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(54) SYSTEM AND METHOD FOR OPERATING A VEHICLE WITH ELECTRIC POWER TAKE-OFF

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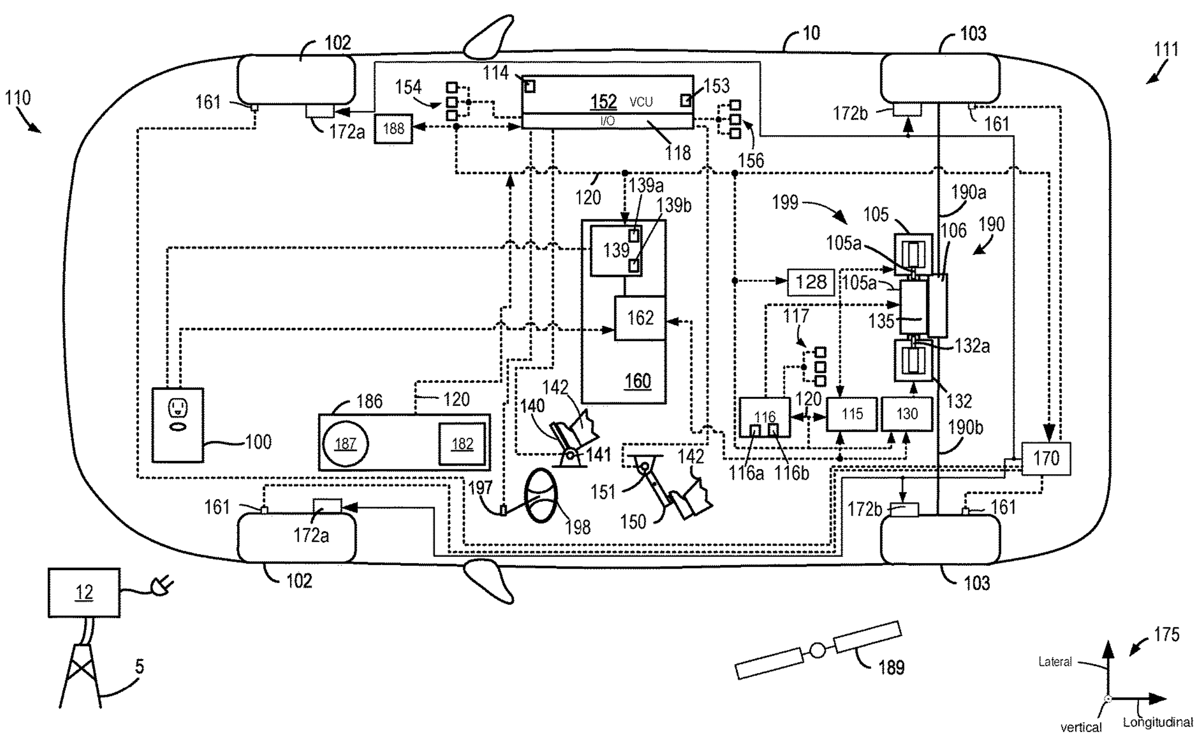
(57) **ABSTRACT**

Methods and systems for controlling a power take-off and engagement of an electric machine of an electric vehicle are described. In one example, a power take-off and engagement of a disconnect clutch are controlled in response to vehicle speed and tractive effort. A first electric machine is fixable coupled to a gear set of a transmission and the driveline disconnect clutch may selectively couple a second electric machine to the gear set.



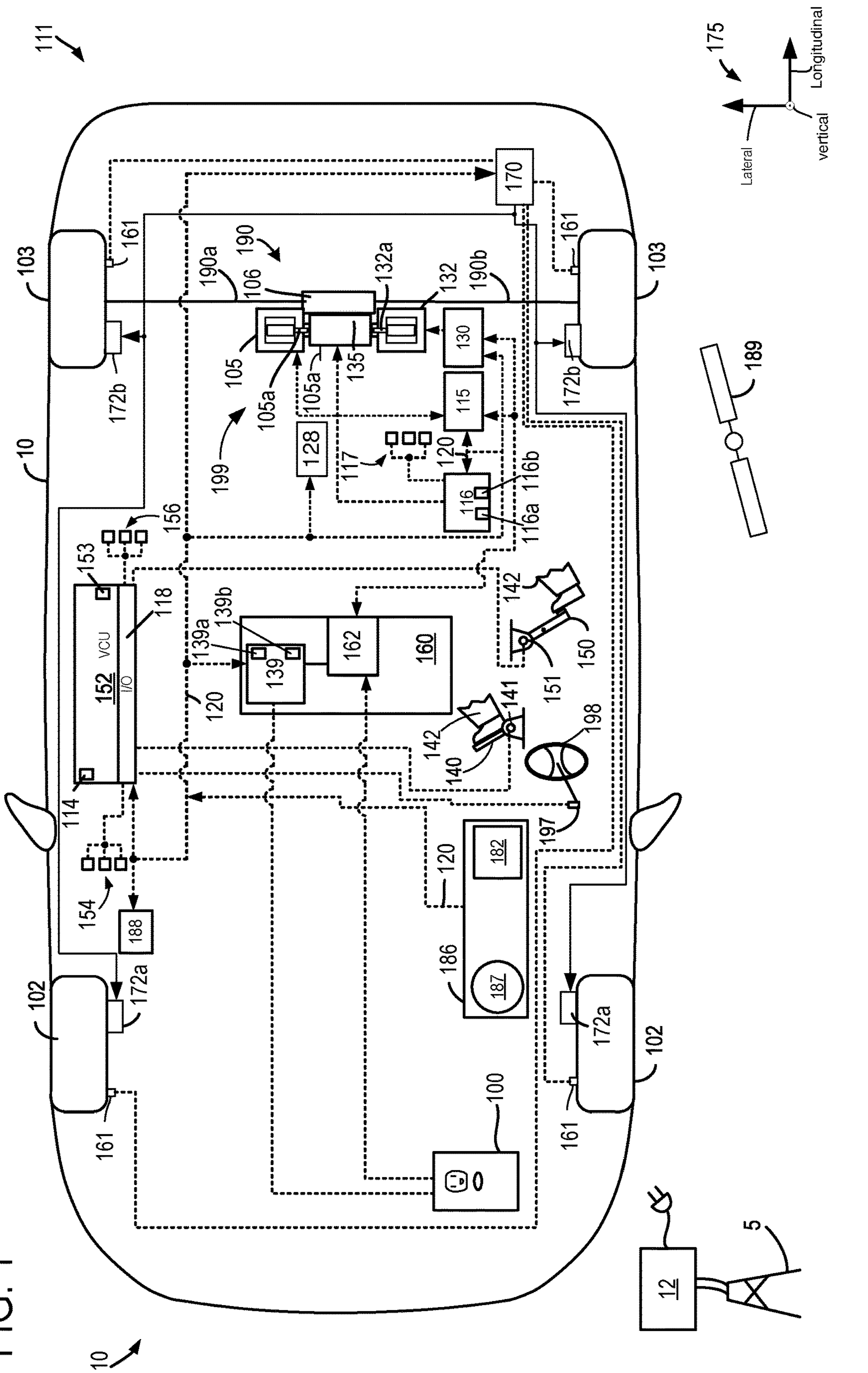


FIG. 1

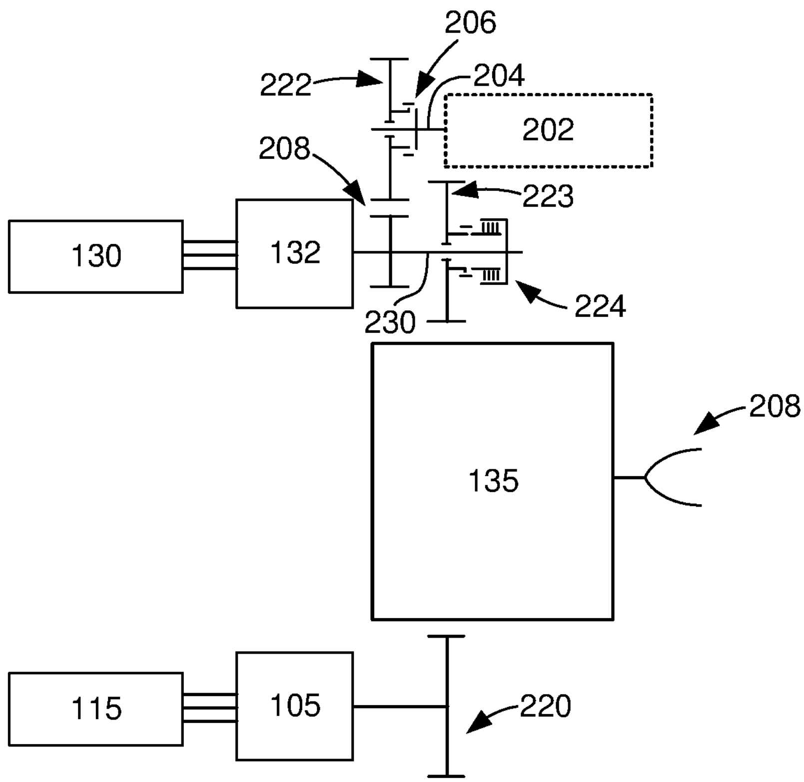


FIG. 2

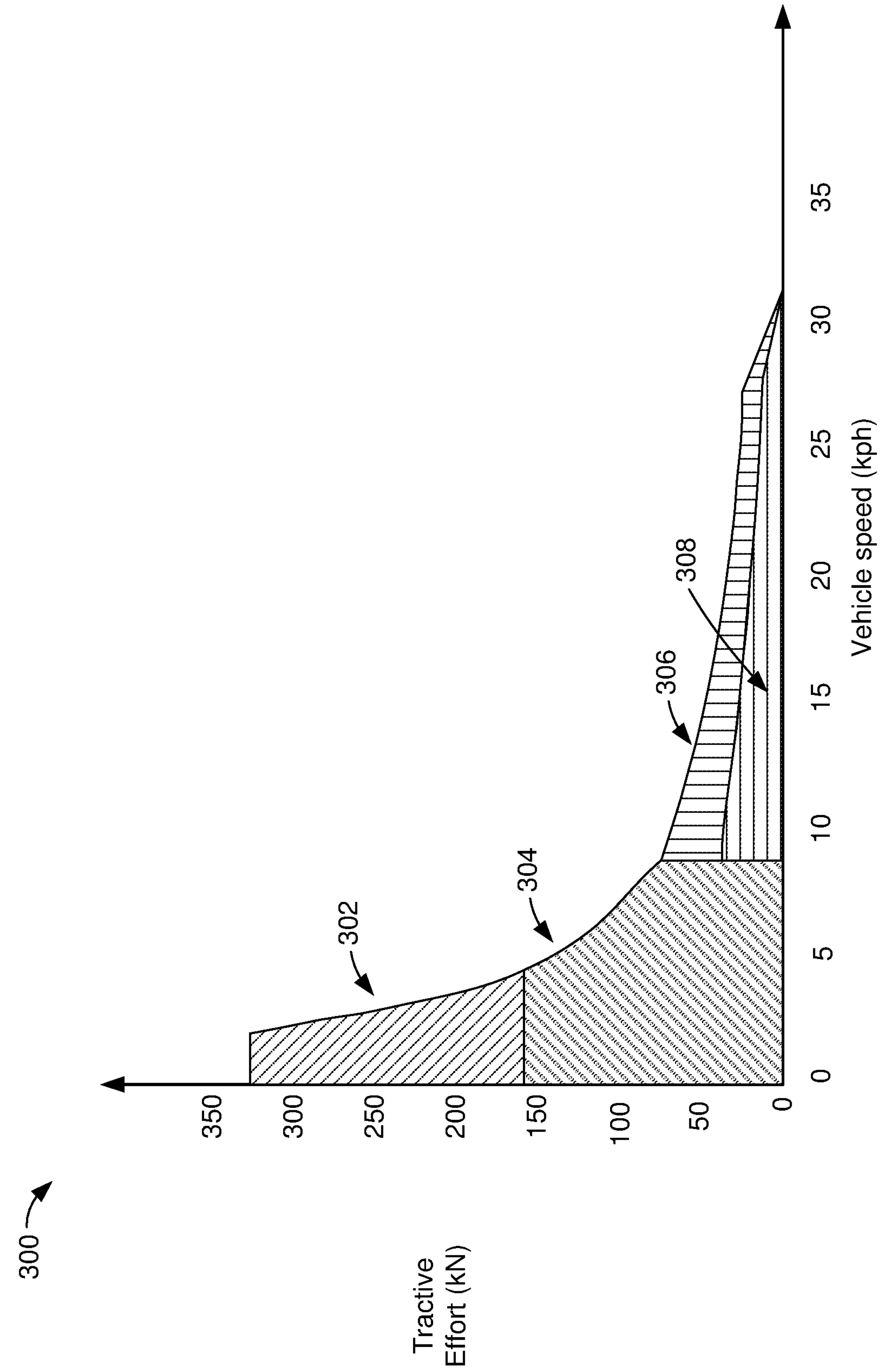

300
Tractive Effort (kN)
350
300
250
200
150
100
50
0
302
304
306
308
0
5
10
15
20
25
30
35
Vehicle speed (kph)

FIG. 3

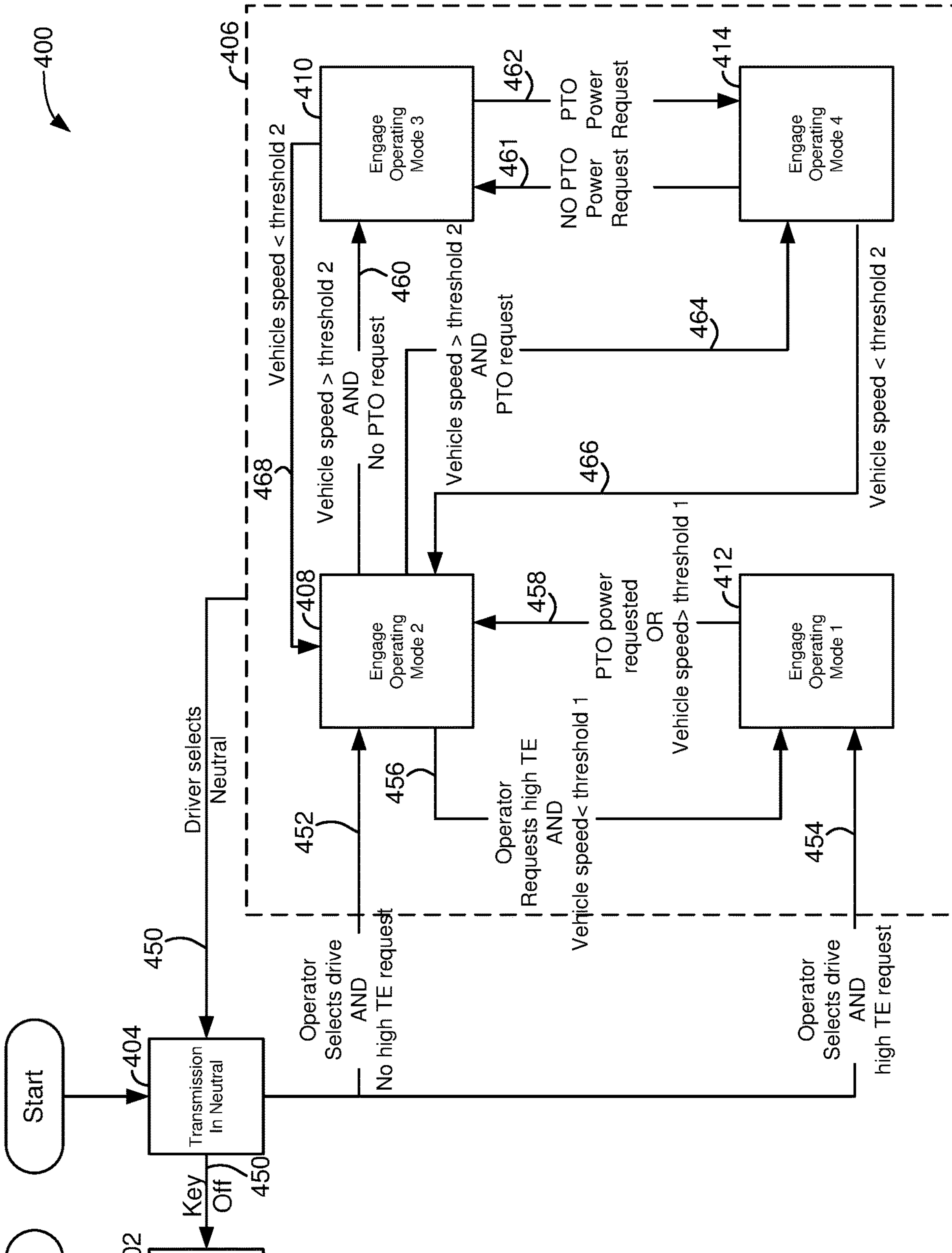

400
Start
End
Shutdown
402
Transmission In Neutral
404
Key Off
450
Driver selects Neutral
450
406
Operator Selects drive AND No high TE request
452
Operator Selects drive AND high TE request
454
Engage Operating Mode 2
408
Engage Operating Mode 1
412
Engage Operating Mode 3
410
Engage Operating Mode 4
414
Operator Requests high TE AND Vehicle speed< threshold 1
456
PTO power requested OR Vehicle speed> threshold 1
458
Vehicle speed > threshold 2 AND No PTO request
460
Vehicle speed > threshold 2 AND PTO request
464
Vehicle speed < threshold 2
468
Vehicle speed < threshold 2
466
NO PTO Power Request
461
PTO Power Request
462

FIG. 4

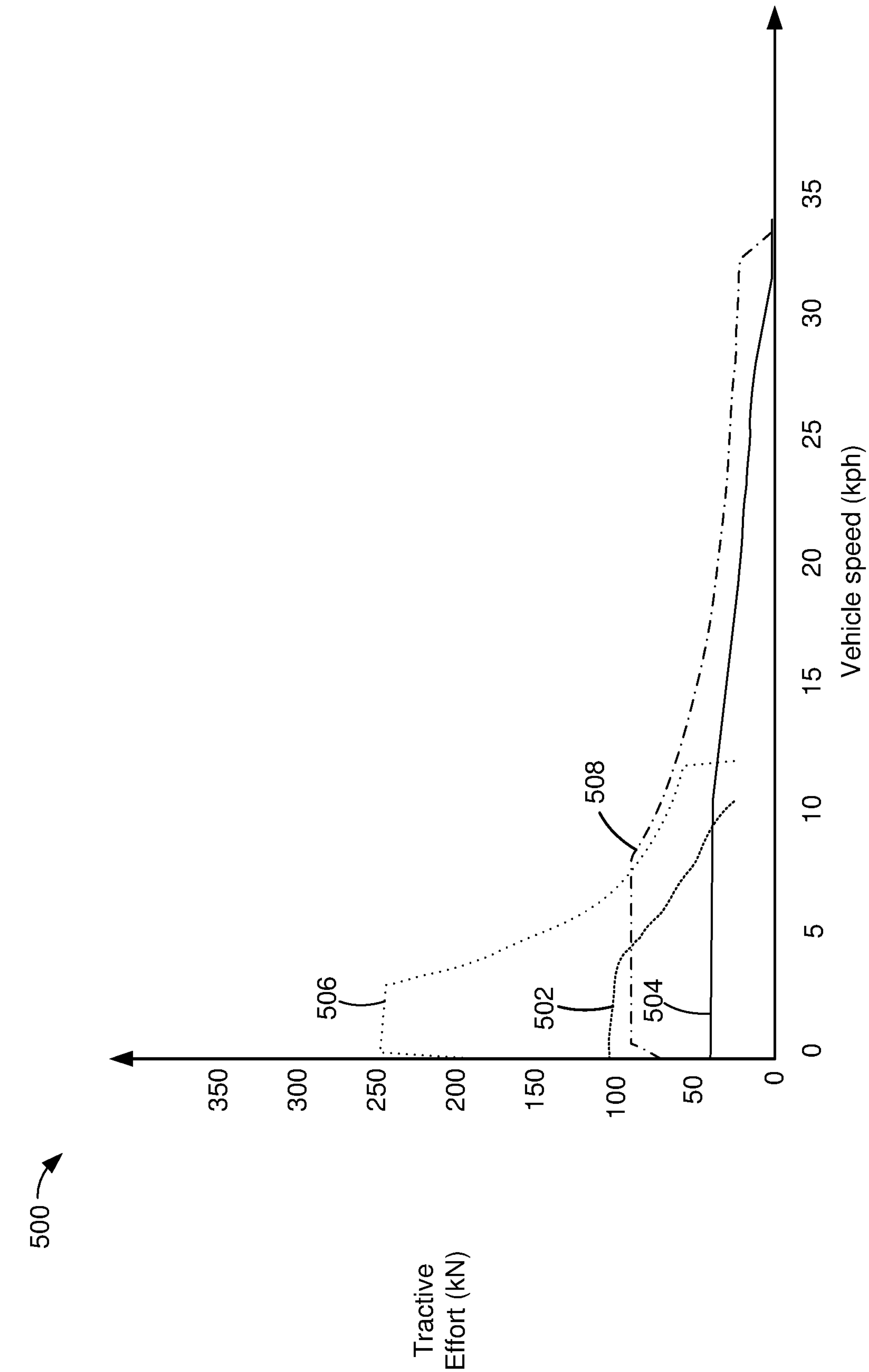

500
Tractive Effort (kN)
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
35
Vehicle speed (kph)
502
504
506
508

FIG. 5

SYSTEM AND METHOD FOR OPERATING A VEHICLE WITH ELECTRIC POWER TAKE-OFF

TECHNICAL FIELD

[0001] The present disclosure relates to operating an electric vehicle that includes a power take-off.

BACKGROUND AND SUMMARY

[0002] Internal combustion engines may be configured to propel a vehicle and provide power to a power take-off device. The power take-off device may supply power to a system that does not operate to deliver power to vehicle wheels. For example, the power take-off may supply mechanical power to drive a pump that pumps hydraulic fluid to operate hydraulic cylinders. Further, the power take-off may rotate a mixing device and/or supply power off-board the vehicle that includes the power take-off. However, power take-offs for electric vehicles provide different challenges than those power take-offs that are powered via an internal combustion engine. For example, electric vehicle power take-offs may not provide rotational power in a desired direction when an electric vehicle is traveling in a forward or a reverse gear. Further, a power take-off of an electric vehicle may not rotate at a desirable speed when a vehicle that includes the power take off device is traveling at a low speed. For at least these reasons, it may be desirable to reexamine power take-offs for electric vehicles.

[0003] The inventors herein have recognized the above-mentioned issues and have developed an electric propulsion system, comprising: a first electric machine; a second electric machine; a transmission, the transmission mechanically coupled to one or more rotatable wheels and the first electric machine; a disconnect clutch configured to selectively couple the second electric machine to the transmission; a power take-off configured to supply rotational mechanical power to a device; a power take-off disconnect clutch configured to selectively couple the second electric machine to the power take-off; and one or more controllers, the one or more controllers including executable non-transitory executable instructions that cause the controller to operate the power take-off disconnect clutch and the disconnect clutch.

[0004] By building a propulsion system that includes a disconnect clutch and a power take-off disconnect clutch, it may be possible to control a direction of power take-off rotation and speed independent of vehicle speed. Further, if operation of the power take-off is not requested or desired, an electric machine that selectively provides mechanical power to a power take-off device may supply tractive effort to a vehicle powertrain. Further still, during some conditions, the electric machine may provide power to the power take-off and the vehicle powertrain. As such, the capabilities of the electric machine may be enhanced.

[0005] The present description may provide several advantages. In particular, the approach may provide enhanced control for a power take-off of an electric machine. Further, the approach may enhance capability of an electric machine and provide independent control over a power take-off that may deliver power to a device that is external from a vehicle powertrain. Additionally, the approach provides for automated control over a power take-off device based on vehicle operating conditions.

[0006] It is to 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 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 restricted to implementations that solve any disadvantages noted above or in any part of this disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. **1** is an illustration of an example vehicle that includes an electric vehicle propulsion system.

[0008] FIG. **2** shows a stick diagram of one example step gear ratio transmission configuration that includes a power take-off device.

[0009] FIG. **3** shows powertrain operating modes according to a relationship between tractive effort and vehicle speed.

[0010] FIG. **4** shows a block diagram of an example method for operating an electric vehicle.

[0011] FIG. **5** shows available tractive effort levels for an example electric vehicle having a two speed transmission.

DETAILED DESCRIPTION

[0012] A method and system for providing power take-off output and tractive effort for an electric vehicle are described. The electric vehicle may include a two-speed transmission (e.g., a transmission with two forward gear ratios) or a transmission having more than two gear ratios. The electric vehicle may include two separate and independent electric machines as shown in FIGS. **1** and **2**. The electric machines and power power-take off may operate in different modes according to a relationship between tractive effort and vehicle speed as shown in FIG. **3**. The electric machines and transmission may be operated according to the method that is illustrated in the block diagram of FIG. **4**. The electric vehicle may provide tractive effort according to which of the transmissions gears are engaged as shown in FIG. **5**.

[0013] FIG. **1** illustrates an example vehicle propulsion system **199** for vehicle **10**. In FIG. **1**, mechanical connections between the various components are illustrated as solid lines, whereas electrical connections between various components are illustrated as dashed lines. Vehicle front end is indicated at **110** and vehicle rear end is indicated at **111**. Vehicle **10** travels in a forward direction when vehicle front end **110** leads movement of vehicle **10**. Vehicle **10** travels in a reverse direction when vehicle rear end **111** leads movement of vehicle **10**. In this example, vehicle **10** is a rear wheel drive vehicle, but in other examples, vehicle **10** may be a four-wheel drive or front wheel drive vehicle.

[0014] Vehicle propulsion system **199** includes a first propulsion source **105** (e.g., an electric machine, such as a motor) and a second electric machine **132**. In one example, propulsion sources **105** and **132** may be synchronous or induction electric machines that may operate as motor or generators. In other examples, propulsion sources **105** and **132** may be a direct current (DC) machine. Second electric machine **132** may selectively provide power to a power take off **129** according to user input to power take off interface **128** as shown in greater detail in FIG. **2**. Vehicle propulsion system **199** also includes a transmission **135**. The propulsion sources **105** and **132** are fastened to the transmission **135**. Propulsion sources **105** and **132** deliver power from their respective rotors **105***a* and **132***a* to transmission **135**. Transmission **135** may be mechanically coupled to differential gears **106**. Differential gears **106** may be coupled to two axle shafts, including a first or right axle shaft **190***a* and a second or left axle shaft **190***b*. Vehicle **10** further includes front wheels **102** and rear wheels **103**.

[0015] The transmission **135** may be referred to as a step ratio transmission and it may be configured as shown in greater detail in FIG. **2**. Transmission **135** may include one or more clutch actuators (not shown) to shift one or more clutches. Electric power inverter **115** is electrically coupled to propulsion source **105** to convert DC power to alternating current (AC) and vise-versa. Likewise, electric power inverter **130** is electrically coupled to propulsion source **132** to convert DC power to alternating current (AC) and vise-versa. Powertrain controller **116** is electrically coupled to sensors **117** and actuators of vehicle propulsion system **199**. For example, sensors **117** may include, but are not limited to inverter switch temperature sensors, electric machine winding temperature sensors, bus bar temperature sensors, etc.

[0016] Transmission **135** may transfer mechanical power to or receive mechanical power from differential gears **106**. Differential gears **106** may transfer mechanical power to or receive mechanical power from rear wheels **103** via right axle shaft **190***a* and left axle shaft **190***b*. Propulsion sources **105** and **132** may consume alternating current (AC) electrical power provided via their respective electric power inverters **115** and **130**. Alternatively, propulsion source **105** and **130** may provide AC electrical power to their respective electric power inverters **115** and **130**. Electric power inverters **115** and **130** may be provided with high voltage direct current (DC) power from battery **160** (e.g., a traction battery, which also may be referred to as an electric energy storage device or battery pack). Electric power inverters **115** and **130** may convert the DC electrical power from battery **160** into AC electrical power for propulsion sources **105** and **132**. Alternatively, electric power inverters **115** and **130** may be provided with AC power from their respective propulsion sources **105** and **132**. Electric power inverters **115** and **130** may convert the AC electrical power from their respective propulsion sources **105** and **132** into DC power to store in battery **160**.

[0017] Propulsion sources **105** and **132** may transfer mechanical power to or receive mechanical power from transmission **135**. As such, transmission **135** may be a multi-speed gear set that may shift between gear ratios when commanded via powertrain controller **116**. Powertrain controller **116** includes a processor **116***a* and memory **116***b*. Memory **116***b* (e.g., storage media) may include read exclusive memory, random access memory, and keep alive memory. The memory may be programmed with computer readable data representing instructions that are executable by a processor for performing the methods and control techniques described herein as well as other variants that are anticipated but not specifically listed. As such, control techniques, methods, and the like expanded upon herein may be stored as instructions in non-transitory memory.

[0018] Battery **160** may periodically receive electrical energy from a power source such as a stationary power grid **5** residing external to the vehicle (e.g., not part of the vehicle). As a non-restricted example, vehicle propulsion system **199** may be configured as a plug-in electric vehicle (EV), whereby electrical energy may be supplied to battery **160** via the stationary power grid **5** and charging station **12**. Electric charge may be delivered to battery **160** via plug receptacle **100**.

[0019] Battery **160** may include a BMS controller **139** (e.g., a battery management system controller) and an electrical power distribution box **162**. BMS controller **139** may provide charge balancing between energy storage elements (e.g., battery cells) and communication with other vehicle controllers (e.g., vehicle control unit **152**). BMS controller **139** includes a core processor **139***a* and memory **139***b* (e.g., random-access memory, read-exclusive memory, and keep-alive memory).

[0020] Vehicle **10** may include a vehicle control unit (VCU) **152** that may communicate with electric power inverter **115**, electric power inverter **130**, powertrain controller **116**, friction or foundation caliper controller **170**, global positioning system (GPS) **188**, BMS controller **139**, and dashboard **186** and components included therein via controller area network (CAN) **120**. VCU **152** includes memory **114**, which may include read-exclusive memory (ROM or non-transitory memory) and random access memory (RAM). VCU also includes a digital processor or central processing unit (CPU) **153**, and inputs and outputs (I/O) **118** (e.g., digital inputs including counters, timers, and discrete inputs, digital outputs, analog inputs, and analog outputs). VCU may receive signals from sensors **154** and provide control signal outputs to actuators **156**. Sensors **154** may include but are not restricted to lateral accelerometers, longitudinal accelerometers, yaw rate sensors, inclinometers, temperature sensors, battery voltage and current sensors, and other sensors described herein. Additionally, sensors **154** may include steering angle sensor **197**, driver demand pedal position sensor **141**, vehicle range finding sensors including radio detection and ranging (RADAR), light detection and ranging (LIDAR), sound navigation and ranging (SONAR), and caliper application pedal position sensor **151**. Actuators may include but are not constrained to inverters, transmission controllers, display devices, human/machine interfaces, friction caliper systems, and battery controller described herein.

[0021] Driver demand pedal position sensor **141** is shown coupled to driver demand pedal **140** for determining a degree of application of driver demand pedal **140** by human **142**. Caliper application pedal position sensor **151** is shown coupled to caliper application pedal **150** for determining a degree of application of caliper application pedal **150** by human **142**. Steering angle sensor **197** is configured to determine a steering angle according to a position of steering wheel **198**.

[0022] Vehicle propulsion system **199** is shown with a global position determining system **188** that receives timing and position data from one or more GPS satellites **189**. Global positioning system may also include geographical maps in ROM for determining the position of vehicle **10** and features of roads that vehicle **10** may travel on.

[0023] Vehicle propulsion system **199** may also include a dashboard **186** that an operator of the vehicle may interact with. Dashboard **186** may include a display system **187** configured to display information to the vehicle operator. Display system **187** may comprise, as a non-restricting example, a touchscreen, or human machine interface (HMI), display which enables the vehicle operator to view graphical information as well as input commands. In some examples, display system **187** may be connected wirelessly to the internet (not shown) via VCU **152**. As such, in some examples, the vehicle operator may communicate via display system **187** with an internet site or software application (app) and VCU **152**.

[0024] Dashboard **186** may further include an operator interface **182** via which the vehicle operator may adjust the operating status of the vehicle. Specifically, the operator interface **182** may be configured to activate and/or deactivate operation of the vehicle driveline (e.g., propulsion source **105**) based on an operator input. Further, an operator may request an axle mode (e.g., park, reverse, neutral, drive) via the operator interface. Various examples of the operator interface **182** may include interfaces that utilize a physical apparatus, such as a key, that may be inserted into the operator interface **182** to activate the vehicle propulsion system **199**, including propulsion sources **105** and **132**, to turn on the vehicle **10**. The apparatus may be removed to shut down the transmission **135** and propulsion sources **105** and **132** to turn off vehicle **10**. Propulsion sources **105** and **130** may be activated via supplying electric power to propulsion sources **105** and **132** as well as electric power inverters **115** and **130**. Propulsion sources **105** and **132** may be deactivated by ceasing to supply electric power to propulsion sources **105** and **132** as well as electric power inverters **115** and **132**. Still other examples may additionally or optionally use a start/stop button that is manually pressed by the operator to start or shut down the propulsion sources **105** and **132** to turn the vehicle on or off. In other examples, a remote electrified axle or electric machine start may be initiated remote computing device (not shown), for example a cellular telephone, or smartphone-based system where a user's cellular telephone sends data to a server and the server communicates with the vehicle control unit **152** to activate the inverters **115** and **130** as well as propulsion sources **105** and **132**. Spatial orientation of vehicle **10** is indicated via axes **175**.

[0025] Vehicle **10** is also shown with a foundation or friction caliper controller **170**. Friction caliper controller **170** may selectively apply and release friction calibers (e.g., **172***a* and **172***b*) via allowing hydraulic fluid to flow to the friction calipers. The friction calipers may be applied and released so as to reduce locking of the friction calipers to front wheels **102** and rear wheels **103**. Wheel position or speed sensors **161** may provide wheel speed data to friction caliper controller **170**. Vehicle propulsion system **199** may provide torque to rear wheels **103** to propel vehicle **10**.

[0026] A human or autonomous driver **142** may request a driver demand wheel torque, or alternatively a driver demand tractive effort, via applying driver demand pedal **140** or via supplying a driver demand wheel torque/tractive effort request to vehicle control unit **152**. Vehicle control unit **152** may then demand a torque or tractive effort from propulsion sources **105** and **132** via commanding powertrain controller **116**. Powertrain controller **116** may command electric power inverters **115** and **130** to deliver the driver demand wheel torque/tractive effort via electrified axle **190** and propulsion sources **105** and **132**. Electric power inverters **115** and **130** may convert DC electrical power from battery **160** into AC power and supply the AC power to propulsion sources **105** and **132**. Propulsion sources **105** and **132** rotate and transfer torque/power to transmission **135**. Transmission **135** may supply torque from propulsion sources **105** and **132** to differential gears **106**, and differential gears **106** transfer torque from propulsion sources **105** and **132** to rear wheels **103** via axle shafts **190***a* and **190***b*.

[0027] During conditions when the driver demand pedal is fully released, vehicle control unit **152** may request a small negative or regenerative power to gradually slow vehicle **10** when a speed of vehicle **10** is greater than a threshold speed. The amount of regenerative power requested may be a function of driver demand pedal position, battery state of charge (SOC), vehicle speed, and other conditions. If the driver demand pedal **140** is fully released and vehicle speed is less than a threshold speed, vehicle control unit **152** may request a small amount of positive torque/power (e.g., propulsion torque) from propulsion source **105**, which may be referred to as creep torque or power. The creep torque or power may allow vehicle **10** to remain stationary when vehicle **10** is on a small positive grade.

[0028] The human or autonomous driver may also request a negative or regenerative driver demand slowing torque, or alternatively a driver demand slowing power, via applying caliper pedal **150** or via supplying a driver demand slowing power request to vehicle control unit **152**. Vehicle control unit **152** may request that a first portion of the driver demanded slowing power be generated via propulsion source **105** via commanding powertrain controller **116**. Additionally, vehicle control unit **152** may request that a portion of the driver demanded slowing power be provided via friction calipers **172***a* and **172***b* via commanding friction caliper controller **170** to provide a second portion of the driver requested slowing power.

[0029] After vehicle control unit **152** determines the slowing power request, vehicle control unit **152** may command powertrain controller **116** to deliver the portion of the driver demand slowing power allocated to propulsion sources **105** and **132**. Propulsion sources **105** and **132** may convert the vehicle's kinetic energy into AC power.

[0030] Powertrain controller **116** includes predetermined transmission gear shift schedules whereby fixed ratio gears of transmission **135** may be selectively engaged and disengaged. Shift schedules stored in powertrain controller **116** may select gear shift points or events as a function of driver demand wheel torque and vehicle speed.

[0031] Turning now to FIG. **2**, a stick diagram of vehicle propulsion system **199** is shown. In this example, vehicle propulsion system **199** includes a transmission **135** that is a step gear ratio transmission with two gear ratios (e.g., a first lower gear ratio and a second higher gear ratio). In other examples, transmission **135** may include additional gear ratios.

[0032] Transmission **135** is mechanically fixedly coupled to first electric machine **105** via gear **220**. Additionally, transmission **135** is mechanically fixedly coupled to gear **223**, but gear **223** may be selectively mechanically coupled to second electric machine **132** via disconnect clutch **224**. In particular, gear **223** is supported via shaft **230**, but it may rotate freely with respect to shaft **230** and second electric machine **132** when disconnect clutch **224** is disengaged. Gear **223** rotates with shaft **230** and second electric machine **132** when disconnect clutch **224** is engaged. Thus, second electric machine **132** may be mechanically coupled to transmission **135** when disconnect clutch **224** is closed. Second electric machine **132** may be mechanically decoupled from transmission **135** when disconnect clutch **224** is open.

[0033] Vehicle propulsion system **199** also includes a mechanical power take-off **204** that may be mechanically coupled to a device **202** that is external to the vehicle propulsion system **199**. In particular, mechanical device **202** may consume mechanical power from power take-off **204**. Alternatively, mechanical device **202** may provide power to power take-off **204**. Power take-off **204** may be selectively coupled to gear **222** via power take-off disconnect clutch **206**. Gear **222** meshes with gear **208** and gear **208** is mechanically coupled to shaft **230** and second electric machine **132**.

[0034] Power take-off **204** may be activated so that mechanical device **202** rotates at a rate that is proportionate to the rate of rotation of the second electric machine **132**. Power take-off may be activated by closing power take-off disconnect clutch **206**. Power take-off **204** may be activated while disconnect clutch **224** is open or closed. If disconnect clutch **224** is closed, second electric machine **132** may rotate at a rate that is proportionate to the rate of rotation of first electric machine **105**. Thus, second electric machine **132** may deliver or receive mechanical power solely to/from device **202**, solely to/from transmission **135**, or to/from both transmission **135** and device **202**. Transmission **135** is mechanically coupled to differential gear set **106** of FIG. **1** via shaft **208**.

[0035] The system of FIGS. **1** and **2** provides for an electric propulsion system, comprising: a first electric machine; a second electric machine; a transmission, the transmission mechanically coupled to one or more rotatable wheels and the first electric machine; a disconnect clutch configured to selectively couple the second electric machine to the transmission; a power take-off configured to supply rotational mechanical power to a device; a power take-off disconnect clutch configured to selectively couple the second electric machine to the power take-off; and one or more controllers, the one or more controllers including executable non-transitory executable instructions that cause the controller to operate the power take-off disconnect clutch and the disconnect clutch. In a first example, the electric propulsion system includes where the power take-off disconnect clutch and the disconnect clutch are operated in response to a relationship between tractive effort and vehicle speed. In a second example that may include the first example, the electric propulsion system includes where the transmission includes a first gear and a second gear. In a third example that may include one or both of the first and second examples, the electric propulsion system further comprises additional executable instructions that cause the one or more controllers to engage the first gear and disengage the second gear in response to a first vehicle operating condition, and additional executable instructions that cause the one or more controllers to engage the second gear and disengage the first gear in response to a second vehicle operating condition. In a fourth example that may include one or more of the first through third examples, the electric propulsion system further comprises additional executable instructions that cause the one or more controllers to engage the power take-off via closing the power take-off disconnect clutch and opening the disconnect clutch in response to a power take-off request and a tractive effort request. In a fifth example that may include one or more of the first through fourth examples, the electric propulsion system further comprises additional executable instructions that cause the one or more controllers to disengage the power take-off via opening the power take-off disconnect clutch and closing the disconnect clutch in response to a power take-off request and a tractive effort request. In a sixth example that may include one or more of the first through fifth examples, the electric propulsion system further comprises additional executable instructions that cause the one or more controllers to fully open the disconnect clutch from a closed position in response to vehicle speed exceeding a threshold speed. In a seventh example that may include one or more of the first through sixth examples, the electric propulsion system further comprises additional executable instructions that cause the one or more controllers to fully open the disconnect clutch from a closed position in response to vehicle speed being less than a threshold speed.

[0036] The system of FIGS. **1** and **2** also provides for an electric propulsion system, comprising: a first electric machine; a second electric machine; a transmission, the transmission mechanically coupled to one or more rotatable wheels and the first electric machine; a disconnect clutch configured to selectively couple the second electric machine to the transmission; a power take-off configured to supply rotational mechanical power to a device; a power take-off disconnect clutch configured to selectively couple the second electric machine to the power take-off; and one or more controllers, the one or more controllers including executable non-transitory executable instructions that cause the controller to open the disconnect clutch in response to increasing driver demand torque when a vehicle speed is greater than a threshold speed, and additional executable instructions that cause the controller to open the disconnect clutch in response to increasing driver demand torque when the vehicle speed is less than the threshold speed. In a first example, the electric propulsion system further comprises additional executable instructions that cause the controller to engage a first gear of the transmission in response to tractive effort and the vehicle speed. In a second example that may include the first example, the electric propulsion system further comprises additional executable instructions that cause the controller to engage a second gear of the transmission in response to tractive effort and the vehicle speed. In a third example that may include one or both of the first and second examples, the electric propulsion system further comprises additional executable instructions that indicate the power take-off being automatically deactivated or automatically activated. In a fourth example that may include one or more of the first through third examples, the electric propulsion system further comprises additional executable instructions that indicate second electric machine being automatically deactivated or automatically activated.

[0037] Turning now to FIG. **3**, a plot **300** showing a relationship between tractive effort, vehicle speed, and powertrain operating mode is shown. Plot **300** includes a vertical axis and a horizontal axis. The vertical axis represents tractive effort, which has units of kilo-Newtons (kN), and the horizontal axis represents vehicle speed, which has units of kilo-meters per hour (kph).

[0038] In plot **300**, the vehicle operating range is comprised of four operating regions (**302**-**308**). The first operating region **302** includes low vehicle speeds and relatively high tractive effort levels. In the first operating region **302**, the power take-off is disconnected from the second electric machine. Additionally, the first electric machine **105** and the second electric machine **132** are mechanically coupled to gears of transmission **135** so that they both may source or receive power to/from transmission **135**. The disconnect clutch **224** is fully closed and the power take-off disconnect clutch **206** is fully open. The vehicle is engaged in first (e.g., low) gear. A vehicle may operate in the first operating region **302** when it is temporarily stuck, driving out of a pothole, or beginning to move a heavy load.

[0039] The second operating region **304** includes low to medium vehicle speeds and low to medium tractive effort levels. In the second operating region **304**, the power take-off may be connected and the first electric machine **105** is the sole electric machine that is mechanically coupled to gears of transmission **135**. The second electric machine **132** is mechanically decoupled from gears of transmission **135** so that first electric **105** is the sole propulsion source in this operating region. The power take-off disconnect clutch **206** is fully closed and the vehicle is engaged in first (e.g., low) gear. A vehicle may operate in the second operating region **304** when a vehicle is approaching or backing away from an area where the power take-off may be put to work (e.g., lifting a container or a dump bed) where power take-off use may be desirable. Thus, the power take-off may be engaged and operating in second operating region **304**.

[0040] The third operating region **306** includes medium to high vehicle speeds and low to low-medium tractive effort levels. In the third operating region **306**, the power take-off is disconnected and the first electric machine **105** and the second electric machine **132** are mechanically coupled via gears of transmission **135** so that both the first electric machine **105** and the second electric machine **132** may provide tractive effort to the vehicle's wheels. The power take-off disconnect clutch **206** is fully open and the disconnect clutch **224** is fully closed. The vehicle is engaged in second (e.g., high) gear. A vehicle may operate in the third operating region **306** when a vehicle is operating at higher speeds, such as when the vehicle is traveling in a straight line or on a straight road.

[0041] The fourth operating region **308** includes medium to high vehicle speeds and low tractive effort levels. In the fourth operating region **308**, the power take-off may be connected and the first electric machine **105** is the sole electric machine that is mechanically coupled to gears of transmission **135**. The second electric machine **132** is mechanically decoupled from gears of transmission **135** so that first electric **105** is the sole propulsion source in this operating region. The power take-off disconnect clutch **206** is fully closed and the vehicle is engaged in second (e.g., high) gear. A vehicle may operate in the fourth operating region **308** when a vehicle is traveling in a straight line and some power take-off power may be desired, such as when a mixer is working onboard the vehicle and the vehicle is on its way to drop off a mixture.

[0042] Referring now to FIG. **4**, a block diagram of a method **400** for operating an electric vehicle with a power take-off is shown. The method of FIG. **4** may be incorporated into and may cooperate with the system of FIGS. **1** and **2**. Further, at least portions of the method of FIG. **4** may be incorporated as executable instructions stored in non-transitory memory of one or more controllers while other portions of the method may be performed via the one or more controllers transforming operating states of devices and actuators in the physical world. Block **406** represents a drive mode and the drive mode includes modes **1-4**.

[0043] At **404**, method **400** is in an operating state where the vehicle's transmission is engaged in neutral or park. The vehicle may not move in a forward or reverse direction when the vehicle's transmission is engaged in neutral or park. The vehicle may be activated when the vehicle is in neutral or park.

[0044] Method **400** may move to a shutdown operating state at block **402** from block **404** as indicated by leader **450** in response to a vehicle key off, movement of a vehicle activation device away from the vehicle, or another signal that is an indication of a desire or request to shut down or deactivate the vehicle. The vehicle may be shutdown by ceasing to supply electric power to the vehicle's traction motors and inverters. Method **400** proceeds to exit after the vehicle is shutdown. Alternatively, method **400** may move to block **412** as indicated by leader **454** in response a request for the vehicle's transmission to enter drive and a tractive effort request that is greater than a first tractive effort threshold.

[0045] At block **412**, the vehicle enters a first operating mode where the vehicle may operate in a first operating region **302** as shown in FIG. **3**. In the first operating mode, the disconnect clutch **224** is fully closed and the power take-off clutch **206** is fully open. This operating mode allows the vehicle to operate at low speed and high tractive effort. The vehicle may remain in first gear in this operating mode. Method **400** may exit block **412** and move to block **408** in response to power take-off (PTO) power being requested or vehicle speed being greater than a first threshold vehicle speed.

[0046] Method **400** may move to block **408** from block **404** as indicated by leader **452** in response to a request for the vehicle's transmission to enter drive and the tractive effort request being less than the first tractive effort threshold. At block **408**, the vehicle enters a second operating mode where the vehicle may operate in a second operating region **304** as shown in FIG. **3**. In the second operating mode, the disconnect clutch **224** is fully open and the power take-off clutch **206** may be fully closed if there is a request for power take-off activation. This operating mode allows the vehicle to operate at low speed with an activated power take-off. The vehicle may remain in first gear in this operating mode. Block **408** may also be entered in response to a power take-off request while the vehicle is operating in the first operating mode or when vehicle speed is greater than a first threshold vehicle speed as indicated by leader **458**. Further, block **408** may also be entered in response to vehicle speed being less than a second threshold speed when the vehicle is at block **410** and operating in a third mode as indicated by leader **468**. Further still, block **408** may be entered in response to vehicle speed being less than a second threshold speed when the vehicle is at block **414** and operating in a fourth mode as indicated by leader **466**.

[0047] Method **400** may exit block **408** and move to block **412** in response to a vehicle operator requesting a tractive effort (TE) that is greater than a threshold tractive effort and vehicle speed being less than a threshold vehicle speed as indicated at leader **456**. Method **400** may be in first gear when method **400** is at blocks **408** and **412**. Method **400** may also exit block **408** and move to block **410** in response to a vehicle speed being greater than a second threshold vehicle speed and no power take-off (PTO) request as indicated at leader **460**. Method **400** may enter second gear when method **400** moves to **410**. Additionally, method **400** may also exit block **408** and move to block **414** in response to a vehicle speed being greater than a second threshold vehicle speed and a power take-off (PTO) request as indicated at leader **464**. Method **400** may enter second gear when method **400** moves to **414**.

[0048] At block **410**, the vehicle enters a third operating mode where the vehicle may operate in a third operating region **306** as shown in FIG. **3**. In the third operating mode, the disconnect clutch **224** is fully closed and the power take-off clutch **206** is fully open. This operating mode allows the vehicle to operate at higher speed and low to medium tractive effort without an engaged power take-off. The vehicle may engage second gear in this operating mode. Method **400** may exit block **410** and move to block **414** as indicated by leader **462** in response to power take-off (PTO) power being requested as indicated by leader **462**. Method **400** may also exit block **410** and move to block **408** as indicated by leader **468** in response to a vehicle speed being less than a second threshold vehicle speed.

[0049] At block **414**, the vehicle enters a fourth operating mode where the vehicle may operate in a fourth operating region **308** as shown in FIG. **3**. In the fourth operating mode, the disconnect clutch **224** is fully open and the power take-off clutch **206** may be fully closed if there is a request for power take-off activation. This operating mode allows the vehicle to operate at higher speeds with an activated power take-off. The vehicle may engage second gear in this operating mode. Block **414** may be exited as indicated by leader **461** in response to no power take-off request. Further, method **400** may exit block **414** and enter block **408** as indicated by leader **466** in response to vehicle speed being less than a second threshold vehicle speed.

[0050] In this way, a vehicle that includes two electric machines and a power take-off may be operated. The method of FIG. **4** allows the vehicle to switch operating modes in a way that allows both power take-off requests and tractive effort demands to be met.

[0051] Method **400** provides for a method for operating a vehicle, comprising: selectively opening and closing a disconnect clutch and a power take-off disconnect clutch that are mechanically coupled to a second electric machine in response to a tractive effort and a vehicle speed; and propelling the vehicle via a first electric machine. In a first example, the method includes where the disconnect clutch selectively couples the second electric machine to a transmission and the first electric machine, and where the first electric machine is mechanically coupled to the transmission. In a second example that may include the first example, the method further comprises selectively engaging the power take-off clutch in response to a power take-off request. In a third example that may include one or both of the first and second examples, the method further comprises indicating disengagement of the power take-off clutch when the power take-off clutch is disengaged in response to vehicle speed. In a fourth example that may include one or more of the first through third examples, the method further comprises indicating engagement of the power take-off clutch when the power take-off clutch is engaged in response to vehicle speed. In a fifth example that may include one or more of the first through fourth examples, the method further comprises indicating disengagement of the disconnect clutch in response to vehicle speed. In a sixth example that may include one or more of the first through fifth examples, the method further comprises indicating engagement of the disconnect clutch in response to vehicle speed.

[0052] Referring now to FIG. **5**, a plot **500** showing a relationship between tractive effort that is available while the transmission is engaged in its different gears versus vehicle speed is shown. Plot **500** includes a vertical axis and a horizontal axis. The vertical axis represents tractive effort, which has units of kilo-Newtons (kN), and the horizontal axis represents vehicle speed, which has units of kilo-meters per hour (kph).

[0053] In plot **500**, maximum tractive effort values that are available while the vehicle's transmission is engaged in first or second gear are shown. In particular, dashed line **502** represents vehicle speeds and a maximum continuous amount of tractive effort that is available from the powertrain of FIGS. **1** and **2** while the vehicle is engaged in first gear and one sole electric machine is mechanically coupled to the driveline and wheels. Solid line **504** represents vehicle speeds and a maximum continuous amount of tractive effort that is available from the powertrain of FIGS. **1** and **2** while the vehicle is engaged in second gear and one sole electric machine is mechanically coupled to the driveline to provide tractive effort at the wheels. Dotted line **506** represents vehicle speeds and a maximum peak or transient amount of tractive effort that is available from the powertrain of FIGS. **1** and **2** while the vehicle is engaged in first gear and one sole electric machine is mechanically coupled to the driveline to provide tractive effort at the wheels. Dash-dot line **508** represents vehicle speeds and a maximum peak or transient amount of tractive effort that is available from the powertrain of FIGS. **1** and **2** while the vehicle is engaged in second gear and one sole electric machine is mechanically coupled to the driveline to provide tractive effort at the wheels.

[0054] From the lines in FIG. **5**, it may be observed that the transmission may be shifted from first gear to second gear when vehicle speed exceeds a maximum vehicle speed achievable with dotted line **506**. Further, it may be observed that the transmission may be shifted from second gear to first gear when a tractive effort demand exceeds a maximum tractive effort achievable with dash-dot line **508**.

[0055] Note that the example control and estimation routines included herein may 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 transmission and/or vehicle hardware. Further, portions of the methods may be physical actions taken in the real world to change a state of a device. Thus, 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 and/or transmission control system. 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 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. One or more of the method steps described herein may be omitted if desired.

[0056] While various embodiments have been described above, it is to 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. As such, 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 may be applied to electric vehicles and hybrid vehicles including induction and synchronous electric machines. 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.

[0057] 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 may 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.

1. An electric propulsion system, comprising:
- a first electric machine;
- a second electric machine;
- a transmission, the transmission mechanically coupled to one or more rotatable wheels and the first electric machine;
- a disconnect clutch configured to selectively couple the second electric machine to the transmission;
- a power take-off configured to supply rotational mechanical power to a device;
- a power take-off disconnect clutch configured to selectively couple the second electric machine to the power take-off; and
- one or more controllers, the one or more controllers including executable non-transitory executable instructions that cause the one or more controllers to operate the power take-off disconnect clutch and the disconnect clutch.

2. The electric propulsion system of claim **1**, where the power take-off disconnect clutch and the disconnect clutch are operated in response to a relationship between tractive effort and vehicle speed.

3. The electric propulsion system of claim **1**, where the transmission includes a first gear and a second gear.

4. The electric propulsion system of claim **3**, further comprising additional executable instructions that cause the one or more controllers to engage the first gear and disengage the second gear in response to a first vehicle operating condition, and additional executable instructions that cause the one or more controllers to engage the second gear and disengage the first gear in response to a second vehicle operating condition.

5. The electric propulsion system of claim **4**, further comprising additional executable instructions that cause the one or more controllers to engage the power take-off via closing the power take-off disconnect clutch and opening the disconnect clutch in response to a power take-off request and a tractive effort request.

6. The electric propulsion system of claim **4**, further comprising additional executable instructions that cause the one or more controllers to disengage the power take-off via opening the power take-off disconnect clutch and closing the disconnect clutch in response to a power take-off request and a tractive effort request.

7. The electric propulsion system of claim **1**, further comprising additional executable instructions that cause the one or more controllers to fully open the disconnect clutch from a closed position in response to vehicle speed exceeding a threshold speed.

8. The electric propulsion system of claim **1**, further comprising additional executable instructions that cause the one or more controllers to fully open the disconnect clutch from a closed position in response to vehicle speed being less than a threshold speed.

9. A method for operating a vehicle, comprising:
- selectively opening and closing a disconnect clutch and a power take-off disconnect clutch that are mechanically coupled to a second electric machine in response to a tractive effort and a vehicle speed; and
- propelling the vehicle via a first electric machine.

10. The method of claim **9**, where the disconnect clutch selectively couples the second electric machine to a transmission and the first electric machine, and where the first electric machine is mechanically coupled to the transmission.

11. The method of claim **10**, further comprising selectively engaging the power take-off disconnect clutch in response to a power take-off request.

12. The method of claim **11**, further comprising indicating disengagement of the power take-off disconnect clutch when the power take-off disconnect clutch is disengaged in response to vehicle speed.

13. The method of claim **11**, further comprising indicating engagement of the power take-off disconnect clutch when the power take-off disconnect clutch is engaged in response to vehicle speed.

14. The method of claim **11**, further comprising indicating disengagement of the disconnect clutch in response to vehicle speed.

15. The method of claim **11**, further comprising indicating engagement of the disconnect clutch in response to vehicle speed.

16. An electric propulsion system, comprising:
- a first electric machine;
- a second electric machine;
- a transmission, the transmission mechanically coupled to one or more rotatable wheels and the first electric machine;
- a disconnect clutch configured to selectively couple the second electric machine to the transmission;
- a power take-off configured to supply rotational mechanical power to a device;

a power take-off disconnect clutch configured to selectively couple the second electric machine to the power take-off; and

one or more controllers, the one or more controllers including executable non-transitory executable instructions that cause the one or more controllers to open the disconnect clutch in response to increasing driver demand torque when a vehicle speed is greater than a threshold speed, and additional executable instructions that cause the one or more controllers to open the disconnect clutch in response to increasing driver demand torque when the vehicle speed is less than the threshold speed.

17. The electric propulsion system of claim **16**, further comprising additional executable instructions that cause the one or more controllers to engage a first gear of the transmission in response to tractive effort and the vehicle speed.

18. The electric propulsion system of claim **17**, further comprising additional executable instructions that cause the one or more controllers to engage a second gear of the transmission in response to tractive effort and the vehicle speed.

19. The electric propulsion system of claim **16**, further comprising additional executable instructions that indicate the power take-off being automatically deactivated or automatically activated.

20. The electric propulsion system of claim **16**, further comprising additional executable instructions that indicate second electric machine being automatically deactivated or automatically activated.

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