US012392407B2

(12) **United States Patent**
Rinaldi et al.

(10) **Patent No.: US 12,392,407 B2**
(45) **Date of Patent: Aug. 19, 2025**

(54) **SYSTEM AND METHOD FOR SEAMLESS SHIFTING IN A DUAL MOTOR TRANSMISSION WITH MINIMAL GEARS**

(71) Applicant: **DANA ITALIA S.R.L.**, Trentino (IT)

(72) Inventors: **Pier Paolo Rinaldi**, Arco (IT); **Giacomo Faggiani**, Rovereto (IT); **Mark Slater**, Warwickshire (GB)

(73) Assignee: **DANA ITALIA S.R.L.**, Trentino (IT)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 222 days.

(21) Appl. No.: **18/161,790**

(22) Filed: **Jan. 30, 2023**

(65) **Prior Publication Data**

US 2024/0255053 A1 Aug. 1, 2024

(51) **Int. Cl.**

F16H 61/04	(2006.01)
B60K 1/02	(2006.01)
B60W 10/08	(2006.01)
F16H 61/688	(2006.01)

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

CPC ***F16H 61/0403*** (2013.01); ***B60W 10/08*** (2013.01); ***F16H 61/688*** (2013.01); *F16H 2061/0422* (2013.01)

(58) **Field of Classification Search**

CPC F16H 61/0403; F16H 61/688; F16H 2061/0422; F16H 61/04; F16H 2003/0811; F16H 3/089; F16H 2061/0433; F16H 2200/0021; F16H 2200/0034; B60K 1/02; B60W 10/08

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,100,207	B2	1/2012	Oba et al.	
9,657,822	B2	5/2017	Park et al.	
9,789,754	B2	10/2017	Zhu et al.	
10,252,608	B2	4/2019	Liu et al.	
11,162,562	B2	11/2021	Yu et al.	
2009/0019967	A1*	1/2009	Himmelmann	B60K 6/46 74/331
2010/0023230	A1*	1/2010	Holmes	B60W 10/113 74/664

(Continued)

FOREIGN PATENT DOCUMENTS

AT	522931	A1 *	3/2021	B60K 1/02
CN	202753745	U *	2/2013	B60K 1/02

(Continued)

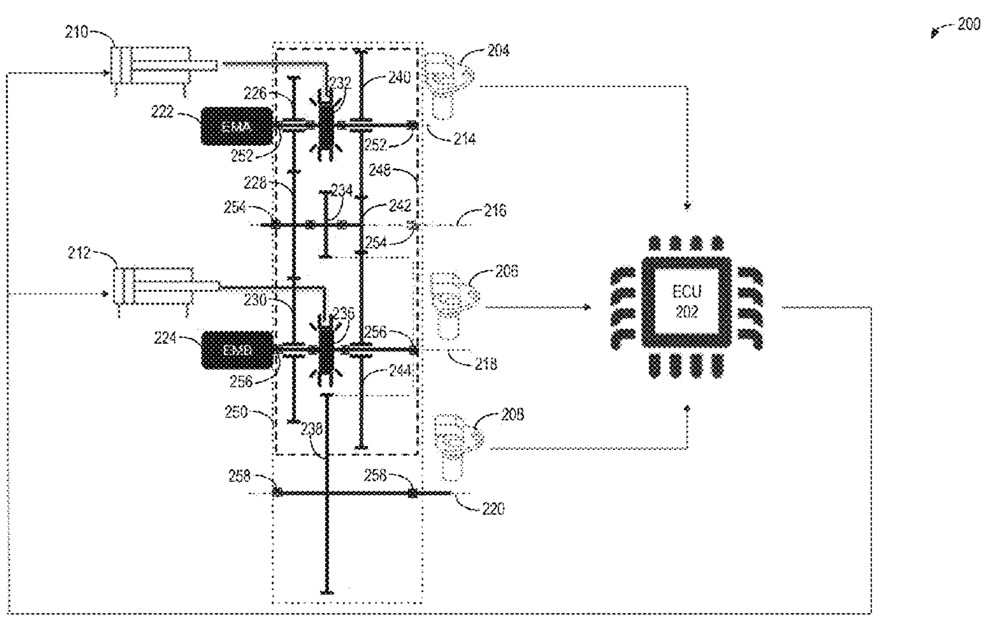
Primary Examiner — Tisha D Lewis

(74) *Attorney, Agent, or Firm* — McCoy Russell LLP

(57) **ABSTRACT**

Methods and systems for a dual motor transmission system that includes an intermediate shaft oriented parallel to both of a first shaft arranged with a first gear mesh, a third gear mesh, and a first low friction engaging device located between the first gear mesh and the third gear mesh and a second shaft arranged with a second gear mesh, a fourth gear mesh, and a second low friction engaging device located between the second gear mesh and the fourth gear mesh, a first electric motor coupled to the first shaft to enable a first reduction ratio and second reduction ratio of the first electric motor between the first shaft and the intermediate shaft, and a second electric motor coupled to the second shaft to enable a first reduction ratio and second reduction ratio of the second electric motor between the second shaft and the intermediate shaft.

14 Claims, 14 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

2014/0358383	A1*	12/2014	Tao	F16H 61/688 701/51
2019/0219159	A1*	7/2019	Rinderknecht	F16H 61/0403
2022/0381323	A1*	12/2022	Hedman	F16H 37/065
2023/0175578	A1*	6/2023	Folkesson	B60K 25/06

FOREIGN PATENT DOCUMENTS

CN	105416049	B *	8/2016	B60K 1/02
EP	2529967	A1	12/2012	
WO	WO-2020148452	A1 *	7/2020	B60K 6/48
WO	WO-2023139228	A1 *	7/2023	B60K 1/02

* cited by examiner

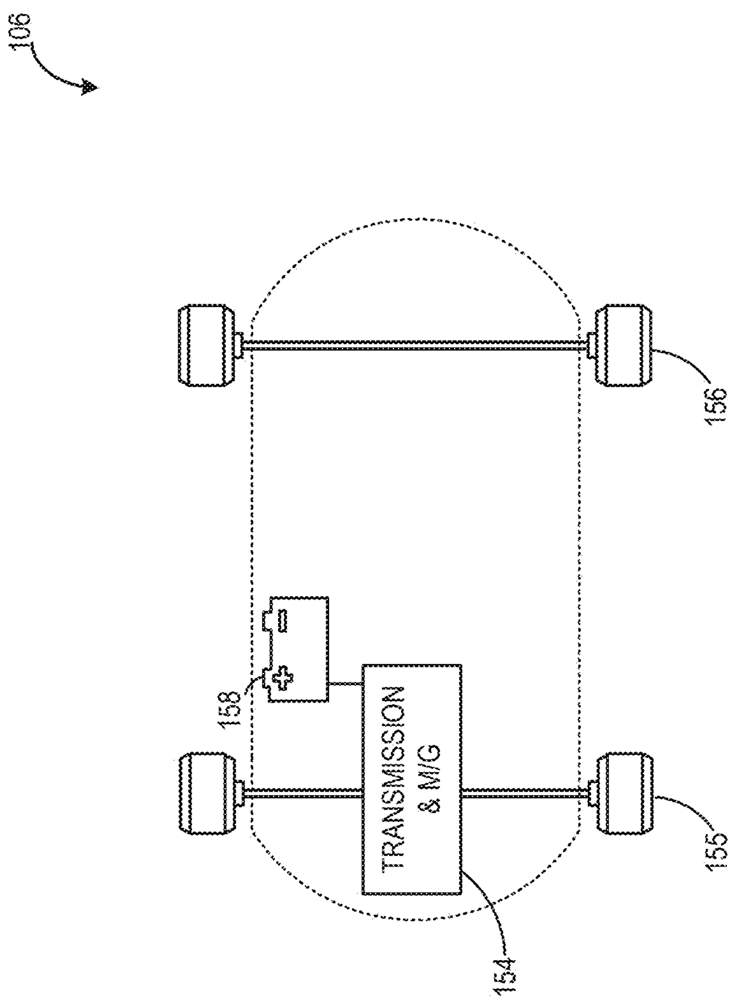


FIG. 1A

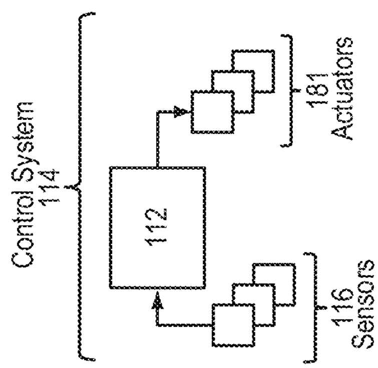


FIG. 1B

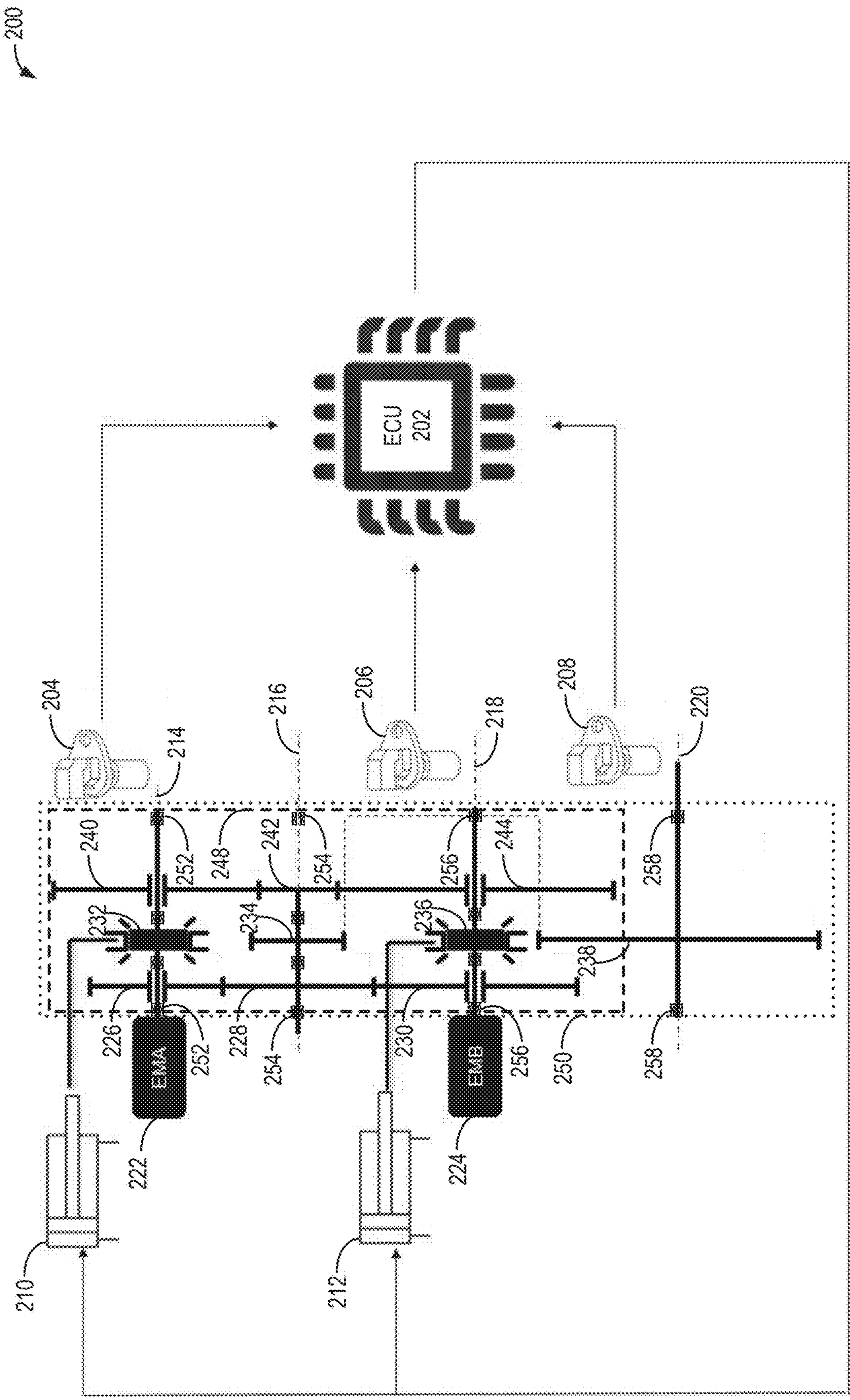

200
ECU
202
204
206
208
210
212
214
216
218
220
222
224
226
228
230
232
234
236
238
240
242
244
248
250
252
254
256
258
EMA
EMB

FIG. 2A

201

Transmission Drive Ranges (260)	EMA (262)	EMB (264)
DRNN	Neutral	Neutral
DR11	First Speed	First Speed
DRN1	Neutral	First Speed
DR21	Second Speed	First Speed
DR2N	Second Speed	Neutral
DR22	Second Speed	Second Speed
DRN2	Neutral	Second Speed

FIG. 2B

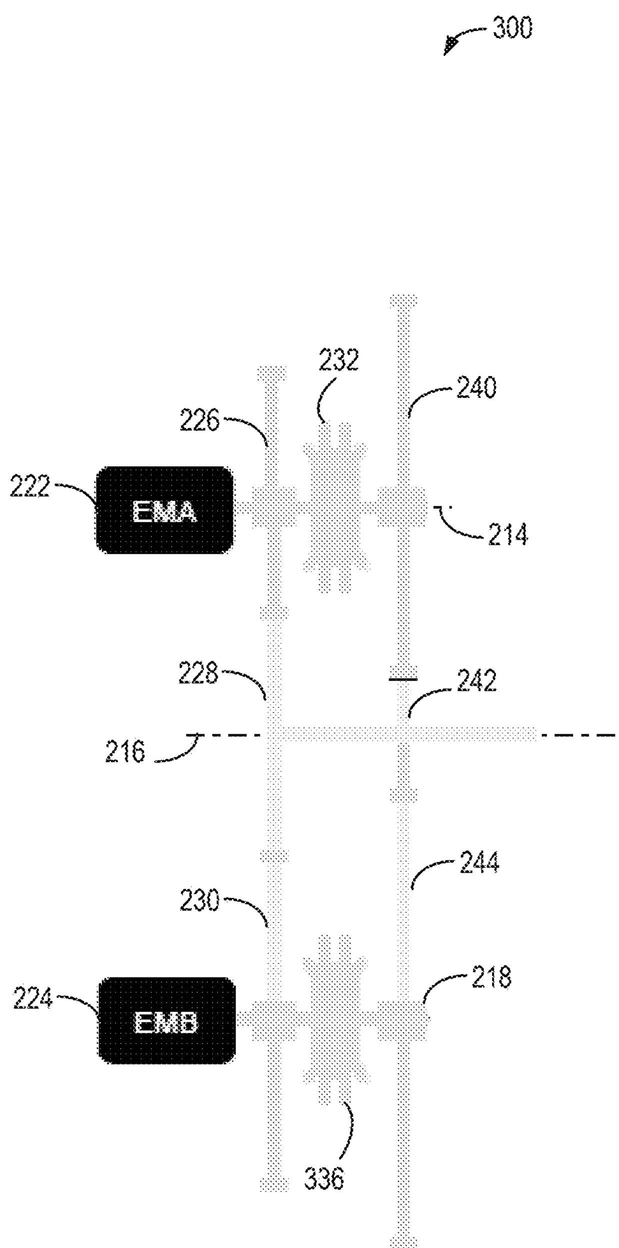


FIG. 3

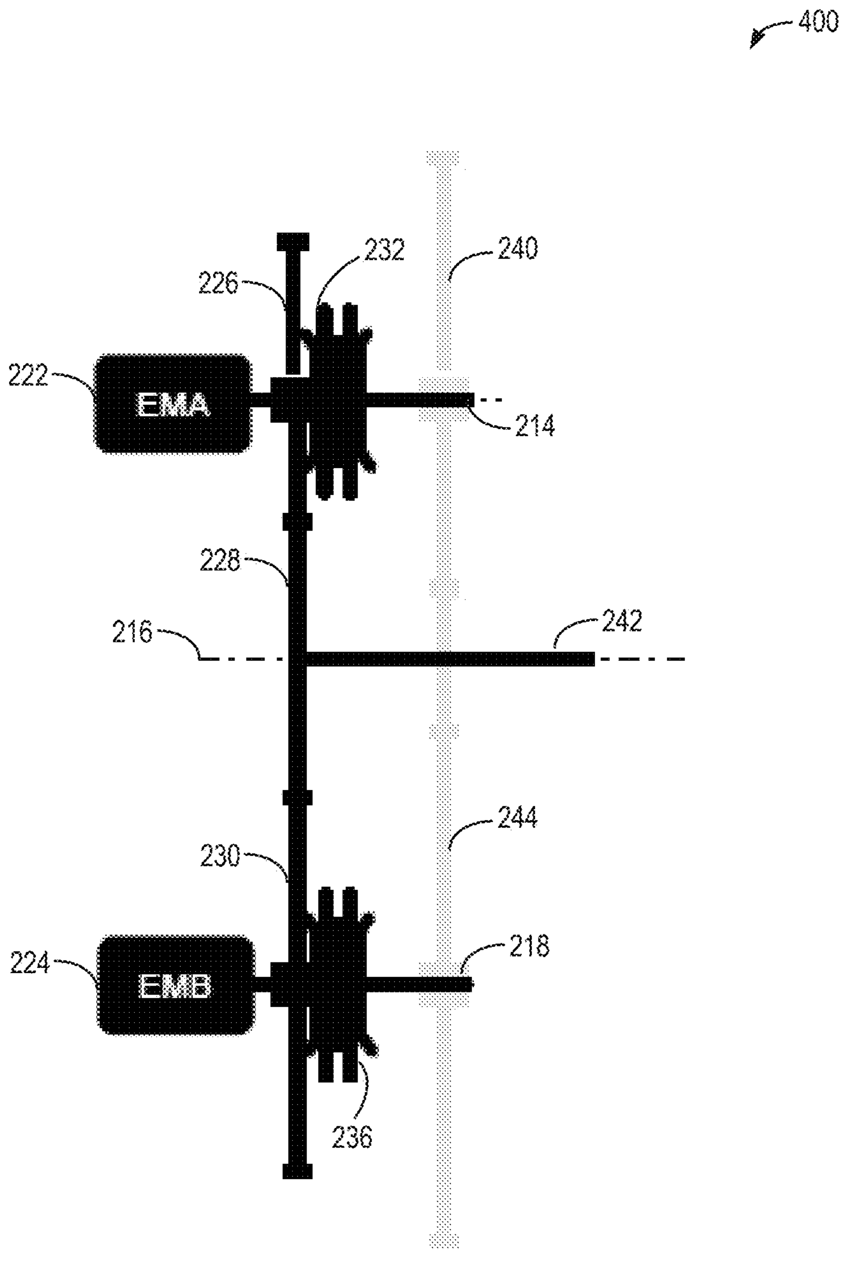


FIG. 4

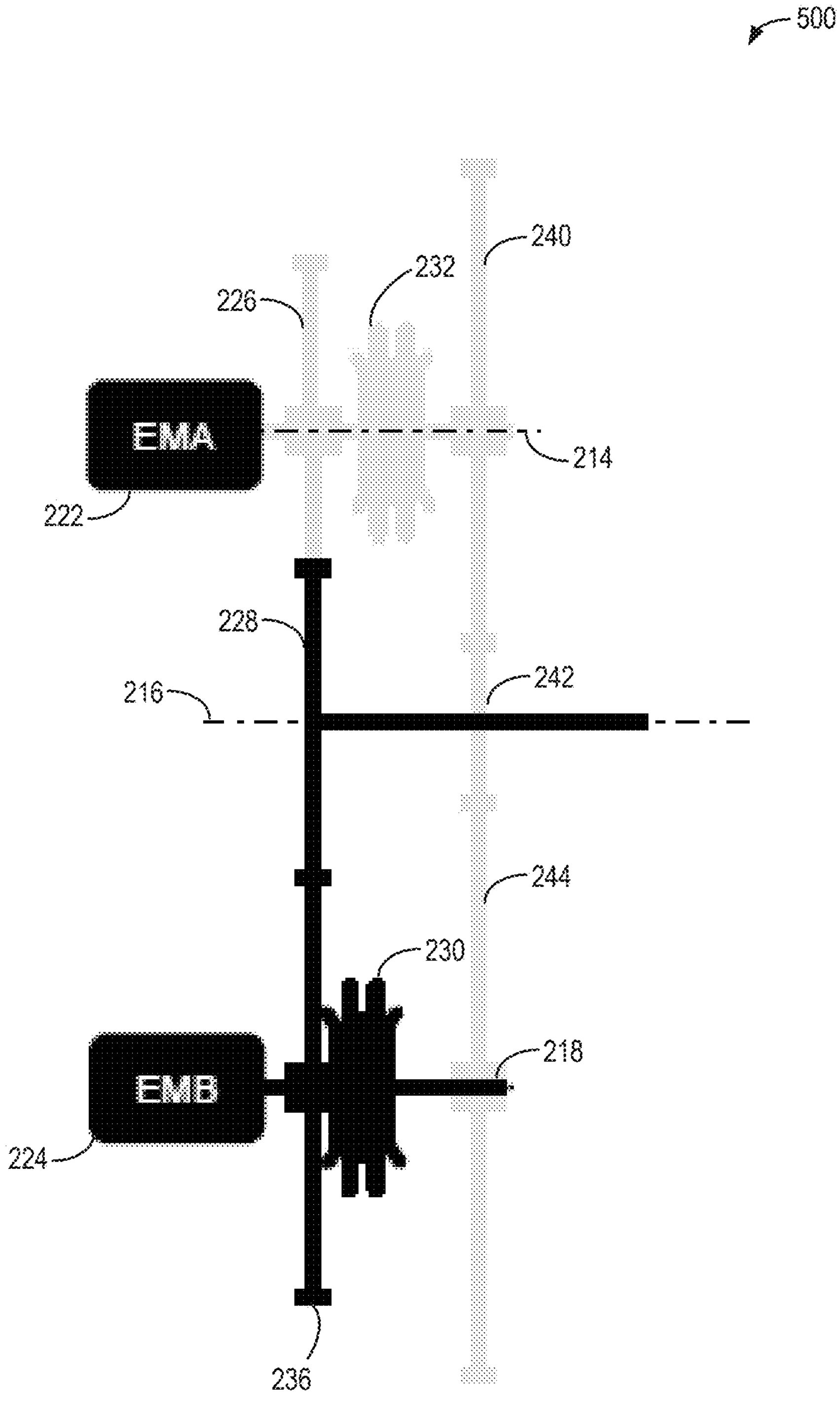


FIG. 5

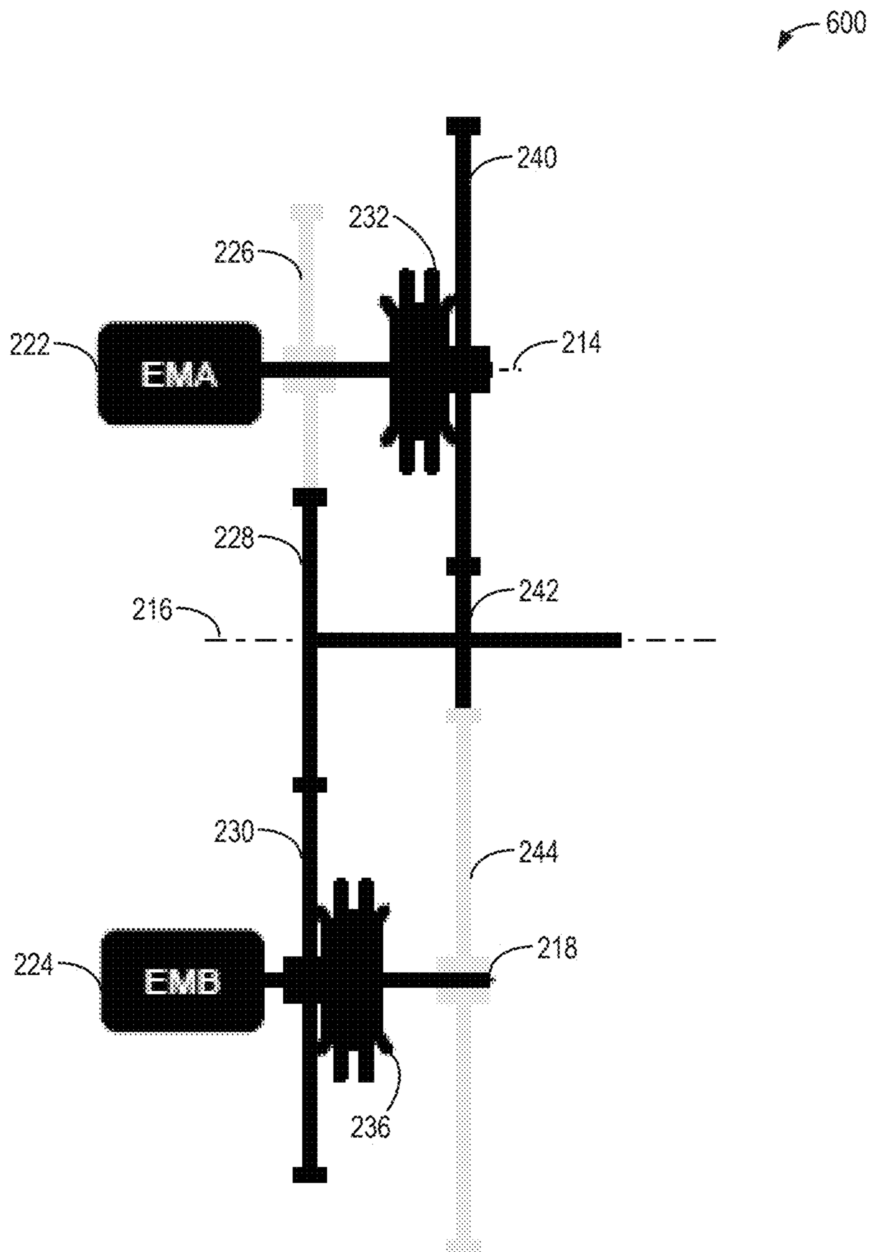


FIG. 6

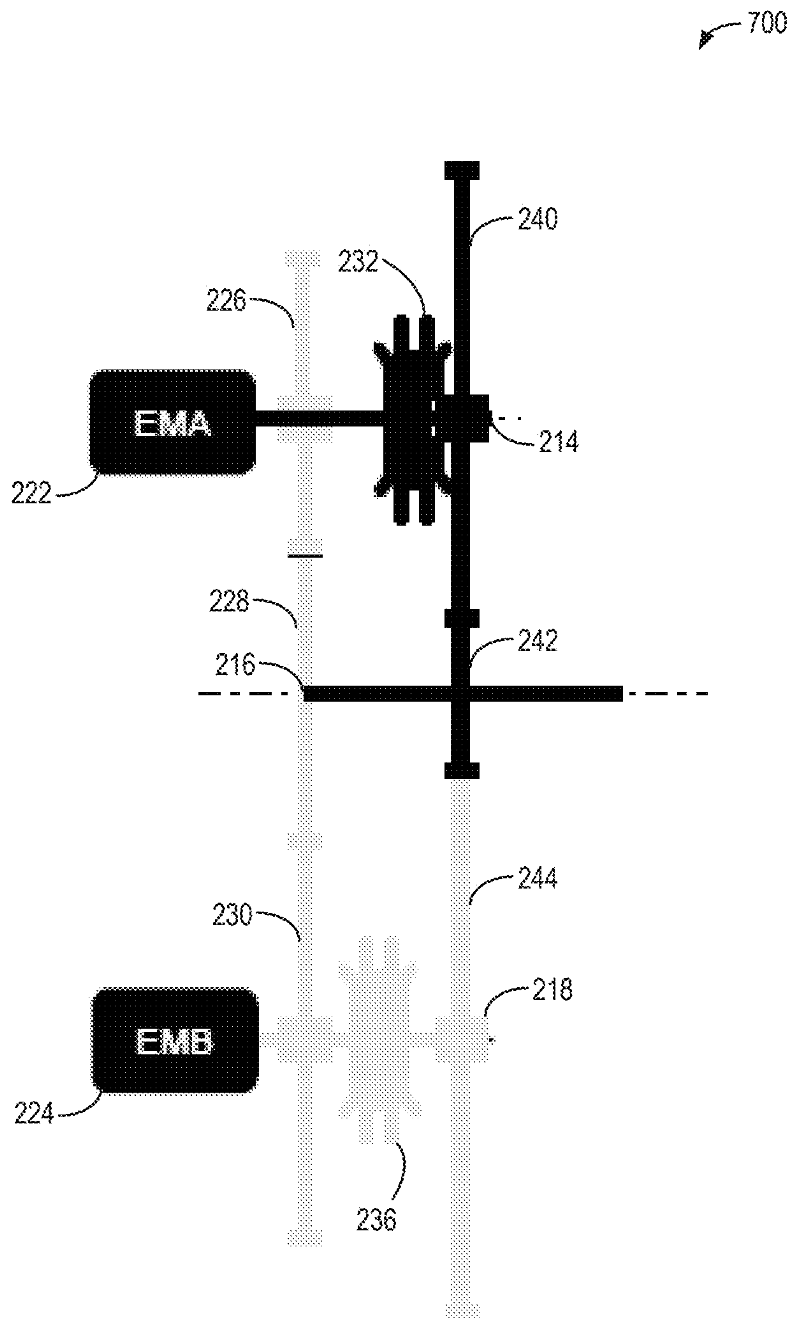


FIG. 7

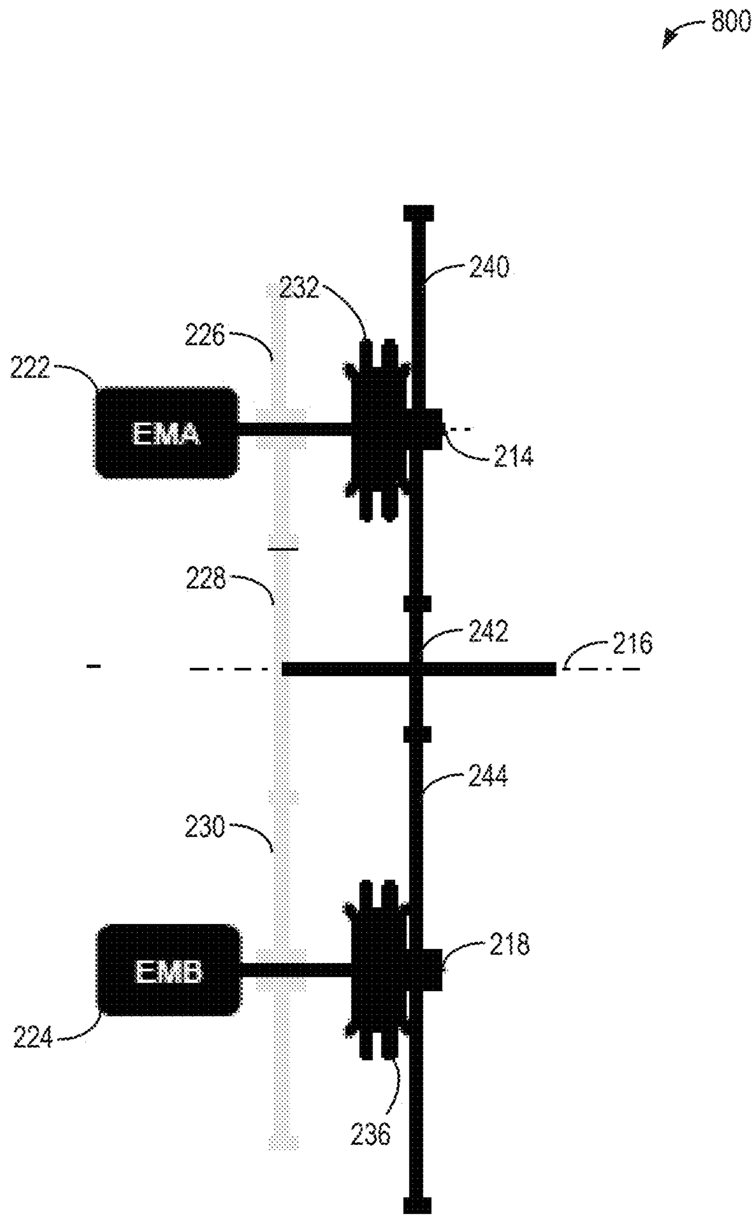


FIG. 8

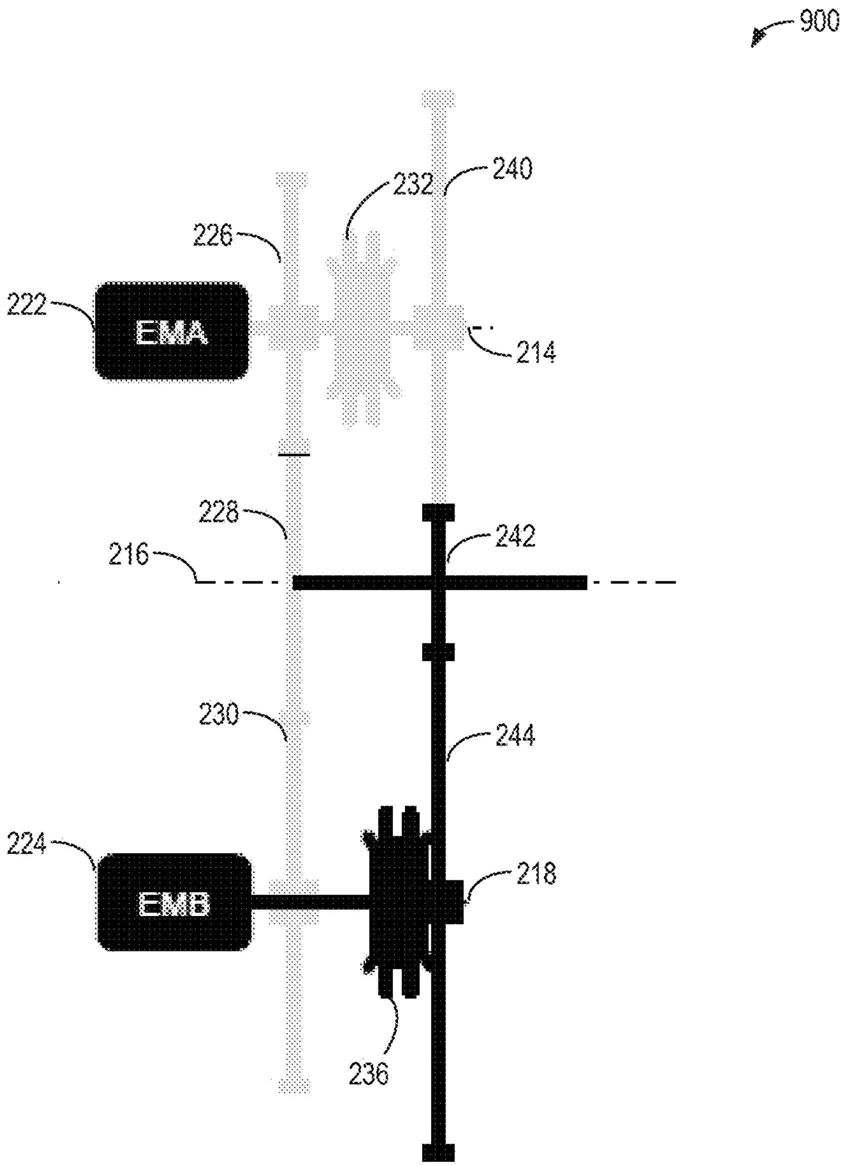


FIG. 9

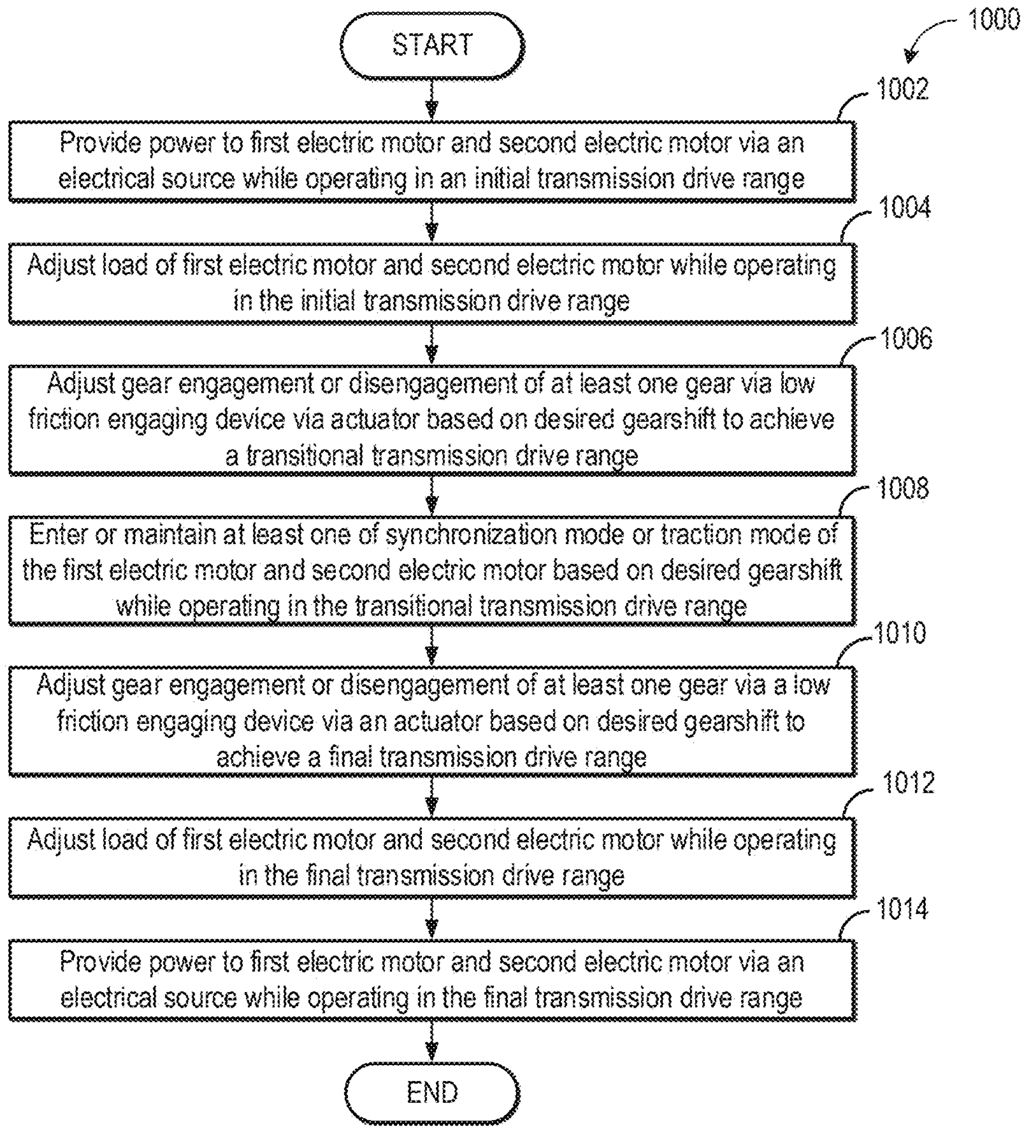
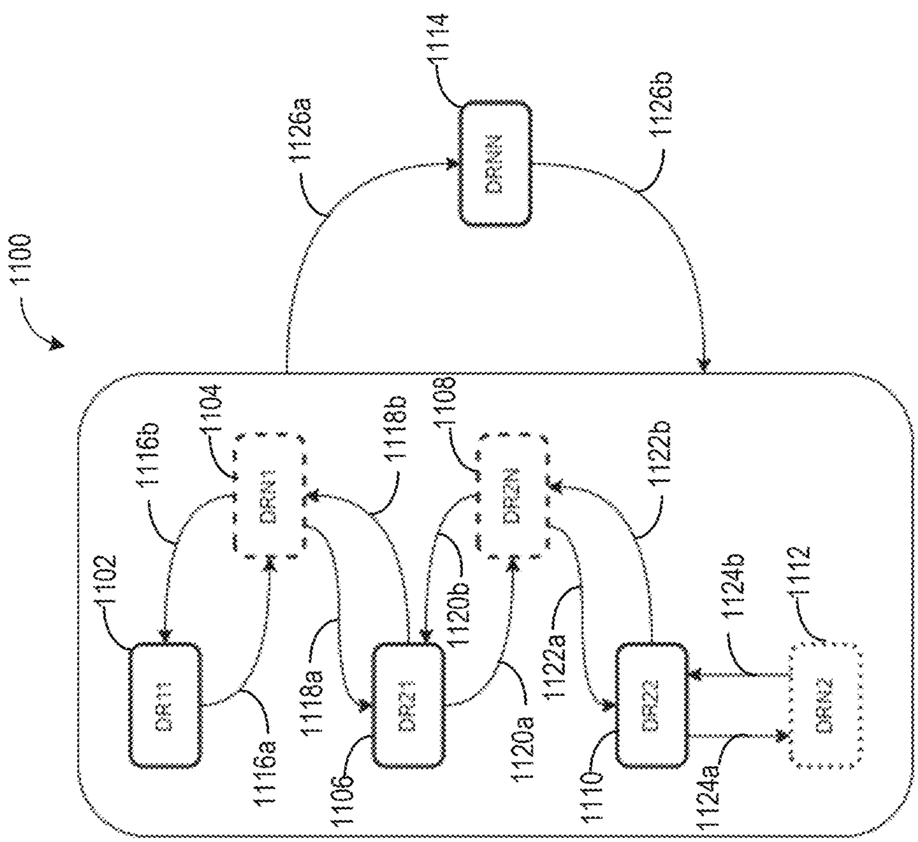

1000
START
1002
Provide power to first electric motor and second electric motor via an electrical source while operating in an initial transmission drive range
1004
Adjust load of first electric motor and second electric motor while operating in the initial transmission drive range
1006
Adjust gear engagement or disengagement of at least one gear via low friction engaging device via actuator based on desired gearshift to achieve a transitional transmission drive range
1008
Enter or maintain at least one of synchronization mode or traction mode of the first electric motor and second electric motor based on desired gearshift while operating in the transitional transmission drive range
1010
Adjust gear engagement or disengagement of at least one gear via a low friction engaging device via an actuator based on desired gearshift to achieve a final transmission drive range
1012
Adjust load of first electric motor and second electric motor while operating in the final transmission drive range
1014
Provide power to first electric motor and second electric motor via an electrical source while operating in the final transmission drive range
END

FIG. 10

FIG. 11


1100
1114
DRNN
1126a
1126b
1102
DR11
1104
DRN1
1106
DR21
1108
DR2N
1110
DR22
1112
DRN2
1116a
1116b
1118a
1118b
1120a
1120b
1122a
1122b
1124a
1124b

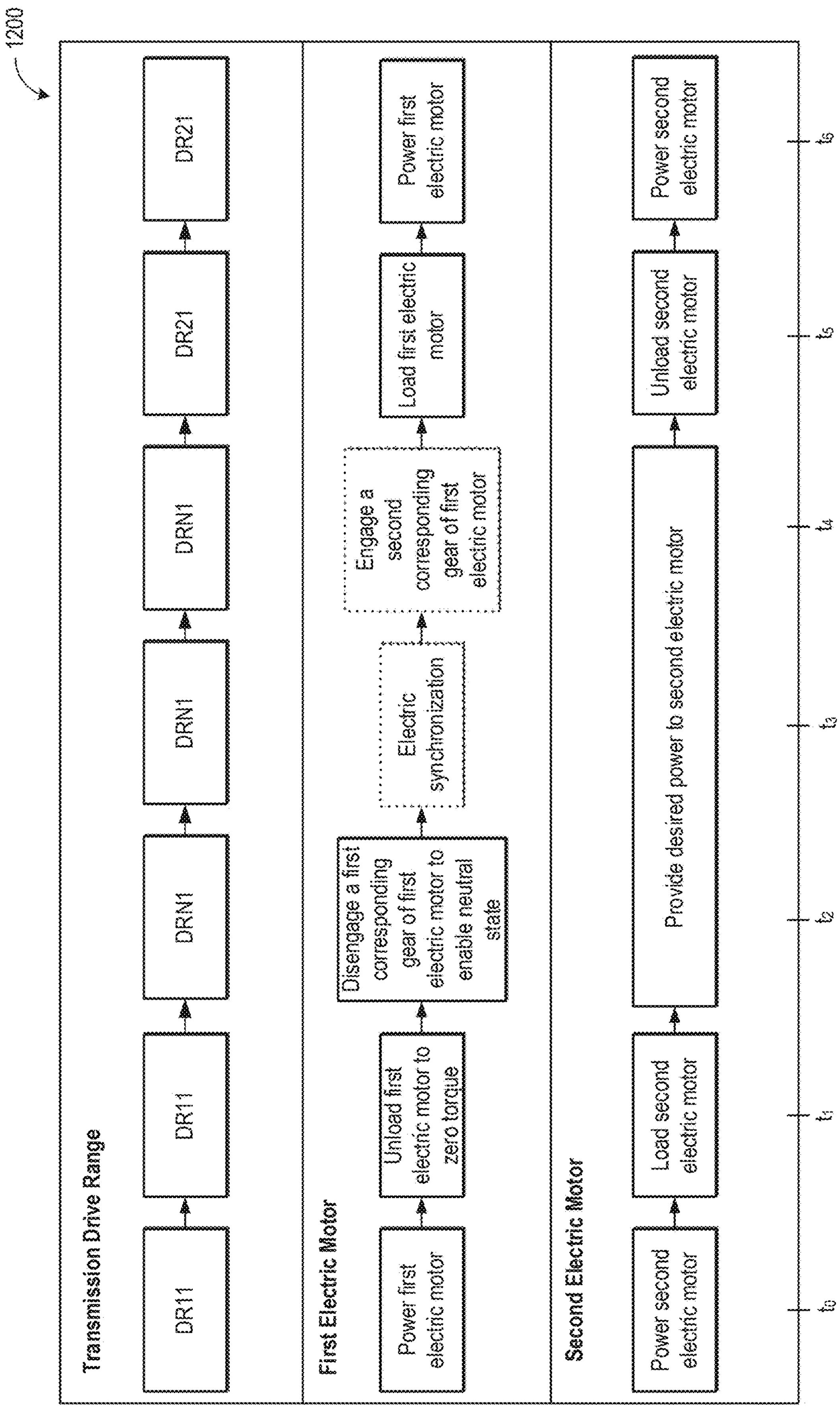

1200
Transmission Drive Range
DR11
DR11
DRN1
DRN1
DRN1
DR21
DR21
First Electric Motor
Power first electric motor
Unload first electric motor to zero torque
Disengage a first corresponding gear of first electric motor to enable neutral state
Electric synchronization
Engage a second corresponding gear of first electric motor
Load first electric motor
Power first electric motor
Second Electric Motor
Power second electric motor
Load second electric motor
Provide desired power to second electric motor
Unload second electric motor
Power second electric motor
t_0
t_1
t_2
t_3
t_4
t_5
t_6

FIG. 12

SYSTEM AND METHOD FOR SEAMLESS SHIFTING IN A DUAL MOTOR TRANSMISSION WITH MINIMAL GEARS

TECHNICAL FIELD

The present disclosure relates generally to mechanical transmission system in which multiple transmission drive ranges and gearshifts are selectively obtainable based on shaft configuration of a dual motor transmission system.

BACKGROUND AND SUMMARY

Single speed ratio transmissions of off highway battery electric vehicles (BEV) utilize an adequately sized motor (e.g., a large enough motor) that is fast enough to achieve maximum vehicle speed and provides high torque at low speeds. However, sizing the motor based on vehicle tractive effort (e.g., high torque) results in poor vehicle top speed whereas sizing the motor based on targeting the vehicle maximum speed may hinder tractive effort performance. As such, incorporating a single speed ratio transmission may result in oversizing the motor.

The demanded torque and maximum vehicle speed may be relaxed by utilizing a transmission with two or more speed ratios. Depending on the design, multi-ratio transmissions may enable different types of gearshifts, including seamless shifting and torque interruption shifting. During a gearshift in seamless shifting, the transmission may provide output torque continuously, enabling the gearshift to be performed unnoticed by a driver, whereas the output torque may be disrupted during a gearshift in torque interruption shifting.

The inventors have recognized various issues with such an approach. For example, if multiple speed ratios are demanded, such as two speeds, seamless shifting of the gearshift may result in lower efficiency due to higher drag torque linked to the presence of clutches and torque interruption shifting of the gear shift may hinder the driver's comfort due to a perceived jerk experienced by the driver. Further issues with regards to seamless shifting include oversizing the motor to compensate for power dissipation during clutch handover.

In one embodiment, the approaches disclosed herein provide a system for a transmission, comprising an intermediate shaft oriented parallel to both of a first shaft comprising a first gear mesh of a plurality of gear meshes, a third gear mesh of the plurality of gear meshes, and a first low friction engaging device located between the first gear mesh and the third gear mesh and a second shaft comprising a second gear mesh of the plurality of gear meshes, a fourth gear mesh of the plurality of gear meshes, and a second low friction engaging device located between the second gear mesh and the fourth gear mesh, a first electric motor coupled to the first shaft to enable a first reduction ratio of the first electric motor via the first gear mesh and a second reduction ratio of the first electric motor via the third gear mesh between the first shaft and the intermediate shaft, and a second electric motor coupled to the second shaft to enable a first reduction ratio of the second electric motor via the second gear mesh and a second reduction ratio of the second electric motor via the fourth gear mesh between the second shaft and the intermediate shaft.

By utilizing the disclosed configuration of the transmission system, seamless shifting without a perceived decrease in tractive effort may be achieved by reducing power dissipation in existing systems. In particular, utilizing low friction engaging devices in the disclosed system may reduce power dissipation and lower efficiency associated with seamless shifting via wet clutches. Further, the disclosed system eliminates torque interruption via maintaining desired torque production with one electric motor and enables seamless shifting via synchronization without the use of mechanical synchronizers and utilizing less gears to achieve a plurality of reduction ratios, and increasing ease of control with regards to synchronization and traction of the dual electric motors by including the low friction engaging devices on the plurality of shafts coupled to the dual electric motors. In this way, as a result of the utilizing less system components, such as gears and the like, in the disclosed simplified configuration, manufacturing costs may be reduced due to reducing spatial aspects of the system with the advantage of increasing efficiency of seamless shifting with null torque interruption.

It should be understood that the summary above is provided to introduce in simplified form a selection of concepts that are further described in the detailed description. It is not meant to identify key or essential features of the claimed subject matter, the scope of which is defined uniquely by the claims that follow the detailed description. Furthermore, the claimed subject matter is not limited to implementations that solve any disadvantages noted above or in any part of this disclosure.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1**A shows a schematic of a car with a transmission, an electric motor, a battery, rear wheels, and front wheels.

FIG. **1** B shows a control system of FIG. **1**A.

FIG. **2**A shows a schematic of a 2-speed transmission system comprising a plurality of shafts and an intermediate shaft coupled to dual electric motors.

FIG. **2**B shows a plurality of transmission drive ranges for the 2-speed transmission system.

FIGS. **3**-**9** show a plurality of power paths to achieve a plurality of transmission drive ranges.

FIG. **10** shows a control method for implementing gearshifts via the 2-speed transmission system.

FIG. **11** shows a flow diagram for implementing gearshifts via the 2-speed transmission system.

FIG. **12** shows a timing diagram for implementing the control method to perform gearshifts to realize a transmission drive range.

DETAILED DESCRIPTION

A transmission system with two or more selectable gears is described herein. In one embodiment, the transmission system may be a 2-speed transmission including a plurality of shafts and an intermediate shaft coupled to dual motors. An arrangement of a plurality of gear meshes comprising a plurality of gears in the system and low friction engaging devices allows the system to achieve gearshifts without decreasing the system's efficiency and increasing a driver's experience by reducing the frequency of perceived jerks of the vehicle. In addition, dog clutches or other frictionless devices are designed to enable seamless gearshifts without torque interruption.

In one embodiment, the systems disclosed herein provide a configuration for a 2-speed schematic wherein the first shaft, the second shaft, and the intermediate shaft are coupled to the plurality of gear meshes. The first shaft may be coupled to a first gear mesh and a third gear mesh. The second shaft may be coupled to a second gear mesh and a fourth gear mesh. In another embodiment, the systems disclosed herein may additionally include a third shaft coupled with a fifth gear mesh. A plurality of dog clutches coupled to the first shaft or second shaft may engage or disengage the plurality of gears of the plurality of gear meshes.

In other embodiments, gearshifts may be enabled via instructions configured, stored, and executed in at least one memory by at least one processor of an electronic control unit (ECU) in a vehicle to adjust one or more actuators based on signals from a plurality of sensors utilized to monitor the transmission system. In particular, specific gears in the plurality of gear meshes may be engaged or disengaged via the plurality of dog clutches via the one or more actuators to achieve different configurations of the first shaft wherein the first electric motor is coupled and the second shaft wherein the second electric motor is coupled. The different configurations of the first shaft and second shaft may enable a plurality of transmission drive ranges.

FIGS. **1**A, **1**B, and **2**A show example configurations with relative positioning of the various components. If shown directly contacting each other, or directly coupled, then such elements may be referred to as directly contacting or directly coupled, respectively, at least in one example. Similarly, elements shown contiguous or adjacent to one another may be contiguous or adjacent to each other, respectively, at least in one example. As an example, components laying in face-sharing contact with each other may be referred to as in face-sharing contact. As another example, elements positioned apart from each other with only a space there-between and no other components may be referred to as such, in at least one example. As yet another example, elements shown above/below one another, at opposite sides to one another, or to the left/right of one another may be referred to as such, relative to one another. Further, as shown in the figures, a topmost element or point of element may be referred to as a "top" of the component and a bottommost element or point of the element may be referred to as a "bottom" of the component, in at least one example. As used herein, top/bottom, upper/lower, above/below, may be relative to a vertical axis of the figures and used to describe positioning of elements of the figures relative to one another. As such, elements shown above other elements are positioned vertically above the other elements, in one example. As yet another example, shapes of the elements depicted within the figures may be referred to as having those shapes (e.g., such as being circular, straight, planar, curved, rounded, chamfered, angled, or the like). Further, elements shown intersecting one another may be referred to as intersecting elements or intersecting one another, in at least one example. Further still, an element shown within another element or shown outside of another element may be referred as such, in one example.

As shown in FIG. **1**A, a schematic depiction of a vehicle system **106** that can derive propulsion power from one or more electric motors **154** (e.g., a drive motor) is shown. In one embodiment, electric motors **154** may be one or more traction motors. Electric motors **154** may receive electrical power from a traction battery **158** to provide torque to rear vehicle wheels **155**. Electric motors **154** may also be operated as a generator to provide electrical power to charge traction battery **158**, for example, during a braking operation. It should be appreciated that while FIG. **1**A depicts electric motors **154** mounted in a rear wheel drive configuration, other configurations are possible, such as employing electric motors **154** in a front wheel configuration, or in a configuration in which vehicle system **106** includes two

electric motors, including a first electric motor mounted to a first shaft and a second electric motor mounted to a second shaft wherein power is transmitted to both the rear vehicle wheels **155** and front vehicle wheels **156** via an intermediate shaft with one end external to a gearbox housing.

Electric motors **154** may include a gearbox integrated therein or the gearbox can integrate the electric motors **154**. Additionally or alternatively, the electric motors **154** may be coupled to an outside of a transmission/gearbox housing. The integrated gearbox may include one or more input speed reduction gear sets. Additionally or alternatively, vehicle system **106** may include multiple traction batteries configured to provide power to different driven wheels, wherein power to the wheels may be predicated based on traction at the wheels, driver demand, and other conditions. In one example, the vehicle system **106** may include a 2-speed schematic wherein there are an equal number of drive speeds.

FIG. **1**B illustrates a control system **114** integrated within the vehicle system **106** of FIG. **1**A. Controller **112** may form a portion of the control system **114**. Control system **114** may receive information from a plurality of sensors **116** and send control signals to a plurality of actuators **181**. As one example, the plurality of sensors **116** may include sensors such as a battery level sensor, clutch activation sensor, etc. As another example, the plurality of actuators **181** may include a clutch, among others. Controller **112** may send a signal to an actuator of the clutch(es) to engage or disengage the clutch(es), so as to couple or decouple power transmission from the electric motors **154** to the rear vehicle wheels **155** or the front vehicle wheels **156**. The controller **112** may receive input data from the plurality of sensors **116**, process the input data, and trigger the plurality of actuators **181** in response to the processed input data based on instruction or code programmed therein corresponding to one or more routines, and stored on a non-transitory memory.

Turning to FIG. **2**A, a line diagram of an exemplary transmission system **200** is shown. The transmission system **200** may include a first electric motor **222** coupled to a first shaft **214** comprising a first gear mesh of a plurality of gear meshes, a third gear mesh of the plurality of gear meshes and a first low friction engaging device, such as a first dog clutch **232**, between the first gear mesh and the third gear mesh. The transmission system **200** may also include a second electric motor **224** coupled to a second shaft **218** comprising a second gear mesh of the plurality of gear meshes, a fourth gear mesh of the plurality of gear meshes, and a second low friction engaging device, such as a second dog clutch **236**, between the first gear mesh and second gear mesh. The transmission system **200** may further comprise an intermediate shaft **216** that may be oriented parallel to both of the first shaft **214** and the second shaft **218**. In some embodiments, the first shaft **214**, the intermediate shaft **216**, and the second shaft **218** may be located on the same plane. As such, the intermediate shaft **216** may be located between the first shaft **214** and the second shaft **218**. In other embodiments, the first shaft **214**, the intermediate shaft **216**, and the second shaft **218** may not be located on the same plane.

The first electric motor **222** is coupled to the first shaft **214** to enable a first reduction ratio of the first electric motor **222** via the first gear mesh and a second reduction ratio of the first electric motor **222** between the first shaft **214** and the intermediate shaft **216** via the third gear mesh. The second electric motor **224** is coupled to the second shaft to enable a first reduction ratio of the second electric motor **224** via the second gear mesh and a second reduction ratio of the second electric motor **224** via the fourth gear mesh between the second shaft **218** and the intermediate shaft **216**.

Transmission system **200** may further include a control system comprising an electronic control unit (ECU) **202** that executes instructions that obtain signals from a plurality of sensors and adjusts one or more actuators via a controller to adjust the various components of the transmission system **200** to achieve a plurality of gearshifts. In all embodiments of the transmission system **200**, the first electric motor **222** and the second electric motor **224** are not co-axial. However, the first electric motor **222** and the second electric motor **224** may be mounted on the same side of the transmission system **200** or on opposite sides of the transmission system **200**. As shown in FIG. **2**A, the first electric motor **222** and the second electric motor **224** are mounted on the same side of the transmission system **200**.

The first gear mesh comprises a first gear **226** and a second gear **228** and the third gear mesh comprises a fourth gear **240** and a fifth gear **242**. The second gear mesh comprises a third gear **230** and the second gear **228** and the fourth gear mesh comprises the fifth gear **242** and a sixth gear **244**. The first gear **226**, the third gear **230**, the fourth gear **240**, and the sixth gear **244** may be idler gears that are locked onto their respective shafts via at least one of the first low friction engaging device and the second low friction engaging device. The first low friction engaging device may be a first dog clutch **232** and the second low friction engaging device may be a second dog clutch **236**. The first shaft **214** may be oriented parallel to the second shaft **218** and may have a different angular velocity at will than the second shaft when none of the idler gears are engaged, and vice versa.

In some embodiments, one end of the intermediate shaft **216** may be external to a gearbox housing to enable coupling to a driveline external to the gearbox housing in a configuration of the transmission system **200** wherein the first shaft **214** is coupled to the first gear **226** and the fourth gear **240**, the intermediate shaft is coupled to the second gear **228** and the fifth gear **242**, and the second shaft **218** is coupled to the third gear **230** and the sixth gear **244**. In some embodiments, one end of the intermediate shaft **216** that may be external to the gearbox housing may transmit torque to axles to drive a set of vehicle wheels. The gearbox housing may enclose the components in the box **248** (e.g., dashed line). In particular, the gearbox housing may enclose the first shaft **214**, the plurality of gears coupled to the first shaft **214**, the intermediate shaft **216**, the plurality of gears coupled to the intermediate shaft **216**, the second shaft **218**, the plurality of gears coupled to the second shaft **218**, and a plurality of bearings. In some embodiments, the first electric motor **222** and the second electric motor **224** may be included in the gearbox housing.

As shown in FIG. **2**A, the first gear **226** and the fourth gear **240** may be locked onto the first shaft **214** via the first dog clutch **232**. Bearings **252**, located at either end of the first shaft **214** and between the first gear **226** and the fourth gear **240**, may support and facilitate rotation of the first shaft **214**. Similarly, the third gear **230** and the sixth gear **244** may be locked onto the second shaft **218** via the second dog clutch **236**. Bearings **256**, located at either end of the second shaft **218** and between the third gear **230** and the sixth gear **244**, may support and facilitate rotation of the second shaft **218**. The second gear **228** and the fifth gear **242** are permanently locked to the intermediate shaft **216**. Bearings **254**, located at either end of the intermediate shaft **216** and between the second gear **228** and the fifth gear **242**, may support and facilitate rotation of the intermediate shaft **216**.

The first gear **226** coupled to the first shaft **214** and the third gear **230** coupled to the second shaft **218** are meshed onto the second gear **228** coupled to the intermediate shaft **216**. The fourth gear **240** coupled to the first shaft **214** the sixth gear **244** coupled to the second shaft **218** are meshed onto the fifth gear **242** coupled to the intermediate shaft **216**.

In some embodiments, the first reduction ratio of the first electric motor **222** exceeds the first reduction ratio of the second electric motor **224** and the second reduction ratio of the first electric motor **222** exceeds the second reduction ratio of the second electric motor **224**. Such a configuration enables a speed of the first electric motor **222** to be greater than a speed of the second electric motor **224**. In contrast, the first reduction ratio of the first electric motor is equal to the first reduction ratio of the second electric motor and the second reduction ratio of the first electric motor is equal to the second reduction ratio of the second electric motor in other embodiments.

In some embodiments wherein one end of the intermediate shaft **216** is not external to the gearbox housing and one end of a third shaft **220** is external to the gearbox housing to enable coupling to the driveline external to the gearbox housing, the transmission system further comprises the third shaft **220** coupled to a fifth gear mesh comprising a seventh gear **234** coupled to the intermediate shaft **216** and an eighth gear **238** permanently locked to the third shaft **220** to enable a third reduction ratio between the intermediate shaft **216** and the third shaft **220**. The third shaft **220** may or may not integrate a differential, in other embodiments. Further, as shown in FIG. **2**A, the third shaft **220** is oriented parallel to the first shaft **214**, the second shaft **218**, and the intermediate shaft **216**. However, in other embodiments, the third shaft **220** may not be oriented parallel to the first shaft **214**, the second shaft **218**, and the intermediate shaft **216**.

In one embodiment, the gearbox housing may enclose the components in the box **250** (e.g., dotted line). In particular, the gearbox housing may enclose the first shaft **214**, the plurality of gears coupled to the first shaft **214**, the intermediate shaft **216**, the plurality of gears coupled to the intermediate shaft **216**, and the second shaft **218**, the plurality of gears coupled to the second shaft **218**, the third shaft **220**, the plurality of gears coupled to the third shaft **220**, and a plurality of bearings. More specifically, the gearbox housing may enclose the same components in the box **248** in addition to the seventh gear **234** coupled to the intermediate shaft **216** and the eighth gear **238** coupled to the third shaft **220**. Bearings **258**, located at either end of the third shaft **220**, may support and facilitate rotation of the third shaft **220**.

The various configurations of the transmission system **200** described herein are advantageous due to utilizing less gears than present transmission systems. In this way, the configuration is simplified and the configuration space is reduced, which may decrease manufacturing costs and reduce the complexity of control systems used to achieve a desired performance of the transmission system **200**. As described above, the transmission system **200** may include the control system comprising a plurality of sensors, one or more actuators, and an electronic control unit (ECU) **202** with instructions stored in at least one memory and executed by at least one processor of the ECU **202** to cause an adjustment of the one or more actuators based on data received by the plurality of sensors to perform gearshifts. The plurality of sensors may include speed sensors and clutch position sensors. The plurality of sensors may include a first sensor **204**, a second sensor **206**, and a third sensor **208**.

In one embodiment, the first sensor **204**, the second sensor **206**, and the third sensor **208** may be speed sensors. In this way, the plurality of sensors may monitor at least a first shaft speed, a second shaft speed, and an intermediate shaft speed. For example, the first sensor **204** may monitor a speed of the first shaft **214**, the second sensor **206** may monitor a speed of the intermediate shaft **216**, and the third sensor **208** may monitor a speed of the second shaft **218**. In other embodiments, the first shaft speed may be inferred by the speed of the first electric motor **222**, the second shaft speed may be inferred by the speed of the second electric motor **224**, and the intermediate shaft speed may be inferred by the vehicle speed based on the configuration of the plurality of gears coupled to the intermediate shaft **216**.

Alternatively, the first shaft **214** speed may be provided by a CAN message from an inverter of the first electric motor **222** and the second shaft **218** speed may be provided by a CAN message from an inverter of the second electric motor **224**. The one or more actuators may be hydraulic actuators, electric actuators, linear actuators, or drum selectors, for example. The one or more actuators may include a first actuator **210** and a second actuator **212**. In one embodiment, the transmission system **200** may include a single actuator, such as when operating a barrel cam device.

In some embodiments, the first gear **226**, the third gear **230**, the fourth gear **240**, and the sixth gear **244** may be engaged or disengaged by at least one actuator in the one or more actuators to enable various configurations of the transmission system **200**. As one example, the first actuator **210** may be communicatively coupled to the first shaft **214** to engage or disengage the first gear **226** or the fourth gear **240** via the first dog clutch **232**. Either both or at least one of the first actuator **210** and the second actuator **212** may be communicatively coupled to the second shaft **218** to disengage or engage the third gear **230** or the sixth gear **244** via the second dog clutch **236**. In another embodiment, wherein one end of the intermediate shaft **216** is not external to the gearbox housing and at least one end of the third shaft **220** is external to the gearbox housing to enable coupling to a driveline external to the gearbox housing, the eighth gear **238** coupled to the third shaft **220** is engaged with the seventh gear **234** coupled to the intermediate shaft **216**.

By utilizing dog clutches and other low friction engaging devices to disengage and engage the plurality of gears, power efficiency losses due to high drag torque related to the presence of clutches, such as in a dual-clutch transmission, may be decreased. In particular, one advantage of utilizing low friction engaging devices and not, for example, wet clutches, is power loss reduction. In this way, seamless gearshifts with null torque interruption, as described below with regards to FIGS. **2A-4**, may be performed without the power efficiency losses experienced with seamless shifting in other transmission systems.

FIG. **2B** shows a table **201** that illustrates a plurality of transmission drive ranges and corresponding states of the first electric motor **222** and the second electric motor **224**. The plurality of transmission drive ranges and corresponding states of the first electric motor **222** and the second electric motor **224** may be realized via the control system described herein. The table **201** includes a first column **260**, a second column **262**, and a third column **264**. The first column **260** may include the plurality of transmission drive ranges, the second column **262** includes the state of the first electric motor **222** for the plurality of transmission drive ranges, and the third column **264** includes the state of the second electric motor **224** for the plurality of transmission drive ranges. The plurality of transmission drive ranges includes a first transmission drive range DRNN, a second transmission drive range DR**11**, a third transmission drive range DRN**1**, a fourth transmission drive range DR**21**, a fifth transmission drive range DR**2**N, a sixth transmission drive range DR**22**, and a seventh transmission drive range DRN**2**.

The plurality of transmission drive ranges described above may be based on a plurality of states of the first electric motor and a plurality of states of the second electric motor. For example, the plurality of states of the first electric motor **222** may include a neutral state, a first speed of the first electric motor **222**, and a second speed of the first electric motor **222**. Similarly, the plurality of states of the second electric motor **224** may include a neutral state, a first speed of the second electric motor **224**, and a second speed of the second electric motor **224**.

As one example, the first transmission drive range DRNN may comprise the first electric motor **222** being in the neutral state and the second electric motor **224** being in the neutral state. The second transmission drive range DR**11** may comprise the first electric motor **222** operating at the first speed of the first electric motor **222** and the second electric motor **224** operating at the first speed of the second electric motor **224**. The third transmission drive range DRN**1** may comprise the first electric motor **222** being in the neutral state and the second electric motor **224** operating at the first speed of the second electric motor **224**. The fourth transmission drive range DR**21** may comprise the first electric motor **222** operating at the second speed of the first electric motor **222** and the second electric motor **224** operating at the first speed of the second electric motor **224**.

The fifth transmission drive range DR**2**N may comprise the first electric motor **222** operating at the second speed of the first electric motor **222** and the second electric motor **224** being in the neutral state. The sixth transmission drive range DR**22** may comprise the first electric motor **222** operating at the second speed of the first electric motor **222** and the second electric motor **224** operating at the second speed of the second electric motor **224**. The seventh transmission drive range DRN**2** may comprise the first electric motor **222** being in the neutral state and the second electric motor **224** operating at the second speed of the second electric motor **224**.

A first configuration of the first shaft **214** may enable the first speed of the first electric motor **222**, a second configuration of the first shaft **214** may enable the second speed of the first electric motor **222**, and a third configuration of the first shaft **214** may enable the neutral state of the first electric motor **222** Similarly, a first configuration of the second shaft **218** may enable the first speed of the second electric motor **224**, a second configuration of the second shaft **218** may enable the second speed of the second electric motor **224**, and a third configuration of the second shaft **218** may enable the neutral state of the second electric motor **224**.

Different combinations of the configurations of the first electric motor **222** and the second electric motor **224** may be result in different power paths of the transmission system **200**. FIGS. **3-9** illustrate a plurality of power paths of the transmission system **200**. The plurality of power paths may include a first power path **300** as illustrated in FIG. **3**, a second power path **400** as illustrated in FIG. **4**, a third power path **500** as illustrated in FIG. **5**, a fourth power path **600** as illustrated in FIG. **6**, a fifth power path **700** as illustrated in FIG. **7**, a sixth power path **800** as illustrated in FIG. **8**, and a seventh power path **900** as illustrated in FIG. **9**. The first power path **300** may result in operating a vehicle in the first transmission drive range DRNN, the second power path **400** may result in operating the vehicle in the second transmission drive range DR11, the third power path **500** may result in operating the vehicle in the third transmission drive range DRN1, the fourth power path **600** may result in operating the vehicle in the fourth transmission drive range DR21, the fifth power path **700** may result in operating the vehicle in the fifth transmission drive range DR2N, the sixth power path **800** may result in operating the vehicle in the sixth transmission drive range DR22, and the seventh power path **900** may result in operating the vehicle in the seventh transmission drive range DRN2.

The first power path **300** may be enabled via the third configuration of the first shaft **214** and the third configuration of the second shaft **218**. The second power path **400** may be enabled via the first configuration of the first shaft **214** and the first configuration of the second shaft **218**. The third power path **500** may be enabled via the third configuration of the first shaft **214** and the first configuration of the second shaft **218**. The fourth power path **600** may be enabled via the second configuration of the first shaft **214** and the first configuration of the second shaft **218**. The fifth power path **700** may be enabled via the second configuration of the first shaft **214** and the third configuration of the second shaft **218**. The sixth power path **800** may be enabled via the second configuration of the first shaft **214** and the second configuration of the second shaft **218**. The seventh power path **900** may be enabled via the third configuration of the first shaft **214** and the second configuration of the second shaft **218**.

In particular, the plurality of configurations includes gears, shafts, and dog clutches that are engaged, such as the plurality of gears, dog clutches, and shafts colored black in the various power paths. Additionally, the plurality of configurations includes gears, shafts, and dog clutches that are not engaged, such as the plurality of gears, dog clutches, and shafts colored light grey in the various power paths. For example, the first configuration of the first shaft **214** may comprise engaging the first gear **226** and disengaging the fourth gear **240** via the first dog clutch **232** via at least one of the one or more actuators to enable a first speed of the first electric motor **222**. The second configuration of the first shaft **214** may comprise disengaging the first gear **226** and engaging the fourth gear **240** via the first dog clutch **232** via at least one of the one or more actuators to enable a second speed of the first electric motor **222**. Finally, the third configuration of the first shaft **214** may comprise disengaging the first gear **226** and disengaging the fourth gear **240** via the first dog clutch **232** via at least one of the one or more actuators to enable the first electric motor **222** to enter a neutral state.

Further, the first configuration of the second shaft **218** may comprise engaging the third gear **230** and disengaging the sixth gear **244** via the second dog clutch **236** via at least one of the one or more actuators to enable a first speed of the second electric motor **224**. The second configuration of the second shaft **218** may comprise disengaging the third gear **230** and engaging the sixth gear **244** via the second dog clutch **236** via at least one of the one or more actuators to enable a second speed of the second electric motor **224**, and a third configuration of the second shaft **218** may comprise disengaging the third gear **230** and disengaging the sixth gear **244** via the second dog clutch **236** via at least one of the one or more actuators to enable the second electric motor **224** to enter a neutral state.

Control of the first electric motor **222** and the second electric motor **224** may increase due to the advantageous placement of the plurality of dog clutches. In particular, due to the first dog clutch **232** and the second dog clutch **236** engaging and disengaging gears on the plurality of shafts directly coupled, and not indirectly coupled, to the first electric motor **222** and the second electric motor **224**, changes in gear engagement may directly affect performance of the first electric motor **222** and the second electric motor **224**. In this way, the gear engagement and disengagements may directly, rather than indirectly, affect the speed of and traction produced by the first electric motor **222** and the second electric motor **224**.

FIG. **10** shows a method **1000** for controlling an operation mode of a first electric motor and a second electric motor to realize a plurality of transmission drive ranges via a plurality of gearshifts. Method **1000** will be described with relation to the systems shown in FIGS. **1A-2A**, but it should be understood that similar methods may be used with other systems without departing from the scope of this disclosure. Instructions for carrying out method **300** may be executed by an electronic control unit (ECU) (such as ECU **202** of FIG. **2A**) based on instructions stored on a memory of a controller and in conjunction with signals received from sensors of the system, such as the sensors described above with reference to FIG. **2A**. The ECU may employ actuators of the system to adjust a plurality of low friction engaging devices, according to the methods described below.

At **1002**, the method **1000** includes providing power to the first electric motor and the second electric motor via a power source while operating in an initial transmission drive range. Electrical power may be provided independently to the first electric motor and the second electric motor via the power source(s). The power source may be a battery, such as the traction battery described above with respect to FIG. **1A**. In this way, an electric current may be supplied to the first electric motor and the second electric motor to power the motors. While power is supplied to the first electric motor and the second electric motor, a transmission system (e.g., transmission system **200** of FIG. **2A**) may operate in the initial transmission drive range. The initial transmission drive may include one amongst the second transmission drive range DR**11**, the fourth transmission drive range DR**21**, and the sixth transmission drive range DR**22** of the plurality of transmission drive ranges discussed above with respect to FIG. **2B**. The initial transmission drive range may be considered a transmission drive range prior to either one or a series of gearshifts, such as downshifts or upshifts, to achieve a different transmission drive range.

At **1004**, the method **1000** incudes adjusting load of the first electric motor and the second electric motor while operating in the initial transmission drive range. In some embodiments, the load may be decreased (unloaded), such that there may be a decrease in current drawn from the power source. In other embodiments, the load may be increased via increasing current drawn from the power source. For example, before performing a gearshift to achieve a different transmission drive range, the first electric motor may be loaded whereas the second electric motor may be unloaded. As such, torque for the second electric motor may be reduced and the torque for the first electric motor may be increased to offset the decrease in torque for the second electric motor while performing the gearshift. In this way, seamless shifting may be enabled via the over-torque capability of the electric motors. Since no gearshifts were performed, the initial transmission drive range is maintained when loading and unloading the first electric motor and the second electric motor.

At **1006**, the method **1000** includes adjusting gear engagement and disengagement of at least one gear via a low friction engaging device via an actuator based on a desired gearshift to achieve a transitional transmission drive range. The transitional transmission drive range may include one of the transmission drive ranges wherein at least one of the two motors is in the neutral state, namely the first transmission drive range DRNN, the third transmission drive range DRN**1**, the fifth transmission drive range DR**2**N, and the seventh transmission drive range DRN**2** of the plurality of transmission drive ranges described above with respect to FIG. **2**B. To enable the transitional transmission drive range, at least one gear in one of a gear mesh of the first electric motor or a gear mesh of the second electric motor may be engaged or disengaged based on whether the gear was originally disengaged or engaged.

In a first example, with the second electric motor not in a neutral state, the gear in the gear mesh of the first electric motor may originally be engaged, indicating that the first electric motor is operating at either a first speed or second speed of the first electric motor as described herein. By disengaging the gear in the gear meshes of the first electric motor, the first electric motor enters a neutral state and the whole system enters a transitional transmission drive range. In a second example, with the first electric motor not in a neutral state, the gear in the gear mesh of the second electric motor may originally be engaged, indicating that the second electric motor is operating at either a first speed or second speed of the second electric motor as described herein. By disengaging the gear in the gear meshes of the second electric motor, the second electric motor enters a neutral state and the whole system enters a transitional transmission drive range.

At **1008**, the method **1000** includes entering or maintaining at least one of a synchronization mode or traction mode of the first electric motor and second electric motor based on the desired gearshift while operating in the transitional transmission drive range. The synchronization mode is an operation mode for speed control and the traction mode is an operation mode for torque control. With regards to the traction mode, the traction mode may ensure that the desired torque is produced during operation. In particular, load of either the first electric motor or second electric motor is maintained or adjusted to enable desired torque production by the first electric motor and the second electric motor or adjusted to compensate for decreases in torque of one of the first electric motor or the second electric motor.

With respect to the synchronization mode, the respective electric motor speed may be decelerated or accelerated until a speed difference between the desired gear and the respective shaft coupled to the electric motor is within a pre-determined speed threshold. To achieve a speed within the pre-determined speed threshold, the speed of the respective electric motor (e.g., one of the first electric motor or the second electric motor) is decelerated or accelerated. Gear speed is determined by vehicle speed and cannot be controlled while shifting. Thus, the synchronization is realized by adjusting the speed of the respective motor instead of a mechanical synchronizer(s). However, other embodiments of the present disclosure may include the mechanical synchronizer(s) to increase efficiency of synchronization.

In some embodiments, both the first electric motor and the second electric motor may operate in the traction mode for the majority of operation and enter the synchronization mode when gearshifts are performed to change the speed of the respective motor. Returning to the first example described wherein the gear in the gear mesh of the first electric motor may originally be engaged and the gearshift caused the first electric motor to enter the neutral state and the transitional transmission drive range. After performing the gear shift, the first electric motor may enter the synchronization mode while the second electric motor, which did not experience a gearshift, may maintain operation in the traction mode. Turning to the second example wherein all the gears in the gear meshes of the second electric motor may originally be disengaged and the gearshift caused the second electric motor to begin operating at the first speed of the second electric motor in the transitional transmission drive range. Similarly, after performing the gearshift, the second electric motor may enter the synchronization mode while the first electric motor, which did not experience a gearshift, may maintain operation in the traction mode.

At **1010**, the method **1000** includes adjusting gear engagement and disengagement of at least one gear via an actuator based on a desired gearshift to achieve a final transmission drive range. The final transmission drive range may include one amongst the second transmission drive range DR**11**, the fourth transmission drive range DR**21**, and the sixth transmission drive range DR**22** of the plurality of transmission drive ranges described above with respect to FIG. **2**B. To enable the final transmission drive range, at least one gear in one of a gear mesh of the first electric motor or a gear mesh of the second electric motor may be engaged or disengaged based on whether the gear was originally disengaged or engaged.

Returning to the first example above wherein the gear in the gear mesh of the first electric motor may originally be engaged and the gearshift caused the first electric motor to enter the neutral state and the transitional transmission drive range. After entering the synchronous mode, a subsequent gearshift may be performed by engaging the gear to enable either the first speed or the second speed of the first electric motor depending on whether the first electric motor was originally operating at the second speed or first speed of the first electric motor. In this way, the final transmission drive range may be achieved via the gearshift.

Turning to the second example wherein the gear in the gear mesh of the second electric motor may originally be engaged and the gearshift caused the second electric motor to enter the neutral state and the transitional transmission drive range. After entering the synchronous mode, a subsequent gearshift may be performed by engaging the gear to enable either the first speed or the second speed of the second electric motor depending on whether the second electric motor was originally operating at the second speed or first speed of the second electric motor. In this way, the final transmission drive range may be achieved via the gearshift. After all the gearshifts are performed for either the first electric motor or the second electric motor, the first electric motor or the second electric motor may exit the synchronization mode and return to the traction mode.

At **1012**, the method **1000** includes adjusting load of the first electric motor and the second electric motor while operating in the final transmission drive range. The loads of the first electric motor may be adjusted once all the gearshifts have been performed and operation of the first electric motor and the second electric motor returns to the traction mode. The load may be decreased (unloaded), such that there may be a decrease in current drawn from the power source by the first electric motor or the second electric motor. Further, the load may be increased, such that there may be an increase in current drawn from the power source by the first electric motor or second electric motor.

Turning to the first example described above, the gear engagement and disengagement of the gear mesh of the second electric motor was maintained throughout the gearshifts. As such, the current supplied to the second motor was increased to compensate for the torque reduction of the first electric motor as gearshifts were performed. After completion of the gearshifts, the second electric motor may be unloaded whereas the first electric motor may be loaded, such that torque produced by the first electric motor and the second electric motor is consistent with the torque requested by the vehicle or pedal position. Since no gearshifts were performed, the final transmission drive range is maintained when loading and unloading the first electric motor and the second electric motor.

At **1014**, the method **1000** includes providing power to the first electric motor and the second electric motor while operating in the final transmission drive range. Electrical power may be provided independently to the first electric motor and the second electric motor via the power source(s). In this way, an electric current may be supplied to the first electric motor and the second electric motor to power the motors while operating in the final transmission drive range. The method **1000** ends.

It may be understood that other embodiments of the method **1000** may depart from the above without departing from the scope of the disclosure. For example, in embodiments wherein the speed of the first electric motor exceeds the speed of the second electric motor, the first electric motor will reach an overspeed limit prior to the second electric motor. Accordingly, the method **300** may include the first electric motor being disconnected via entering the neutral state to avoid overspeeding of the first electric motor when a vehicle is operating in a transmission drive range wherein both the first electric motor and the second electric motor are operating at the second speed and a nominal speed of the vehicle is exceeded. In this way, the integrity of the first electric motor is maintained.

FIG. **11** shows a flow diagram **1100** for implementing a plurality of gearshifts to realize transitional transmission drive ranges and final transmission drive ranges for a transmission system. As illustrated in FIG. **11**, boxes with solid lines denote initial transmission drive and final transmission drive ranges, boxes with dashed lines denote transitional transmission drive ranges, and boxes with dotted lines denote optional transmission drive ranges. A transmission system may operate in plurality of transmission drive ranges as described above, including the first transmission drive range DRNN, the second transmission drive range DR**11**, the third transmission drive range DRN**1**, the fourth transmission drive range DR**21**, the fifth transmission drive range DR**2**N, the sixth transmission drive range DR**22**, and the seventh transmission drive range DRN**2** as described herein. The gearshifts may be performed according to the systems and methods described herein in with respect to FIGS. **2**A-**10**.

Depending on the series of gearshifts, the following plurality of transmission drive ranges, including the second transmission drive range DR**11**, the fourth transmission drive range DR**21**, and the sixth transmission drive range DR**22**, may be considered initial transmission drive ranges and final transmission drive ranges. Similarly, the following plurality of transmission drive ranges, including the first transmission drive range DRNN, the third transmission drive range DRN**1**, the fifth transmission drive range DR**2**N, and the seventh transmission drive range DRN**2**, may be considered transitional transmission drive ranges.

At box **1102**, a transmission system, such as the transmission system **200** described above with respect to FIG. **2**A, may be in an initial transmission drive range such as the second transmission drive range DR**11**. A gearshift **1116***a* may enable the transmission system to obtain a first transitional transmission drive range at box **1104**, such as the third transmission drive range DRN**1** for example. As shown, a gearshift **1116***b* may enable the transmission system to return to the second transmission drive range DR**11** from the third transmission drive range DRN**1**. In this way, the second transmission drive range DR**11** may be considered the initial transmission drive range in the gearshift **1116***a* and the final transmission drive range in the gearshift **1116***b*.

At box **1106**, the transmission system may enter the fourth transmission drive range DR**21** via a gearshift **1118***a*. As illustrated, a gearshift **418***b* may enable the transmission system to return to the first transitional transmission drive range (e.g., the third transmission drive range DRN**1**) from the fourth transmission drive range DR**21**. At box **1108**, the transmission system may enter the fifth transmission drive range DR**2**N via a gearshift **1120***a*. The fifth transmission drive range DR**2**N may be considered a second transitional transmission drive range. As illustrated, a gearshift **1120***b* may enable the transmission system to return to the fourth transmission drive range DR**21** from the fifth transmission drive range DR**2**N.

At box **1110**, the transmission system may enter the sixth transmission drive range DR**22** via a gearshift **1122***a*. As illustrated, a gearshift **1122***b* may enable the transmission system to return to the second transitional transmission drive range (e.g., the fifth transmission drive range DR**2**N) from the sixth transmission drive range DR**22**. At box **1112**, the transmission system may optionally enter an overspeed management mode wherein, as described herein with respect to FIG. **10**, a first electric motor may be disconnected to prevent overspeeding of the first electric motor. Accordingly, the transmission system may enter an optional transmission drive range (e.g., the sixth transmission drive range DRN**2**) via a gearshift **1124***a*. As illustrated, a gearshift **1124***b* may enable the transmission system to return to the sixth transmission drive range DR**22** from the seventh transmission drive range DRN**2**.

In some embodiments, the first transmission drive range DRNN may be an initial transmission drive range and final transmission drive range for any of the transitional transmission drive ranges described above. For example, the transmission system may enter the first transmission drive range DRNN via a gearshift **1126***a* at box **1114**. As such the transmission system may have originally been operating in a different transitional transmission drive range and the gearshift **1126***a* allowed the transmission system to operate in the first transmission drive range DRNN. In this way, the first transmission drive range DRNN may act as a final transmission drive range. Additionally, the first transmission drive range DRNN may act as an initial transmission drive range. As one example, a different transitional transmission drive range may be enabled via a gearshift **1126***b*. In this way, the transmission system may originally be operating in an initial transmission drive range (e.g., the first transmission drive range DRNN) prior to the gearshift **1126***b*.

Turning to FIG. **12**, a timing diagram **1200** wherein the control method as described herein is applied to a first electric motor and a second electric motor to achieve a transmission drive range via a plurality of gearshifts. At a time t_0, a vehicle is originally operating at an initial transmission drive range DR**11** wherein the first electric motor is operating at a first speed in traction mode (e.g., indicated by solid lines) and the second electric motor is operating at a second speed in traction mode (e.g., indicated by solid lines). Further, the first electric motor and the second electric motor are powered by a power source(s). The vehicle continues to operate at the transmission drive range DR**11** and traction mode at t_1. In anticipation of a series of gearshifts of the first electric motor, the first electric motor is unloaded to zero torque and the second electric motor is loaded to a power that compensates for the reduction in power of the first electric motor.

At a time t_2, the desired power is provided to the second electric motor as a first corresponding gear of the first electric motor is disengaged to enable a neutral state of the first electric motor, realizing a transitional transmission drive range DRN**1**. In this way, torque reduction may be prevented by increasing the torque of the second electric motor to compensate for the decrease in torque from the first electric motor. If the second electric motor satisfies the torque demand, seamless shifting occurs. However, if the second electric motor does not satisfy the torque demand, torque dip may prevent seamless shifting. At a time t_3, the desired power continues to be provided to the second electric motor as electric synchronization compensates for the change in speed of the first electric motor in the transitional transmission drive range DRN**1**. As such, the first electric motor is operating in the synchronization mode (e.g., indicated by dotted lines) whereas the second electric motor is operating in the traction mode (e.g., indicated by solid lines). The speed of the first electric motor is decelerating to a value until a pre-determined speed threshold between the respective shaft wherein the first electric motor is coupled and the gear is realized.

The desired power continues to be provided to the second electric motor as a second corresponding gear of the first electric motor is engaged to enable the first electric motor to operate at a second speed of the first electric motor, enabling a final transmission drive range DR**21** at a time t**4**. Further, the first electric motor continues to operate in the synchronization mode and the second electric motor continues to operate in the traction mode. At a time t_5, the first electric motor is loaded to increase torque produced by the first electric motor and the second electric motor is unloaded to decrease torque produced while in the final transmission drive range DR**21** in the traction mode. In this way, the second electric motor no longer compensates for the first electric motor in regards to torque production and torque production by the first electric motor and the second electric motor is based on vehicle torque request, pedal load request, and the like. After supplying the appropriate load, the first electric motor and second electric motor are powered at a time t_6 in the final transmission drive range in the traction mode.

While various embodiments have been described above, it should be understood that they have been presented by way of example, and not limitation. It will be apparent to persons skilled in the relevant arts that the disclosed subject matter may be embodied in other specific forms without departing from the spirit of the subject matter. The embodiments described above are therefore to be considered in all respects as illustrative, not restrictive.

The technical effect of utilizing a control system coupled to a transmission system wherein a first electric motor is coupled to a first shaft comprising a plurality of gear meshes and a first low friction engaging device, a second motor is coupled to a second shaft comprising a plurality of gears meshes and a second low friction engaging device, and the first shaft and second shaft are oriented parallel to an intermediate shaft comprising a plurality of gears is that gearshifts may be performed with increased efficiency of seamless shifting with null torque interruption and reduced manufacturing costs due to utilizing less gears and other mechanical components.

The disclosure also provides support for a transmission system, comprising: an intermediate shaft oriented parallel to both of a first shaft comprising a first gear mesh of a plurality of gear meshes, a third gear mesh of the plurality of gear meshes, and a first low friction engaging device located between the first gear mesh and the third gear mesh and a second shaft comprising a second gear mesh of the plurality of gear meshes, a fourth gear mesh of the plurality of gear meshes, and a second low friction engaging device located between the second gear mesh and the fourth gear mesh, a first electric motor coupled to the first shaft to enable a first reduction ratio of the first electric motor via the first gear mesh and a second reduction ratio of the first electric motor between the first shaft and the intermediate shaft via the third gear mesh, and a second electric motor coupled to the second shaft to enable a first reduction ratio of the second electric motor via the second gear mesh and a second reduction ratio of the second electric motor via the fourth gear mesh between the second shaft and the intermediate shaft. In a first example of the system, the first electric motor and the second electric motor are not co-axial, and the first shaft, the intermediate shaft, and the second shaft are not located in a same plane.

In a second example of the system, optionally including the first example, the first gear mesh comprises a first gear and a second gear, the second gear mesh comprises the second gear and a third gear, the third gear mesh comprises a fourth gear and a fifth gear, and the fourth gear mesh comprises the fifth gear and a sixth gear, and wherein the first gear, the third gear, the fourth gear, and the sixth gear are idler gears locked onto their respective shafts via at least one of the first low friction engaging device or second low friction engaging device. In a third example of the system, optionally including one or both of the first and second examples, the second gear and the fifth gear are permanently locked to the intermediate shaft, and the first low friction engaging device is a first dog clutch and the second low friction engaging device is a second dog clutch. In a fourth example of the system, optionally including one or more or each of the first through third examples, at least one end of the intermediate shaft is external to a gearbox housing to enable coupling to a driveline external to the gearbox housing in a pre-determined configuration wherein the first shaft is coupled to the first gear, fourth gear, and the first low friction engaging device, the intermediate shaft is coupled to the second gear and the fifth gear, and the second shaft is coupled to the third gear, the sixth gear, and the second low friction engaging device.

In a fifth example of the system, optionally including one or more or each of the first through fourth examples, one of the first shaft and second shaft has a different angular velocity at will than the second shaft or first shaft, respectively, when none of its idler gears are engaged. In a sixth example of the system, optionally including one or more or each of the first through fifth examples, the first gear coupled to the first shaft and the third gear coupled to the second shaft are meshed onto the second gear coupled to the intermediate shaft, and the fourth gear coupled to the first shaft and the sixth gear coupled to the second shaft are meshed onto the fifth gear coupled to the intermediate shaft. In a seventh example of the system, optionally including one or more or each of the first through sixth examples, the first reduction ratio of the first electric motor exceeds the first reduction ratio of the second electric motor and the second reduction ratio of the first electric motor exceeds the second reduction ratio of the second electric motor, enabling a speed of the first electric motor to be greater than the speed of the second electric motor.

In an eighth example of the system, optionally including one or more or each of the first through seventh examples, the first reduction ratio of the first electric motor is equal to the first reduction ratio of the second electric motor and the second reduction ratio of the first electric motor is equal to the second reduction ratio of the second electric motor. In a ninth example of the system, optionally including one or more or each of the first through eighth examples, in an optional configuration wherein at least one end of the intermediate shaft is not external to the gearbox housing and one end of a third shaft is external to the gearbox housing to enable coupling with the driveline external to the gearbox housing, the transmission system further comprises the third shaft coupled to a fifth gear mesh comprising a seventh gear coupled to the intermediate shaft and an eighth gear permanently locked to the third shaft to enable a third reduction ratio between the intermediate shaft and the third shaft.

The disclosure also provides support for a transmission system, comprising: a control system comprising a plurality of sensors, one or more actuators, and an electronic control unit (ECU) communicatively coupled to a first electric motor coupled to a first shaft comprising a plurality of gears and a first low friction engaging device located between the plurality of gears, a second electric motor coupled to a second shaft comprising the plurality of gears and a second low friction engaging device located between the plurality of gears, and an intermediate shaft comprising the plurality of gears wherein instructions stored in at least one memory and executed by at least one processor of the ECU to cause an adjustment of the one or more actuators based on data received by the plurality of sensors to perform gearshifts of the transmission system.

In a first example of the system, the plurality of sensors monitors at least a first shaft speed, a second shaft speed, and an intermediate shaft speed, and the plurality of sensors includes speeds sensors and clutch position sensors. In a second example of the system, optionally including the first example, the plurality of gears comprises at least a first gear, a second gear, a third gear, a fourth gear, a fifth gear, and a sixth gear wherein the first gear, the third gear, the fourth gear, and the sixth gear that are engaged or disengaged by at least one of the first low friction engaging device and the second low friction engaging device via the one or more actuators to enable various configurations of the transmission system.

In a third example of the system, optionally including one or both of the first and second examples, the various configurations of the transmission system comprise a first configuration of the first shaft may comprise engaging the first gear and disengaging the fourth gear via the first low friction engaging device via at least one of the one or more actuators to enable a first speed of the first electric motor, a second configuration of the first shaft may comprise disengaging the first gear and engaging the fourth gear via the first low friction engaging device via at least one of the one or more actuators to enable a second speed of the first electric motor, and a third configuration of the first shaft may comprise disengaging the first gear and disengaging the fourth gear via the first low friction engaging device via at least one of the one or more actuators to enable the first electric motor to enter a neutral state.

In a fourth example of the system, optionally including one or more or each of the first through third examples, the various configurations of the transmission system comprise a first configuration of the second shaft may comprise engaging the third gear and disengaging the sixth gear via the second low friction engaging device via at least one of the one or more actuators to enable a first speed of the second electric motor, a second configuration of the second shaft may comprise disengaging the third gear and engaging the sixth gear via the second low friction engaging device via at least one of the one or more actuators to enable a second speed of the second electric motor, and a third configuration of the second shaft may comprise disengaging the third gear and disengaging the sixth gear via the second low friction engaging device via at least one of the one or more actuators to enable the second electric motor to enter a neutral state.

The disclosure also provides support for a method, comprising: powering a first electric motor via a power source while operating in an initial transmission drive range, powering a second electric motor via the power source while operating in the initial transmission drive range, adjusting load of the first electric motor and the second electric motor while operating in the initial transmission drive range, adjusting gear engagement or disengagement of at least one gear via a low friction engaging device via an actuator based on a desired gearshift to achieve a transitional transmission drive range, entering or maintaining at least one of a synchronization mode or traction mode of the first electric motor and the second electric motor based on desired gearshift while operating in the transitional transmission drive range, adjusting gear engagement or disengagement of at least one gear via the low friction engaging device via the actuator based on the desired gearshift to achieve a final transmission drive range, adjusting load of the first electric motor and the second electric motor while operating in the final transmission drive range, and providing power to the first electric motor and the second electric motor while operating in the final transmission drive range.

In a first example of the method, a transmission drive range comprises a state of the first electric motor and a state of the second electric motor wherein the first electric motor and the second electric motor may be in one of a neutral state, operating at a first speed, or operating at a second speed. In a second example of the method, optionally including the first example, the synchronization mode is an operation mode for speed control of the first electric motor and the second electric motor wherein speed of a respective electric motor decelerates or accelerates to a value wherein a speed difference between a respective shaft coupled to the respective electric motor and a desired gear is within a pre-determined speed threshold.

In a third example of the method, optionally including one or both of the first and second examples, the traction mode is an operation mode for torque control of the first electric motor and the second electric motor wherein load of either the first electric motor and second electric motor is maintained or adjusted to enable desired torque production by the first electric motor and the second electric motor or adjusted to compensate for decreases in torque of one of the first electric motor or the second electric motor. In a fourth example of the method, optionally including one or more or each of the first through third examples, the first electric motor is disconnected via entering the neutral state to avoid overspeeding of the first electric motor when a vehicle is operating in the transmission drive range wherein both the first electric motor and second electric motor are operating at the second speed and a nominal speed of the vehicle is exceeded.

Note that the example control and estimation routines included herein can be used with various powertrain and/or vehicle system configurations. The control methods and routines disclosed herein may be stored as executable instructions in non-transitory memory and may be carried out by the control system including the controller in combination with the various sensors, actuators, and other vehicle hardware. Further, portions of the methods may be physical actions taken in the real world to change a state of a device. The specific routines described herein may represent one or more of any number of processing strategies such as event-driven, interrupt-driven, multi-tasking, multi-threading, and the like. As such, various actions, operations, and/or functions illustrated may be performed in the sequence illustrated, in parallel, or in some cases omitted. Likewise, the order of processing is not necessarily required to achieve the features and advantages of the example examples described herein, but is provided for ease of illustration and description. One or more of the illustrated actions, operations and/or functions may be repeatedly performed depending on the particular strategy being used. Further, the described actions, operations and/or functions may graphically represent code to be programmed into non-transitory memory of the computer readable storage medium in the vehicle control system, where the described actions are carried out by executing the instructions in a system including the various hardware components in combination with the electronic controller. One or more of the method steps described herein may be omitted if desired.

It will be appreciated that the configurations and routines disclosed herein are exemplary in nature, and that these specific examples are not to be considered in a limiting sense, because numerous variations are possible. For example, the above technology can be applied to powertrains that include different types of propulsion sources including different types of electric machines and transmissions. The subject matter of the present disclosure includes all novel and non-obvious combinations and sub-combinations of the various systems and configurations, and other features, functions, and/or properties disclosed herein.

The following claims particularly point out certain combinations and sub-combinations regarded as novel and non-obvious. These claims may refer to "an" element or "a first" element or the equivalent thereof. Such claims should be understood to include incorporation of one or more such elements, neither requiring nor excluding two or more such elements. Other combinations and sub-combinations of the disclosed features, functions, elements, and/or properties may be claimed through amendment of the present claims or through presentation of new claims in this or a related application. Such claims, whether broader, narrower, equal, or different in scope to the original claims, also are regarded as included within the subject matter of the present disclosure.

The invention claimed is:

1. A transmission system of a vehicle, comprising:

an intermediate shaft oriented parallel to both of and offset to each of a first shaft comprising only a first gear mesh and a third gear mesh of a plurality of gear meshes, and a first dog clutch located between the first gear mesh and the third gear mesh and a second shaft comprising only a second gear mesh and a fourth gear mesh of the plurality of gear meshes, and a second dog clutch located between the second gear mesh and the fourth gear mesh;

a first electric motor coupled to the first shaft to enable one of a first reduction ratio of the first electric motor via the first gear mesh and a second reduction ratio of the first electric motor between the first shaft and the intermediate shaft via the third gear mesh; and

a second electric motor coupled to the second shaft to enable one of a first reduction ratio of the second electric motor via the second gear mesh and a second reduction ratio of the second electric motor via the fourth gear mesh between the second shaft and the intermediate shaft; and

a control system with instructions stored in memory and configured to: operate with the first dog clutch engaged to the third gear mesh, the second dog clutch engaged with the fourth gear mesh, a speed of the first electric motor exceeding a speed of the second electric motor, and disconnect the first electric motor via entering a neutral state by disengaging the first dog clutch in response to the first electric motor reaching an overspeed limit prior to the second electric motor and a vehicle speed exceeding a nominal speed.

2. The system of claim **1**, wherein the first electric motor and the second electric motor are not co-axial, and the first shaft, the intermediate shaft, and the second shaft are not located in a same plane.

3. The system of claim **1**, wherein the first gear mesh comprises a first gear coupled to the first shaft and a second gear coupled to the intermediate shaft, the second gear mesh comprises the second gear and a third gear coupled to the second shaft, the third gear mesh comprises a fourth gear coupled to the first shaft and a fifth gear coupled to the intermediate shaft, and the fourth gear mesh comprises the fifth gear and a sixth gear coupled to the second shaft, and wherein the first gear, the third gear, the fourth gear, and the sixth gear are idler gears locked onto their respective shafts via at least one of the first dog clutch or the second dog clutch.

4. The system of claim **3**, wherein the second gear and the fifth gear are permanently locked to the intermediate shaft.

5. The system of claim **1**, wherein at least one end of the intermediate shaft is external to a gearbox housing to enable coupling to a driveline external to the gearbox housing in a pre-determined configuration wherein the first shaft is coupled the first dog clutch and the second shaft is coupled the second dog clutch and wherein one of the first shaft and the second shaft has a different angular velocity than the other one of the second shaft or first shaft, respectively, when none of its idler gears are engaged.

6. The system of claim **5**, wherein the first gear coupled to the first shaft and the third gear coupled to the second shaft are meshed onto the second gear coupled to the intermediate shaft, and the fourth gear coupled to the first shaft and the sixth gear coupled to the second shaft are meshed onto the fifth gear coupled to the intermediate shaft.

7. The system of claim **1**, wherein the first reduction ratio of the first electric motor exceeds the first reduction ratio of the second electric motor and the second reduction ratio of the first electric motor exceeds the second reduction ratio of the second electric motor, enabling a speed of the first electric motor to be greater than the speed of the second electric motor.

8. The system of claim **1**, wherein the first reduction ratio of the first electric motor is equal to the first reduction ratio of the second electric motor and the second reduction ratio of the first electric motor is equal to the second reduction ratio of the second electric motor.

9. The system of claim **5**, wherein in an optional configuration wherein at least one end of the intermediate shaft is not external to the gearbox housing and one end of a third shaft is external to the gearbox housing to enable coupling with the driveline external to the gearbox housing, the transmission system further comprises the third shaft coupled to a fifth gear mesh comprising a seventh gear coupled to the intermediate shaft and an eighth gear permanently locked to the third shaft to enable a third reduction ratio between the intermediate shaft and the third shaft.

10. A method, comprising:

powering a first electric motor via a power source while operating in an initial transmission drive range, a transmission drive range comprising a state of the first electric motor and a state of the second electric motor wherein the first electric motor and the second electric motor is in one of a neutral state, operating at a first speed, or operating at a second speed;

powering a second electric motor via the power source while operating in the initial transmission drive range;

adjusting load of the first electric motor and the second electric motor while operating in the initial transmission drive range;

adjusting gear engagement or disengagement of at least one gear via a dog clutch via an actuator based on a desired gearshift to achieve a transitional transmission drive range;

entering or maintaining at least one of a synchronization mode or traction mode of the first electric motor and the second electric motor based on desired gearshift while operating in the transitional transmission drive range;

adjusting gear engagement or disengagement of at least one gear via the dog clutch via the actuator based on the desired gearshift to achieve a final transmission drive range;

adjusting load of the first electric motor and the second electric motor while operating in the final transmission drive range; and

providing power to the first electric motor and the second electric motor while operating in the final transmission drive range, wherein the first electric motor is disconnected via entering the neutral state to avoid overspeeding of the first electric motor when a vehicle is operating in the transmission drive range wherein both the first electric motor and second electric motor are operating at the second speed and a nominal speed of the vehicle is exceeded.

11. The method of claim **10**, wherein the synchronization mode is an operation mode for speed control of the first electric motor and the second electric motor wherein speed of a respective electric motor decelerates or accelerates to a value wherein a speed difference between a respective shaft coupled to the respective electric motor and a desired gear is within a pre-determined speed threshold.

12. The method of claim **10**, wherein the traction mode is an operation mode for torque control of the first electric motor and the second electric motor wherein load of either the first electric motor and second electric motor is maintained or adjusted to enable desired torque production by the first electric motor and the second electric motor or adjusted to compensate for decreases in torque of one of the first electric motor or the second electric motor.

13. The system of claim **1**, wherein the first dog clutch is the only dog clutch coupled to the first shaft and the second dog clutch is the only dog clutch coupled to the second shaft.

14. The system of claim **9**, wherein the third shaft is parallel to each of the first shaft, the second shaft, and the intermediate shaft.

* * * * *