, controller **260** sends a command to actuator **268** of mode selector assembly **236** to shift selector sleeve **264** such that the inner splines of selector sleeve **264** are out of mesh with the outer splines of gear system **232** and in mesh with the outer splines of gear system **234** while maintaining engagement with lock **266**. As rotation of selector sleeve **264** remains prevented by engagement with lock **266**, rotation of gear system **234** and thus of second ring gear **214** is prevented. Gear system **232** is now free to rotate such that second motor generator **226** may function as an input to rotate first sun gear **210**. Electrically variable transmission **200** is now in the configuration depicted in and described with reference to FIG. **5**A, which is particularly useful for operating in the low speed mode of the vehicle.

[0046] In this manner, electrically variable transmission **200** is operable to adjust the gear ratio between input shaft **250** and output gear **220** of compound planetary gear assembly **202** to provide not only variable speed control but also smooth power delivery for an off-road vehicle without the limitations associated with belt-driven continuously variable transmissions. In addition, electrically variable transmission **200** may be selectively configured for optimal performance in each of a low speed mode, an intermediate speed mode and a high speed mode of the vehicle. Importantly, by structurally offsetting the components of electrically variable transmission **200** such that each of rotational axis **248** of crankshaft **246**, rotational axis **222** of compound planetary gear assembly **202**, rotational axis **230** of first motor generator **226**, rotational axis **242** of second motor generator **238** and rotational axis **256** of output driveshaft **254** is parallel to each other, electrically variable transmission **200** can be assembled in a sufficiently compact package to fit within the tight space requirements of an off-road vehicle.

[0047] Referring next to FIG. **6** in the drawings, an alternate powertrain including an electrically variable transmission **300**, which is representative of electrically variable transmissions **36**, **130**, will now be discussed. Electrically variable transmission **300** includes a compound planetary gear assembly **302** formed from a first planetary gear set **304** and a second planetary gear set **306**. First planetary gear set **304** include a first ring gear **308**, a first sun gear **310** and a first planet carrier **312** that includes a plurality of first planet gears, such as first planet gears **312***a*, **312***b*. Second planetary gear set **306** include a second ring gear **314**, a second sun gear **316** and a second planet carrier **318** that includes a plurality of second planet gears, such as second planet gears **318***a*, **318***b*. In compound planetary gear assembly **302**, first planet carrier **312** and second planet carrier **318** are coupled together for common rotation and are coupled to an output gear **320** for rotation therewith. Each of first ring gear **308**, first sun gear **310**, first planet carrier **312**, second ring gear **314**, second sun gear **316**, second planet carrier **318** and output gear **320** share a common rotational axis indicated at **322**, which is considered to be the rotational axis of compound planetary gear assembly **302**.

[0048] Electrically variable transmission **300** includes a first motor generator **326** that is operable to rotate an input gear **328** about a rotational axis **330** thereof. Input gear **328** is in torque transferring communication with first sun gear **310** of first planetary gear set **304** via a gear train including a gear system **332**. Input gear **328** is in selective torque transferring communication with second ring gear **314** of second planetary gear set **306** via a gear train including gear system **332**, a gear system **334** and a mode selector assembly **336**. Electrically variable transmission **300** also includes a second motor generator **338** that is operable to rotate an input gear **340** about a rotational axis **342** thereof. Input gear **340** is in torque transferring communication with second sun gear **316** of second planetary gear set **306**. In the illustrated embodiment, each of rotational axis **322** of compound planetary gear assembly **302**, rotational axis **330** of first motor generator **326** and rotational axis **342** of second motor generator **338** is parallel to each of the other rotational axes of electrically variable transmission **300**.

[0049] The primary input to electrically variable transmission **300** is provided by engine **344**, which is representative of engines **34**, **130**. In the illustrated embodiment, engine **344** includes a crankshaft **346** that is operable to rotate about a rotational axis **348**. Engine **344** is in torque transferring communication with first ring gear **308** of first planetary gear set **304** via an input shaft **350**. In the illustrated arrangement, rotational axis **348** of crankshaft **346** is common with rotational axis **322** of compound planetary gear assembly **302** and is parallel to each of rotational axis **330** of first motor generator **326** and rotational axis **342** of second motor generator **338**. The primary output from electrically variable transmission **300** is to the final drive of the off-road vehicle. In the illustrated embodiment, output gear **320** of compound planetary gear assembly **302** is in torque transferring communication with the final drive via a gear train including an output driveshaft **354** that is operable to rotate about a rotational axis **356**. In the illustrated arrangement, rotational axis **356** of output driveshaft **354** is parallel to each of rotational axis **348** of crankshaft **346**, rotational axis **322** of compound planetary gear assembly **302**, rotational axis **330** of first motor generator **326** and rotational axis **342** of second motor generator **338**.

[0050] The operation of electrically variable transmission **300** is substantially similar to that of electrically variable transmission **200** including having a low speed configuration in which the inner splines of locked selector sleeve **364** are out of mesh with the outer splines of gear system **332** and in mesh with the outer splines of gear system **334**, an intermediate speed configuration in which the inner splines of locked selector sleeve **364** are in mesh with the outer splines of gear system **332** and in mesh with the outer splines of gear system **334**, and a high speed configuration in which the inner splines of unlocked selector sleeve **364** are in mesh with the outer splines of gear system **332** and in mesh with the outer splines of gear system **334**. In addition, electrically variable transmission **300** is shifted between the speed configurations responsive to commands from controller **360** sent over a wire communication system **362** that distributes power and signal communications between battery **358**, controller **360**, engine **344**, first motor generator **326**, second motor generator **338**, mode selector assembly **336** and to other electrical components of the vehicle. The commands enable actuator **368** to shift selector sleeve **364** in and out of engagement with gear system **332** as well as in and out of engagement with lock **366**.

[0051] In this manner, electrically variable transmission **300** is operable to adjust the gear ratio between input shaft **350** and output gear **320** of compound planetary gear assembly **302** to provide not only variable speed control but also smooth power delivery for an off-road vehicle without

embodiments, implementations, contexts, applications and/or figures. Other substitutions, modifications, changes and omissions may be made in the design, operating conditions and arrangement of the embodiments without departing from the scope of the present disclosure. Such modifications and combinations of the illustrative embodiments as well as other embodiments will be apparent to persons skilled in the art upon reference to the description. It is, therefore, intended that the appended claims encompass any such modifications or embodiments.

What is claimed is:

1. An electrically variable transmission for an off-road vehicle having an internal combustion engine with a crankshaft, the transmission comprising:

a compound planetary gear assembly having first and second planetary gear sets, the first planetary gear set including a first ring gear, a first sun gear and a first planet carrier, the second planetary gear set including a second ring gear, a second sun gear and a second planet carrier, the first and second planet carriers coupled together for common rotation, the first ring gear in torque transferring communication with the crankshaft, the compound planetary gear assembly having a first rotational axis;

a first motor generator having a first input gear in torque transferring communication with the first sun gear, the first input gear having a second rotational axis;

a second motor generator having a second input gear in torque transferring communication with the second sun gear, the second input gear having a third rotational axis; and

an output gear coupled to the first and second planet carriers for common rotation therewith;

wherein, the first, second and third rotational axes are parallel rotational axes.

2. The transmission as recited in claim **1** wherein, the crankshaft has a fourth rotational axis; and second motor generator is configurable as an input to the compound planetary gear assembly.

8. The transmission as recited in claim **7** wherein, an output torque and an output speed of the compound planetary gear assembly is controlled by varying at least one of an engine speed, a first motor generator speed and a second motor generator speed.

9. The transmission as recited in claim **1** wherein, in an intermediate speed mode of the vehicle, the first sun gear, the second ring gear and the first motor generator are stationary and each of the engine and the second motor generator is configurable as an input to the compound planetary gear assembly.

10. The transmission as recited in claim **9** wherein, an output torque and an output speed of the compound planetary gear assembly is controlled by varying at least one of an engine speed and a second motor generator speed.

11. The transmission as recited in claim **9** wherein, the second motor generator is configurable as an output of the compound planetary gear assembly operable to charge a battery.

12. The transmission as recited in claim **1** wherein, in a

15. An off-road vehicle comprising:

an internal combustion engine with a crankshaft;

a compound planetary gear assembly having first and second planetary gear sets, the first planetary gear set including a first ring gear, a first sun gear and a first planet carrier, the second planetary gear set including a second ring gear, a second sun gear and a second planet carrier, the first and second planet carriers coupled together for common rotation, the first ring gear in torque transferring communication with the crankshaft, the compound planetary gear assembly having a first rotational axis;

a first motor generator having a first input gear in torque transferring communication with the first sun gear, the first input gear having a second rotational axis;

a second motor generator having a second input gear in torque transferring communication with the second sun gear, the second input gear having a third rotational axis;

an output gear coupled to the first and second planet carriers for common rotation therewith; and

at least one ground-engaging member in torque transferring communication with the output gear, the at least one ground-engaging member configured to provide ground propulsion for the vehicle responsive to torque from the output gear;

second motor generator is configurable as an input to the compound planetary gear assembly.

8. The transmission as recited in claim **7** wherein, an output torque and an output speed of the compound planetary gear assembly is controlled by varying at least one of an engine speed, a first motor generator speed and a second motor generator speed.

9. The transmission as recited in claim **1** wherein, in an intermediate speed mode of the vehicle, the first sun gear, the second ring gear and the first motor generator are stationary and each of the engine and the second motor generator is configurable as an input to the compound planetary gear assembly.

15. An off-road vehicle comprising:

an internal combustion engine with a crankshaft;

a compound planetary gear assembly having first and second planetary gear sets, the first planetary gear set including a first ring gear, a first sun gear and a first planet carrier, the second planetary gear set including a second ring gear, a second sun gear and a second planet carrier, the first and second planet carriers coupled together for common rotation, the first ring gear in torque transferring communication with the crankshaft, the compound planetary gear assembly having a first rotational axis;

a first motor generator having a first input gear in torque transferring communication with the first sun gear, the first input gear having a second rotational axis;