ELECTRIC VEHICLE

Abstract

An electric vehicle has an electric motor as a drive source and includes a control device, a first indicator, a second indicator, and a third indicator. The control device switches a relationship among base torque, an operation amount of the first indicator, and a vehicle speed of the electric vehicle, in a plurality of predetermined relationships in accordance with operation of the second indicator, decreases the torque of the electric motor from the base torque in response to a direction from the third indicator, and accepts input from the second indicator only when an operation amount of the third indicator is larger than a predetermined amount.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application claims priority under 35 U.S.C. § 119 to Japanese Patent Application No. 2024-024728, filed on Feb. 21, 2024, the contents of which application are incorporated herein by reference in their entirety.

FIELD

[0002] The present disclosure relates to an electric vehicle having an electric motor as a drive source.

BACKGROUND ART

[0003] Patent Literature 1 discloses an electric vehicle which can simulate a behavior of a vehicle including a manual transmission and using an engine as a power source (transmission vehicle) by controlling an electric motor. The electric vehicle has an MT traveling mode (MT mode) for reproducing the behavior of the transmission vehicle in addition to an EV traveling mode (EV mode) for performing normal traveling of the electric vehicle. The driver can switch between the MT mode and the EV mode by a switch or the like. In the MT mode, shift positions of the transmission vehicle are also virtually reproduced, and the driver can perform gear shift operation by his/her own hands as if he/she drives the transmission vehicle.

LIST OF RELATED ART

[0004] Patent Literature 1: Japanese Patent No. 6787507

SUMMARY

[0005] According to the above-described conventional technique, the driver can experience operation of the transmission vehicle by the electric vehicle. In such an electric vehicle, it is considered to achieve both operation feeling closer to that of the transmission vehicle and ease of operation.

[0006] An object of the present disclosure is to provide an electric vehicle capable of reproducing a behavior of a transmission vehicle, in which the driver can experience operational feeling similar to that of a transmission vehicle, while maintaining ease of operation.

[0007] The present disclosure provides an electric vehicle having an electric motor as a drive source. The electric vehicle includes a control device configured to control the electric motor, a first indicator that gives a continuous direction to the control device in accordance with a first operation amount of the first indicator, a second indicator that gives a relative direction to the control device for each operation of the second indicator, and a third indicator that gives a continuous or discrete direction to the control device in accordance with a third operation amount of the third indicator. The control device is configured to execute switching a relationship among base torque, the first operation amount, and a vehicle speed of the electric vehicle, in a plurality of predetermined relationships in accordance with operation of the second indicator, the base torque being torque of the electric motor in a state where the third indicator is not operated, decreasing the torque of the electric motor from the base torque in response to a direction from the third indicator, and accepting input from the second indicator only when the third operation amount is larger than a predetermined amount.

[0008] According to the electric vehicle of the present disclosure, input from the second indicator is accepted only when the operation amount of the third indicator is larger than the predetermined amount. The third indicator, which outputs the continuous or discrete direction according to the operation amount, corresponds to a clutch pedal in a transmission vehicle. The second indicator, which outputs the relative direction for each operation, corresponds to a sequential shifter in the

transmission vehicle. That is, in the electric vehicle of the present disclosure, it is necessary to operate a device corresponding to the clutch pedal in order to perform operation simulating gear shift operation of the transmission vehicle. This makes it possible to bring the operational feeling closer to that of the transmission vehicle.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. **1** is a diagram showing a configuration of an electric vehicle according to an embodiment of the present disclosure.

[0010] FIG. **2***a* is a diagram showing an example of a relative direction type shift device.

[0011] FIG. **2***b* is a diagram showing another example of the relative direction type shift device.

[0012] FIG. **3** is a diagram showing still another example of the relative indication type shift device.

[0013] FIG. **4***a* is a diagram showing still another example of the relative indication type shift device.

[0014] FIG. **4***b* is a diagram showing still another example of the relative indication type shift device.

[0015] FIG. **5***a* is a diagram showing still another example of the relative indication type shift device.

[0016] FIG. **5***b* is a diagram showing still another example of the relative indication type shift device.

[0017] FIG. **6** is a diagram showing a configuration of a control device related to travel control of the electric vehicle.

[0018] FIG. **7** is a time chart showing an example of operation when upshift is performed.

[0019] FIG. **8** is a time chart showing an example of operation when downshift is performed.

DETAILED DESCRIPTION

[0020] Embodiments of the present disclosure will be described with reference to the accompanying drawings.

1. Configuration of Power System of Electric Vehicle

[0021] FIG. **1** is a diagram schematically showing a configuration of an electric vehicle **100** according to an embodiment of the present disclosure. First, a configuration of a power system of the electric vehicle **100** will be described with reference to FIG. **1**.

[0022] The electric vehicle **100** includes two electric motors (M) **4**F and **4**R as power sources for driving. The electric motors **4**F and **4**R are arranged at the front and the rear, respectively. The electric motors **4**F and **4**R are, for example, three phase alternating current motors. The front electric motor **4**F is connected to a front drive shaft **5**F, which drives front wheels **6**F. The rear electric motor **4**R is connected to a rear drive shaft **5**R, which drives rear wheels **6**R. The front wheels **6**F are suspended by front suspension **7**F, in which the right and left can be controlled independently and electronically. The rear wheels **6**R are suspended by rear suspension **7**R, in which the right and left can be controlled independently and electronically.

[0023] Inverters (INV) **3**F and **3**R are attached to the front electric motor **4**F and the rear electric motor **4**R, respectively. The front inverter **3**F and the rear inverter **3**R are connected to a battery (BATT) **2**. The battery **2** stores electric energy for driving the electric motors **4**F and **4**R. That is, the electric vehicle **100** is a battery electric vehicle (BEV) which travels with electric energy stored in the battery **2**. The inverters **3**F and **3**R are, for example, voltage-type inverters and control torque of the electric motors **4**F and **4**R by PWM control.

2. Configuration of Control System of Electric Vehicle

[0024] Next, a configuration of a control system of the electric vehicle **100** will be described with

reference to FIGS. **1** to **5**.

[0025] The electric vehicle **100** includes a vehicle speed sensor **11**. At least one of wheel speed sensors (not shown the figure) installed at the right and left front wheels **6**F and the right and left rear wheels **6**R is used as the vehicle speed sensor **11**. The electric vehicle **100** includes an accelerator pedal stroke sensor **12**. The accelerator pedal stroke sensor **12** is installed at an accelerator pedal **22** and outputs a signal indicating an accelerator position, that is, an amount of operation of the accelerator pedal **22**. The accelerator pedal **22** is continuously operated by the driver, and the signal indicating the accelerator position is continuously transmitted to a control device **101** while the electric vehicle **100** is traveling. The accelerator pedal **22** is a pedal-type device operated by a foot, but a device for accelerator operation may be a device operated by a hand. For example, the electric vehicle **100** may include a lever type accelerator operation device or a dial type accelerator operation device operated by a hand instead of the accelerator pedal **22**.

[0026] The electric vehicle **100** further includes a brake pedal stroke sensor **13**. The brake pedal stroke sensor **13** is installed at a brake pedal **23** and outputs a signal indicating a break position, that is, an amount of operation of the brake pedal **23**. The brake pedal **23** is continuously operated by the driver, and the signal indicating the breake position is continuously transmitted to the control device **101** while the electric vehicle **100** is traveling.

[0027] The accelerator pedal **22** and the brake pedal **23** are driving operation members, which are used for driving the electric vehicle **100**. In addition to these driving operation members, the electric vehicle **100** includes a gear shift operation member for performing virtual gear shift operation simulating gear shift operation of a transmission vehicle. The gear shift operation members include a relative direction type shift device **24** and a dummy clutch operation device **25** described below.

[0028] The relative direction type shift device **24** is a device for the driver to perform gear shift operation. The driver can relatively direct a shift position (gear stage), in other words, can select the shift position based on a current shift position, by operating the relative direction type shift device **24**. The driver can sequentially shift up or shift down the shift position one stage at a time in order using the relative direction type shift device **24**. For example, the driver can switch the shift position in order of the 1st, 2nd, 3rd, and so on by using the relative direction type shift device **24**. The driver selects the shift position to be directed by sequentially switching the shift positions. However, since the electric vehicle **100** does not include an actual transmission, the shift position directed by the relative direction type shift device **24** is a virtual shift position.

[0029] The relative direction type shift device **24** may be any device as long as the driver can relatively direct the shift position, and the structure thereof is not particularly limited. An example of the relative direction type shift device **24** is shown in FIGS. **2** to **5**.

[0030] As an example of the relative direction type shift device **24**, each of FIGS. **2***a* and **2***b* shows a dummy paddle shifter **24** simulating a paddle shifter which is a kind of a sequential shifter. The dummy paddle shifter **24** is a dummy different from an original paddle shifter. The dummy paddle shifter **24** has a structure similar to a shift paddle attached to a steering wheel or a steering column and includes right and left paddles which can be moved independently. The dummy paddle shifter **24** may be attached to a steering wheel **27** or may be attached to a steering column. FIG. **2***a* shows a dummy paddle shifter simulating a paddle shifter attached to the steering wheel, and FIG. **2***b* shows a dummy paddle shifter simulating a paddle shifter attached to the steering column. A shift switch **14** is inastalled at the dummy paddle shifter **24**. The shift switch **14** outputs an upshift signal when the right paddle is pulled, and outputs a downshift signal when the left paddle is pulled.

[0031] FIG. **3** shows a button type device installed at the steering wheel **27** as another example of the relative direction type shift device **24**. The shift switch **14** is also installed at the button type relative direction type shift device **24**. The shift switch **14** outputs the upshift signal when the right button is pressed and outputs the downshift signal when the left button is pressed. The button type relative direction type shift device **24** may be attached to a place other than the steering wheel. For

example, buttons installed on a center console may be used as the relative direction type shift device **24**.

[0032] As still another example of the relative direction type shift device **24**, each of FIGS. **4***a* and **4***b* shows a dummy shift lever **24** simulating a shift lever which is a kind of sequential shifter. The dummy shift lever **24** is a dummy different from an original shift lever. FIG. **4***a* shows an example of the dummy shift lever **24** installed on the center console, and FIG. **4***b* shows an example of the dummy shift lever **24** installed at the steering column. The shift switch **14** is also installed at the dummy shift lever **24**. The shift switch **14** outputs the upshift signal when the shift lever is moved forward or toward the upper side, and outputs the downshift signal when the shift lever is moved backward or toward the lower side. The dummy shift lever **24** may be installed at a place other than the center console and the steering column.

[0033] Each of FIGS. **5***a* and **5***b* shows a still another example of the relative direction type shift device **24**. For example, the relative direction type shift device **24** may be a toggle switch as shown in FIG. **5***a*. When the driver tilts a knob forrward, the switch outputs the upshift signal, and when the driver tilts the knob backward, the switch outputs the downshift signal. Alternatively, the relative direction type shift device **24** may be a rotary switch as shown in FIG. **5***b*. When the driver turns a knob to the right, the switch outputs the upshift signal, and when the driver turns the knob to the left, the switch outputs the downshift signal. These switches may be installed at any place in the electric vehicle **100** as long as the driver can operate the switch from the driver's seat.

[0034] As still another example, the relative direction type shift device **24** may be a touch panel type device. That is, a screen for selecting upshift or downshift may be displayed on a touch panel.

[0035] Operation of the relative direction type shift device **24** performed by the driver as exemplified above is discrete operation, and the relative direction type shift device **24** (shift switch **14**) discretely outputs a signal indicating upshift or downshift each time the operation is performed by the driver.

[0036] Reference is made again to FIG. **1**. A dummy clutch operation device **25** is a device for reproducing clutch operation in the transmission vehicle. An example of the dummy clutch operation device **25** is a dummy clutch pedal, which simulates a clutch pedal of the transmission vehicle. The dummy clutch pedal is a dummy different from an original clutch pedal. The dummy clutch pedal has a structure similar to the clutch pedal installed in the conventional transmission vehicle. For example, the dummy clutch pedal includes a reaction force mechanism, which generates reaction force against depression by the driver. A position of the dummy clutch pedal when no pressing force is applied is a start position of the dummy clutch pedal, and a position of the dummy clutch pedal when the dummy clutch pedal is fully depressed is an end position of the dummy clutch pedal. The driver can operate the dummy clutch pedal from the start position to the end position against the reaction force from the reaction force mechanism.

[0037] Alternatively, the dummy clutch operation device **25** may be a lever type operation device or a dial type operation device which is operated by a hand. The driver can also operate the dummy clutch operation device **25** which is lever type or dial type against the reaction force from the start position to the end position and can feel the operation feeling as if operating the clutch pedal installed in the conventional transmission vehicle.

[0038] A clutch sensor **15** is installed in the dummy clutch operation device **25**. The clutch sensor **15** outputs a signal indicating an operation amount of the dummy clutch operation device **25**. Operation of the dummy clutch operation device **25** by the driver is continuous operation, and the signal indicating the operation amount is continuously transmitted to the control device **101** while the electric vehicle **100** is traveling or stopped. When the dummy clutch operation device **25** is the dummy clutch pedal, a depression amount of the pedal is acquired as the operation amount of the dummy clutch operation device **25**. However, since the electric vehicle **100** does not include an actual clutch, the operation amount of the dummy clutch operation device **25**, that is, the colutch operation amount is a virtual clutch operation amount.

[0039] The electric vehicle **100** includes a human-machine interface (HMI) **20** as an interface with a driver, an in-vehicle speaker **21**, and a display device **26**. The HMI **20** includes a touch panel display. The HMI **20** displays information on the touch panel display and receives input by touch operation on the touch panel display by the driver. The in-vehicle speaker **21** provides information to the driver by voice and can output virtual engine sound described below. The display device **26** can display a virtual rotational speed of a virtual engine (hereinafter referred to as a virtual engine speed) described later.

[0040] The electric vehicle **100** includes the control device **101**. Sensors and devices to be controlled which are mounted on the electric vehicle **100** are connected to the control device **101** via an in-vehicle network. Various sensors in addition to the vehicle speed sensor **11**, the accelerator pedal stroke sensor **12**, the brake pedal stroke sensor **13**, the shift switch **14**, and the clutch sensor **15** are mounted on the electric vehicle **100**.

[0041] The control device **101** is typically an electronic control unit (ECU). The control device **101** may be a combination of a plurality of ECUs. The control device **101** includes at least a processor **102** and a memory **103**. The memory **103** includes a RAM which temporarily stores data, and a ROM which stores a program **104** executable by the processor **102** and various data **105** related to the program. The program **104** is composed of a plurality of instructions. The processor **102** reads the program **104** and the data **105** from the memory **103** and executes the program and the data to generate a control signal based on a signal acquired from each sensor. The number of processors **102** included in the control device **101** may be one or may be plural.

[0042] The control device **101** can control the electric vehicle **100** in various control modes. The driver can select the control mode by touching and operating the touch panel display of the HMI **20**. Specifically, when touch operation on the touch panel display of the HMI **20** is performed, one or more programs **104** associated with each touch operation are read from the memory **103** and executed by the processor **102**. Hereinafter, the control mode of the electric vehicle **100** by the control device **101**, which can be selected by the driver by operating the HMI **20**, will be described.

3. Control Mode of Electric Vehicle

[0043] The control modes of the electric vehicle **100** selectable by the control device **101** include at least an EV mode and an MT mode. The driver can select the control mode from a selection menu displayed on the touch panel display of the HMI **20**.

[0044] If the EV mode is selected, the control mode of the electric vehicle **100** is switched to the EV mode. The EV mode is a mode in which the vehicle travels by controlling the electric motor with normal torque characteristics. In the EV mode, the gear shift operation of the relative direction type shift device **24** and the clutch operation of the dummy clutch operation device **25** are invalidated. In the EV mode, the driver can basically drive the electric vehicle **100** only by operating the accelerator pedal **22**, the brake pedal **23**, and the steering wheel **27**.

[0045] If the MT mode is selected, the control mode of the electric vehicle **100** is switched to the MT mode. The MT mode is a control mode for operating the electric vehicle **100** like the transmission vehicle. In the MT mode, operation of the relative direction type shift device **24** and the dummy clutch operation device **25** is enabled, and the operation when a manual transmission type gear ratio is switched is reproduced by the gear shift operation of the relative direction type shift device **24**.

[0046] The driver may be able to select options regarding engine characteristics, engine sound, drive mode, suspension characteristics, the number of shift positions, and the like. By appropriately combining these options, the driver can determine the characteristics of the transmission vehicle that the driver wants the electric vehicle **100** to simulate. In this way, the control mode of the electric vehicle **100** can be switched to the driver's preference by operating the touch panel display of the HMI **20**.

[0047] The electric vehicle **100** may include a mode change switch for switching between the EV mode and the MT mode. The driver may be able to switch between the EV mode and the MT mode

by pressing the mode change switch instead of operating a display screen of the touch panel display.

[0048] Such a control mode switched by the driver is related to travel control of the electric vehicle **100**. In the next chapter, the travel control of the electric vehicle **100** by the control device **101** will be described.

4. Travel Control of Electric Vehicle

[0049] FIG. **6** is a diagram showing a configuration of the control device **101** related to the travel control of the electric vehicle **100**. More specifically, FIG. **6** shows a configuration particularly related to torque control in the travel control. The processor **102** functions as a travel control device by the processor **102** executing one or more programs **104** for the travel control stored in the memory **103**.

[0050] A control mode signal is input from the HMI **20** to the control device **101** as a travel control device. The control mode signal includes information on the control mode selected by the driver. The control device **101** executes a process P**110** based on the control mode signal. In the process P**110**, the control mode is switched according to the control mode signal. Switching the control mode between the EV mode and the MT mode particularly affects the travel control in the switching of the control mode.

[0051] If the control mode is switched to the EV mode, the control device **101** executes a process P**120** for calculating the torque in the EV mode. In the process P**120**, the control device **101** acquires the vehicle speed from the signal of the vehicle speed sensor **11** and acquires the accelerator position from the signal of the accelerator pedal stroke sensor **12**. The control device **101** has a motor torque map with the accelerator position and the vehicle speed as parameters. The control device **101** inputs the vehicle speed and the accelerator position to the motor torque map and controls the inverters **3**F and **3**R such that the electric motors **4**F and **4**R generate the torque obtained from the motor torque map.

[0052] If the control mode is switched to the MT mode, the control device **101** executes a process P**130** for calculaing the torque in the MT mode. The process P**130** includes a process P**131** for calculating torque to be generated at the drive wheel. The process P**130** also includes a process P**132** and a process P**133**. The process P**132** is a process for calculating torque to be generated in the front electric motor **4**F, and the process P**133** is a process for calculating torque to be generated in the rear electric motor **4**R. The process P**130** and the process P**133** are executed according to the driving wheel torque calculated in the process P**130** and torque distribution between the front wheels **6**F and the rear wheels **6**R.

[0053] The vehicle model MOD**01** is used for calculating the drive wheel torque in the process P**130**. The vehicle model MOD**01** includes an engine model MOD**11**, a clutch model MOD**12**, and a transmission model MOD**13**. An engine, a clutch, and a transmission virtually realized by the vehicle model MOD**01** are referred to as a virtual engine, a virtual clutch, and a virtual transmission, respectively. In the engine model MOD**11**, the virtual engine is modeled. In the clutch model MOD**12**, the virtual clutch is modeled. In the transmission model MOD**13**, the virtual transmission is modeled.

[0054] The engine model MOD**11** calculates the virtual engine speed and virtual engine torque. The virtual engine speed is calculated from the vehicle speed, a total reduction ratio, and a slip ratio of the virtual clutch. The virtual engine torque is calculated from the virtual engine speed and the accelerator position. The vehicle speed is acquired from the signal of the vehicle speed sensor **11**. The accelerator position is acquired from the signal of the accelerator pedal stroke sensor **12**. The total reduction ratio is a value obtained by multiplying the gear ratio of the virtual transmission by a reduction ratio determined by a mechanical structure from the virtual transmission to the drive wheels. In the engine model MOD**11**, the relationship between the virtual engine speed and the virtual engine torque is defined for each accelerator position. The engine characteristics of the engine model MOD**11** may be selected by the driver operating the HMI **20**.

[0055] The clutch model MOD**12** calculates a torque transmission gain. The torque transmission gain is a gain for calculating a degree of torque transmission of the virtual clutch according to the clutch operation amount. The clutch operation amount is acquired from the signal of the clutch sensor **15**. If the dummy clutch operation device **25** is the dummy clutch pedal, the clutch operation amount is **0**% at the start position of the dummy clutch pedal **25** and is 100% at the end position of the dummy clutch pedal **25**. In the clutch model MOD**12**, the torque transmission gain is given according to the clutch operation amount. The torque transmission gain is converted into a clutch torque capacity of the virtual clutch, that is, the virtual clutch torque capacity. Then, the virtual clutch torque input from the virtual clutch to the virtual transmission is calculated based on a comparison between the virtual clutch torque capacity and the virtual engine torque calculated in the engine model MOD**11**. In the clutch model MOD**12**, a value obtained by subtracting the torque transmission gain from 1 is calculated as a slip ratio. The slip ratio is used to calculate the virtual engine speed in the engine model MOD**11**.

[0056] The transmission model MOD**13** calculates a virtual gear ratio. The virtual gear ratio is a gear ratio determined by the virtual shift position in the virtual transmission. The virtual gear ratio is set for each shift position. The maximum virtual gear ratio is set for the first position, and the virtual gear ratio is reduced in the order of the second position, the third position, the fourth position, and so on. The shift position is shifted up by one stage in response to the upshift signal from the shift switch **14**, and the shift position is shifted down by one stage in response to the downshift signal from the shift switch **14**. At this time, the control device **101** accepts input from the shift switch **14** only when the operation amount of the dummy clutch operation device **25**, that is, the clutch operation amount, is equal to or larger than a predetermined amount. If the clutch operation amount is less than the predetermined amount, the input from the shift switch **14** is invalidated and even if the relative direction type shift device **24** is operated, up-shifting or down-shifting is not performed.

[0057] There is no physical limitation on the number of the shift positions directed by the relative direction type shift device **24**. Therefore, the number of the shift positions may be variable, and a different transmission model MOD**13** may be used according to the number of shift positions.

[0058] The transmission model MOD**13** calculates a virtual transmission torque using the virtual gear ratio and the virtual clutch torque. The virtual transmission torque is virtual torque output from the virtual transmission. The control device **101** controls the inverters **3**F and **3**R so as to change the torque output from the electric motors **4**F and **4**R in accordance with the virtual transmission torque. The virtual transmission torque changes discontinuously in accordance with the switching of the virtual gear ratio. This discontinuous change in the virtual transmission torque causes a torque shock in the electric vehicle **100**, and the electric vehicle **100** is made to look like a vehicle having a stepped transmission.

[0059] The vehicle model MOD**01** calculates the drive wheel torque from the virtual transmission torque and the reduction ratio. The drive wheel torque is a total amount of torque applied to the right and left front wheels **6**F and the right and left rear wheels **6**R. The torque distribution to the front wheels **6**F and the rear wheels **6**R can be fixed or can be changed actively or passively. For example, the driver may be able to select a four wheel drive mode, in which the four wheels are driven, or a rear-wheel drive mode, in which only the rear wheels are driven.

[0060] In the process P**132**, the torque of the front electric motor **4**F (front motor torque) in the MT mode is calculated by multiplying the drive wheel torque calculated in the process P**131** by the torque distribution ratio to the front wheel **6**F and the reduction ratio from an output-shaft of the front electric motor **4**F to the front wheels **6**F. The control device **101** controls the front inverter **3**F such that the front electric motor **4**F generates the front motor torque calculated in the process P**132**.

[0061] In the process P**133**, the torque of the rear electric motor **4**R (rear motor torque) in the MT mode is calculated by multiplying the drive wheel torque calculated in the process P**131** by the

torque distribution ratio to the rear wheels **6R** and the reduction ratio from an output shaft of the rear electric motor **4R** to the rear wheels **6R**. The control device **101** controls the rear inverter **3R** such that the rear electric motor **4R** generates the rear motor torque calculated in the process P**133**.

[0062] The vehicle model MOD**01** is predetermined and stored in the memory **103**. Considering the motor torque of the electric motors **4F** and **4R** calculated in the process P**130** by the vehicle model MOD**01**, when the clutch operation amount is **0**%, the motor torque with respect to the vehicle speed and the accelerator position under a certain virtual shift position is constant. Hereinafter, the motor torque determined by the virtual shift position, the vehicle speed, and the accelerator position is referred to as base torque of the electric motors **4F** and **4R**. As the clutch operation amount increases, the motor torque is reduced from the base torque, and the mortor torque is set to zero when the clutch operation amount exceeds a predetermined operation amount. When the virtual shift position is switched, the relationship of the base torque with the vehicle speed and the accelerator position is switched accordingly.

5. Sound Control of Electric Vehicle

[0063] The control device **101** may also perform sound control for controlling the sound emitted by the in-vehicle speaker **21**. The processor **102** functions as a sound control device by the processor **102** executing one or more programs **104** for the sound control stored in the memory **103**. The processor **102** which functions as the torque control device and the processor **102** which functions as the sound control device may be separate processors or the same processor.

[0064] The control device **101** as the sound control device can generate artificially generated sound from the in-vehicle speaker **21**. One kind of the artificial sound is virtual engine sound simulating engine sound in a conventional internal combustion engine vehicle. When the control mode signal indicating that the MT mode is selected is input from the HMI **20**, the control device **101** as the sound control device generates the virtual engine sound based on the virtual engine torque and the virtual engine speed calculated in the process P**131**.

[0065] If the driver can select the engine sound, the engine sound selected in the HMI **20** is used as a sound source of the virtual engine sound generated from the in-vehicle speaker **21**. However, the sound of the sound source is not used as it is. A sound pressure of the engine sound is calculated such that the sound pressure increases as the virtual engine torque increases, and a frequency of the engine sound is calculated such that the frequency increases as the virtual engine speed increases. Then, for example, the sound pressure of the sound source is changed by an amplifier, and the frequency of the sound source is changed by a frequency modulator, and the virtual engine sound is reproduced from the in-vehicle speaker **21**. The virtual engine torque and the virtual engine speed change according to the accelerator operation, the gear shift operation, and the clutch operation by the driver. By changing the sound pressure and the frequency of the virtual engine sound in accordance with the virtual engine torque and the virtual engine speed, which change in accordance with the operation by the driver, the driver can be given a sense of reality as if he or she were driving a real transmission vehicle.

6. Other Embodiments of Dummy Clutch Operation Device

[0066] The dummy clutch operation device **25** may be a device for switching ON/OFF of the clutch. For example, the dummy clutch operation device **25** may be a switch, and the clutch may be turned off (the clutch operation amount is 100%) by turning on the switch, and the clutch may be turned on (the clutch operation amount is 0%) by turning off the switch. Alternatively, even in a case where the dummy clutch operation device **25** is a pedal type operation device operated by a foot, the dummy clutch operation device **25** may not necessarily be a device for inputting a continuous operation amount, and the clutch may be turned off when the driver steps on the pedal and the clutch may be turned on when the driver releases the foot from the pedal. In this case, operation input by the driver to the dummy clutch operation device **25** is discrete operation, and the clutch sensor **15** discretely outputs a signal indicating ON or OFF of the clutch every time the operation by the driver is performed.

[0067] In a case where the dummy clutch operation device **25** is such device for switching the clutch between ON and OFF, the torque transmission gain input to the vehicle model MOD**12** shown in FIG. **6** is 1 when the clutch is ON, and is 0 when the clutch is OFF. The control device **101** accepts input from the relative direction type shift device **24** when the clutch is ON, and invalidates the input when the clutch is OFF.

7. Gear Shift Operation Using Relative Direction Type Shift Device and Dummy Clutch Operation Device

[0068] As described above, the driver of the electric vehicle **100** can experience the operation of the transmission vehicle in the electric vehicle **100** by operating the HMI **20** to switch the control mode to the MT mode. As one kind of operation simulating the transmission vehicle, in the MT mode, the driver can manually perform the virtual gear shift operation (shift change) to switch the virtual shift position.

[0069] The gear shift operation in the electric vehicle **100** is performed by the relative direction type shift device **24**. Further, the driver needs to perform the clutch operation of the dummy clutch operation device **25** by himself/herself in addition to the gear shift operation by the relative direction type shift device **24**. Since the driver performs the clutch operation by himself/herself using the dummy clutch operation device **25**, and thus the operation feeling becomes closer to that of the actual transmission vehicle, it is pleasant for the driver who wants to enjoy driving as of the transmission vehicle.

[0070] Further, since the dummy clutch operation device **25** is installed, the dummy clutch operation device **25** can be used for operation other than the gear shift operation. For example, the driver can generate a virtual neutral state by operating the dummy clutch operation device **25**. Thus, a behavior closer to a behavior of the transmission vehicle can be reproduced, and the driver can get more options of how to enjoy driving.

[0071] The following effects are obtained by performing the gear shift operation by the relative direction type shift device **24**. For comparison, a case where a device used for gear shift operation is a device simulating an H-type shifter of the transmission vehicle is considered. In the H-type shifter, the shift position is absolutely designated by a position of a lever. However, since the driver cannot operate the shift lever while looking at the driver's hand during driving, the driver may erroneously shift the shift lever to a wrong shift position. In contrast, in the case of the relative direction type shift device **24**, the virtual shift position is changed one stage at a time by the operation of the driver. Since the shift position is changed stepwise and one stage at a time, the shift position several stages higher or lower is not selected by mistake. Therefore, the driver can easily perform the gear shiht operation.

[0072] The relative direction type shift device **24** is more effective when provided at the steering wheel **27** or the steering column. The driver holds the steering wheel **27** while driving the electric vehicle **100**, so when the relative direction type shift device **24** is provided at the steering wheel **27** or the steering column, the driver can operate the relative direction type shift device **24** without taking one hand off the steering wheel **27**. Therefore, a force for holding the steering wheel can be stabilized, and thus stable traveling is enabled. Further, since the time for releasing the hand from the steering wheel **27** is not required, the gear shift operation can be performed quickly.

[0073] Further, it is more effective that the relative direction type shift device **24** installed at the steering wheel is a device in which a paddle or a button corresponding to upshift and a paddle or a button corresponding to downshift are provided separately on the right side and the left side as in the examples shown in FIG. **2***a*, **2***b* or **3**. In this case, it is easy for the driver to understand which one of the paddles or the buttons corresponds to the upshift and which one of the paddles or the buttons corresponds to the downshift without looking at his/her hand, and thus it is possible to suppress erroneous operation by the driver.

8. Control of Virtual Engine Speed

[0074] The control device **101** accepts the gear shift operation input to the relative direction type

shift device **24** when a condition that an operation amount equal to or larger than a predetermined amount is input to the dummy clutch operation device **25** is satisfied. Other conditions may be set in order for the control device **101** to accept the gear shift operation. Here, a case where a condition related to the virtual engine speed is set is described.

[0075] Specifically, an appropriate range is set in advance for the virtual engine speed. When the driver performs the gear shift operation, the control device **101** predicts the virtual engine speed assuming that the virtual shift position is switched in response to the gear shift operation. Then, if it is predicted that the virtual engine speed after the shift position is changed is out of the appropriate range, the control device **101** does not accept the gear shift operation. The virtual engine speed after the shift positon is changed can be predicted from the current speed based on the vehicle model MOD**01**. An upper limit of the range of the appropriate engine speed is set to be a lower limit of the engine speed at which over-revolution occurs, and a lower limit of the range of the appropriate engine speed is set to be an upper limit of the engine speed at which under-revolution occurs. Although the electric vehicle **100** does not actually have an engine, in which the over-revolution or the under-revolution occurs, the upper limit and the lower limit of the engine speed are set based on the engine characteristics of the simulated transmission vehicle. If the driver can select the engine characteristics using the HMI **20**, the upper limit and the lower limit of the engine speed may be set for each engine characteristic. In this way, by preventing the virtual engine from being in the over-revolution or under-revlotuion, the behavior of the electric vehicle **100** can be made closer to that of the transmission vehicle, and the driver's satisfaction can be increased.

[0076] The control device **101** may have a function corresponding to an automatic blipping function of the transmission vehicle. That is, if the downshift is performed, the virtual engine speed may be automatically increased in accordance with the vehicle speed. Thus, the virtual engine speed can be naturally changed, and the behavior of the electric vehicle **100** can be made closer to that of the transmission vehicle.

9. Time Chart

9-1. Example of Time Chart of Upshift

[0077] FIG. **7** is a time chart showing an example of a case where the upshift is performed. Here, an example in a case where the relative direction type shift device **24** is the dummy paddle shifter and the dummy clutch operation device **25** is the dummy clutch pedal is described. However, the same can be applied to a case where the relative direction type shift device **24** is other device and the dummy clutch operation device **25** is other device. In addition, here, the threshold value of the clutch operation amount for accepting the input from the relative direction type shift device **24** is set to 70%. However, the threshold value of the clutch operation amount is not limited to 70% and can be arbitrarily set.

[0078] At time T**0** when the time chart starts, the shift position is set to the N stage. At time T**1**, the driver operates the paddle on the upshift side of the relative direction type shift device **24**. However, at this time, the operation amount is not input to the dummy clutch pedal, and the clutch operation amount is **0**%. Therefore, the control device **101** does not accept the upshift direction from the shift switch **14**, and the virtual shift position is not changed.

[0079] At time T**2**, the driver depresses the dummy clutch pedal, and the clutch operation amount becomes 100%. Since the clutch operation amount exceeding the threshold value is input, the control device **101** is brought into a state where the control device **101** can accept the input from the relative direction type shift device **24**. In this state, the driver operates the paddle on the upshift side at time T**3**. Then, the control device **101** accepts the upshift signal input from the shift switch **14**, and the upshift is performed.

[0080] Thereafter, the driver re-depresses the dummy clutch pedal, and at time T**4**, the paddle on the upshift side of the relative direction type shift device **24** is operated again in a state in which the clutch operation amount is 100%. Since the operation amount larger than the threshold value, the control device **101** receives the upshift signal, and the virtual shift position is shifted up by one

stage, as at the time T**3**.

[0081] In the example of FIG. **7**, the input of the upshift signal is accpeted and the virtual shift position is switched at the time when the switch is pressed, not at the time when the switch that has been pressed once returns. In this way, by setting the timing of switching the virtual shift position to the time point at which the switch is pressed, it is possible to reduce the sense of discomfort for the driver and to make the operation easy.

9-2. Example of Time Chart of Downshift

[0082] FIG. **8** is a time chart showing an example of downshift. Similarly to FIG. **7**, an example in a case where the relative direction type shift device **24** is the dummy paddle shifter, the dummy clutch operation device **25** is the dummy clutch pedal, and the threshold value of the clutch operation amount for receiving the input from the relative direction type shift device **24** is 70% is described. The operation at the time of downshift is basically the same as that at the time of upshift.

[0083] At time T**0** when the time chart starts, the shift position is set to the N+3th position. At time T**1**, the driver operates the paddle on the downshift side of the relative direction type shift device **24**. However, at this time, the operation amount is not input to the dummy clutch pedal. Therefore, the control device **101** does not accpet the downshift direction from the shift switch **14**, and the virtual shift position is not changed.

[0084] At time T**2**, the driver depresses the dummy clutch pedal, and the clutch operation amount becomes 100%. Since the clutch operation amount exceeding the threshold value is input, the control device **101** is brought into a state where the control device **101** can accept the input from the relative direction type shift device **24**. In this state, the driver operates the paddles on the downshift side at time T**3**. Then, the control device **101** accpets the downshift signal input from the shift switch **14**, and the virtual shift position is shifted down by one stage. The reason why the virtual engine speed temporarily increases after the time T**3** is that the automatic blipping function is activated. This is the control described in chapter 8.

[0085] At time T**4**, the paddle on the downshift side of the relative direction type shift device **24** is operated again while the driver continues to depress the dummy clutch pedal. Since the operation amount larger than the threshold value is input to the dummy clutch pedal, the control device **101** accpets the downshift signal, and the virtual shift position is further shifted down by one stage. In addition, the automatic blipping function is activated, and the virtual engine speed temporarily increases after the downshift. The virtual engine speed changes in the same manner when the driver depresses the accelerator pedal **22**. That is, when the accelerator pedal **22** is depressed in a state where the clutch operation amount is 100%, the virtual engine speed displayed on the display device **26** increases.

[0086] As in the example of FIG. **8**, the control device **101** may permit multiple shift change while the driver is depressing the dummy clutch pedal. That is, when the operation of the relative direction type shift device **24** is performed a plurality of times in a state where the dummy clutch pedal is continuously depressed, all of the plurality of times of operation may be accepted, and the virtual shift position may be shifted down by a plurality of stages. Therefore, the need for the driver to re-depress the dummy clutch pedal is eliminated, and thus quick gear shift operation is enabled.

[0087] At time T**5**, the paddle on the downshift side is operated again in a state where the dummy clutch pedal is depressed. At this time, the condition for accepting the shift change is satisfied with respect to the operation amount of the dummy clutch operation device **25**. However, the control device **101** does not accept the gear shift operation because the virtual engine speed does not satisfy the predetermined condition. Specifically, the virtual engine speed assuming that the shift change is accepted exceeds the upper limit of the appropriate range set in advance, and therefore, the shift change direction is not accepted. This is an example of the condition regarding the virtual engine speed described in Chapter **8**.

Claims

1. An electric vehicle having an electric motor as a drive source, comprising: a control device configured to control the electric motor; a first indicator that gives a continuous direction to the control device in accordance with a first operation amount of the first indicator; a second indicator that gives a relative direction to the control device for each operation of the second indicator; and a third indicator that gives a continuous or discrete direction to the control device in accordance with a third operation amount of the third indicator, wherein the control device is configured to execute: switching a relationship among base torque, the first operation amount, and a vehicle speed of the electric vehicle, in a plurality of predetermined relationships in accordance with operation of the second indicator, the base torque being torque of the electric motor in a state where the third indicator is not operated; decreasing the torque of the electric motor from the base torque in response to a direction from the third indicator; and accepting input from the second indicator only when the third operation amount is larger than a predetermined amount.

2. The electric vehicle according to claim 1, wherein the second indicator is installed at a steering wheel or a steering column of the electric vehicle.

3. The electric vehicle according to claim 2, wherein the second indicator is a dummy paddle shifter that simulates a paddle shifter of a manual transmission.

4. The electric vehicle according to claim 1, wherein the electric vehicle further comprises a vehicle speed sensor configured to measure the vehicle speed, the control device comprises a storage device configured to store a range of an appropriate vehicle speed determined for each of the plurality of predetermined relationships, and the control device is further configured to execute: determining whether the vehicle speed is within the range of the appropriate vehicle speed determined for a relationship among the base torque after switching, the first operation amount, and the vehicle speed when the second indicator and the third indicator are operated; and not accepting operation of the second indicator if the vehicle speed is not within the range of the appropriate vehicle speed determined for the relationship among the base torque after switching, the first operation amount, and the vehicle speed.

5. The electric vehicle according to claim 1 further comprising a display device configured to display a virtual engine speed, wherein the control device is further configured to associates the first operation amount with display of the virtual engine speed when the first indicator is operated in a state where the third operation amount is a maximum amount.

6. The electric vehicle according to claim 1, wherein the first indicator is an accelerator pedal.

7. The electric vehicle according to claim 6, wherein the plurality of predetermined relationships is determined in advance so as to reproduce a relationship between an operation amount of an accelerator pedal and engine torque in each of a plurality of gear ratios of a transmission vehicle.

8. The electric vehicle according to claim 1, wherein the control device is further configured to executes: switching between a first mode and a second mode in accordance with selection by a driver of the electric vehicle, the first mode being a mode in which operation of the second indicator and the third indicator are invalidated, the second mode being a mode in which operation of the second indicator and the third indicator are enabled; and selecting a relationship among the base torque, the first operation amount, and the vehicle speed from the plurality of predetermined relationships in accordance with the vehicle speed when the first mode is switched to the second mode.