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Control apparatus for vehicle

Abstract

A control apparatus for a vehicle includes an offset torque calculator configured to perform calculation of offset torque to be applied to at least one wheel of the vehicle. The offset torque is required to stop the vehicle on a sloping road having a predetermined gradient. The control apparatus includes a motor controller configured to, for stopping the vehicle on the sloping road having the predetermined gradient, perform control of causing output torque of the motor-generator to asymptotically approach the offset torque.

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Background/Summary

CROSS REFERENCE TO RELATED APPLICATION (1) The present application is a bypass continuation application of currently pending international application No. PCT/JP2021/008122 filed on Mar. 3, 2021 designating the United States of America, the entire disclosure of which is incorporated herein by reference, the internal application being based on and claiming the benefit of priority from Japanese Patent Application No. 2020-066556 filed on Apr. 2, 2020.

TECHNICAL FIELD
(1) The present disclosure relates to control apparatuses for a vehicle.
BACKGROUND
(2) One of such typical control apparatuses for a vehicle is configured to drive a motor-generator installed in the vehicle to thereby control how the vehicle travels.
SUMMARY
(3) An exemplary aspect of the present disclosure provides a control apparatus that includes a motor controller for a vehicle. The motor controller is configured to, for stopping the vehicle on a sloping road having a predetermined gradient, perform control of causing output torque of a motor-

generator to asymptotically approach offset torque, i.e., compensation torque, that is required to stop the vehicle on the sloping road.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) Other aspects of the present disclosure will become apparent from the following description of embodiments with reference to the accompanying drawings in which:

(2) FIG. **1** is a diagram illustrating a schematic configuration of a vehicle according to the first embodiment of the present disclosure;

(3) FIG. **2** is a block diagram illustrating an electrical configuration of the vehicle according to the first embodiment;

(4) FIG. **3** is a block diagram illustrating a configuration of an EV ECU according to the first embodiment;

(5) FIG. **4** is a diagram illustrating maps that are used for the EV ECU to calculate a value of a normal torque command T**10*** as a function of a current position of an accelerator pedal, a current shift position, a current value of a speed of a vehicle;

(6) FIG. **5**A is a diagram schematically illustrating a vehicle traveling on the surface of an uphill road;

(7) FIG. **5**B is a diagram schematically illustrating a vehicle traveling on the surface of a downhill road;

(8) FIG. **6** is a flowchart schematically illustrating a part of a learning routine of offset torque carried out by a stop controller according to the first embodiment;

(9) FIG. **7** is a flowchart schematically illustrating the remaining part of the learning routine of the offset torque carried out by the stop controller according to the first embodiment;

(10) FIG. **8** is a flowchart schematically illustrating a stop control routine carried out by the stop controller according to the first embodiment;

(11) FIGS. **9**A to **9**D are a joint timing chart schematically illustrating how (i) the speed of the vehicle, (ii) total output torque of motor-generators, (iii) first acceleration of the vehicle in a traveling direction of the vehicle, (iv) second acceleration of the vehicle, and (v) the offset torque change over time;

(12) FIGS. **10**A to **10**D are a joint timing chart schematically illustrating how (i) the speed of the vehicle, (ii) a stop-control mode, (iii) a final torque command, and (iv) braking force change over time;

(13) FIG. **11** is a block diagram illustrating a configuration of an EV ECU according to the second embodiment; and

(14) FIG. **12** is a diagram illustrating maps that are used for the stop controller according to a modification to calculate a value of a parameter as a function of a value of the speed of the vehicle and a value of the offset torque.

DETAILED DESCRIPTION OF EMBODIMENTS

(15) An example of control apparatuses for controlling a motor-generator installed in a vehicle is disclosed in Japanese Patent Application Publication No. 2020-22268. The vehicle disclosed in the above patent publication is an electric vehicle. The electric vehicle includes first and second motor-generators. Each of the first and second motor-generators generates power and transfers the generated power to a corresponding pair of wheels of the vehicle, thus causing the electric vehicle to travel. In the electric vehicle, braking devices are provided for the respective wheels. Each braking device is configured to brake the corresponding wheel in accordance with hydraulic pressure.

(16) The control apparatus disclosed in the patent publication controls operations of each of the

first and second motor-generators to thereby control how the electric vehicle travels. The control apparatus disclosed in the patent publication activates each braking device to thereby cause the corresponding braking device to apply braking force to the corresponding wheel, thus controlling how to brake the electric vehicle.
(17) Typical vehicles each have an adaptive cruise control (ACC) function of automatically controlling the speed of the corresponding vehicle to cause the corresponding vehicle to follow a preceding vehicle in front of the corresponding vehicle. These typical vehicles having the ACC function are required to smoothly stop as early as possible in response to stop of the preceding vehicle.
(18) Such an electric vehicle disclosed in the patent publication is configured such that each of the first and second motor-generators serves as a generator to recover energy in a regenerative mode to apply braking force, i.e., braking torque, to the corresponding pair of wheels. Braking of a vehicle's wheel using the energy recovering operation of a motor-generator can control the braking force, i.e., the braking torque, to be applied to the vehicle's wheel more closely than braking of a vehicle's wheel using hydraulic pressure by a braking device. Braking of a vehicle's wheel based on the energy recovering operation of a motor-generator also has a more advantage for reduction in electricity consumption than braking of a vehicle's wheel based on hydraulic pressure by a braking device.
(19) From this viewpoint, it is preferable to brake an electric vehicle, which is traveling based on the ACC function, using the motor-generator's braking force.
(20) It may be unfortunately difficult to brake, using the motor-generator's braking force, a vehicle that is traveling on a slope due to, as disturbance factors, the gradient of the slope and/or the weight of the vehicle. Specifically, excessively small amount of motor-generator's braking force may make it difficult to stop the vehicle on a slope, and an excessively large amount of motor-generator's braking force may stop the vehicle on a slope, but may impose a shock on one or more occupants of the vehicle at the stop of the vehicle, resulting in the one or more occupants having a feeling of discomfort.
(21) The above issue may be a common issue for not only vehicles with the ACC function but also various vehicles capable of stopping using motor-generator's braking force.
(22) From this viewpoint, the present disclosure seeks to provide control apparatuses for a vehicle, each of which is capable of stopping the vehicle on a slope more smoothly.
(23) An exemplary measure of the present disclosure is to provide a control apparatus for causing a motor-generator of a vehicle to apply drive power to at least one wheel of the vehicle, and operate, at a stop of the vehicle, in a regenerative mode to apply braking force to the at least one wheel of the vehicle. The control apparatus includes an offset torque calculator configured to perform calculation of offset torque to be applied to the at least one wheel of the vehicle. The offset torque is required to stop the vehicle on a sloping road having a predetermined gradient. The control apparatus includes a motor controller configured to, for stopping the vehicle on the sloping road having the predetermined gradient, perform control of causing output torque of the motor-generator to asymptotically approach the offset torque.
(24) The above configuration of the control apparatus according to the exemplary measure of the present disclosure causes the output torque of the motor-generator to gradually change toward the offset torque, making it possible to prevent the occurrence of shock at the stop of the vehicle.
(25) The above configuration of the control apparatus additionally causes the motor-generator to apply the offset torque to the at least one wheel at the stop of the vehicle on the sloping road having the predetermined gradient, making it possible to hold the vehicle in a stopped state on the sloping road having the predetermined gradient.
(26) This therefore enables the vehicle to stop on such a sloping road more smoothly.
(27) The following describes exemplary embodiments of the present disclosure with reference to the accompanying drawings. In the drawings, elements, which are structurally and/or functionally

identical to one another, are each assigned with a common reference character, and duplicated descriptions of the structurally and/or functionally identical elements among the exemplary embodiments are omitted for the sake of facilitating the understanding of the exemplary embodiments.

First Embodiment

(28) A vehicle **10** according to the first embodiment includes a right rear wheel **11**, a left rear wheel **12**, a right front wheel **13**, a left front wheel **14**, a steering apparatus **20**, in-wheel motors **30***a* and **30***b*, and braking devices **40***a* to **40***d*.

(29) The steering apparatus **20**, which is comprised of a steering wheel **21**, a steering shaft **22**, and a steering mechanism **23**, is configured to transfer, in response to application of steering torque to the steering wheel **21** based on driver's rotation of the steering wheel **21**, the steering torque to the steering mechanism **23** through the steering shaft **22**. The steering mechanism **23** is configured to change, based on the steering torque, a steering angle of each of the right front wheel **13** and the left front wheel **14**.

(30) In particular, the steering apparatus **20** includes a torque sensor **24** and an actuator **25**. The torque sensor **24** measures the steering torque applied to the steering wheel **21** based on driver's rotation of the steering wheel **21**. The actuator **25** is configured to create assist torque based on the steering torque measured by the torque sensor **24**, and apply, to the steering shaft **22**, the assist torque, thus assisting driver's rotation of the steering wheel **21**.

(31) The in-wheel motors **30***a* and **30***b* are installed in the respective right rear wheel **11** and left rear wheel **12**.

(32) Referring to FIG. **2**, the in-wheel motor **30***a* includes a motor-generator **31***a*, an inverter **32***a*, a motor-generator (MG) ECU **33***a*, a torque sensor **34***a*, and a rotation sensor **35***a*. Similarly, the in-wheel motor **30***b* includes a motor-generator **31***b*, an inverter **32***b*, an MG ECU **33***b*, a torque sensor **34***b*, and a rotation sensor **35***b*.

(33) The torque sensors **34***a* and **34***b* serve as torque measuring units.

(34) The inverter **32***a* is configured to convert direct-current (DC) power supplied from a battery installed in the vehicle **10** into three-phase alternating-current (AC) power, and supply the converted three-phase AC power to the motor-generator **31***a*.

(35) The motor-generator **31***a* serves as a motor to cause the vehicle **10** to travel. The motor-generator **31** serves as a motor to generate drive power based on the three-phase AC power supplied from the inverter **32***a*. The drive power supplied to the right rear wheel **11** rotates the right rear wheel **11**, thus causing the vehicle **10** to travel.

(36) The motor-generator **31***a* also serves as a power generator when the vehicle **10** is braked. The motor-generator **31** serves as a power generator to operate in a regenerative mode to (i) generate regenerative three-phase AC power, and (ii) apply braking force, i.e., braking torque, to the right rear wheel **11**. The regenerative three-phase AC power is converted by the inverter **32***a* to DC power, and the DC power is charged in the battery of the vehicle **10**.

(37) The MG ECU **33***a* includes a microcomputer as its essential component; the microcomputer is comprised of at least one CPU and at least one memory. The at least one CPU of the MG ECU **33***a* runs program instructions stored in the at least one memory to thereby controllably drive the inverter **32***a*, thus controlling how the motor-generator **31***a* is energized.

(38) The torque sensor **34***a* is configured to measure output torque of the motor-generator **31***a*, and output, to the MG ECU **33***a*, a torque-based signal that correlates to the measured output torque. The rotation sensor **35***a* is configured to measure a rotational speed of the output shaft of the motor-generator **31***a*, and output, to the MG ECU **33***a*, a speed-based signal that correlates to the measured rotational speed.

(39) The MG ECU **33***a* is configured to obtain, based on the torque-based and speed-based signals, information about the output torque and the rotational speed of the motor-generator **31***a*.

(40) Because the configuration and operations of each of the motor-generator **31***b*, inverter **32***b*,

MG ECU **33***b*, torque sensor **34***b*, and rotation sensor **35***b* are substantially identical to those of the corresponding one of the motor-generator **31***a*, inverter **32***a*, MG ECU **33***a*, torque sensor **34***a*, and rotation sensor **35***a*, detailed descriptions of the configuration and operations of each of the motor-generator **31***b*, inverter **32***b*, MG ECU **33***b*, torque sensor **34***b*, and rotation sensor **35***b* are omitted.
(41) Referring to FIG. **1**, the braking devices **40***a* to **40***d* are mounted to the respective wheels **11** to **14**. Each of the braking devices **40***a* to **40***d* is configured to apply braking force to the corresponding one of the wheels **11** to **14** in accordance with hydraulic pressure supplied from a hydraulic circuit installed in the vehicle **10**, thus braking the vehicle **10**. As each braking device **40***a* to **40***d*, a friction braking device can be used, which applies friction force to a rotating member of the corresponding wheel **11** to **14**.
(42) The right rear wheel **11** and left rear wheel **12** respectively serve as driving wheels of the vehicle **10**, and the right front wheel **13** and left front wheel **14** respectively serve as driven wheels of the vehicle **10**.
(43) Next, the following describes an electrical configuration of the vehicle **10** with reference to FIG. **2**.
(44) Referring to FIG. **2**, the vehicle **10** includes an accelerator position sensor **60**, a shift position sensor **61**, an acceleration sensor **62**, a vehicle speed sensor **63**, a preceding-vehicle detection sensor **64**, an operation unit **65**, and a brake position sensor **66**. The vehicle **10** includes an electric-vehicle (EV) ECU **70**, an adaptive cruise control (ACC) ECU **71**, and a brake ECU **72**; these ECUs serve to perform various control tasks of the vehicle **10**. The acceleration sensor **62** of the first embodiment serves as a second acceleration determiner, and various components illustrated in FIG. **2** constitute a control apparatus **80**.
(45) The accelerator position sensor **60** is configured to measure a current position of an accelerator pedal of the vehicle **10** operable by a driver and output, to the EV ECU **70**, a measurement signal indicative of the measured position of the accelerator pedal.
(46) The shift position sensor **61** is configured to measure a current position of a shift lever of the vehicle **10** operable by a driver and output, to the EV ECU **70**, a measurement signal indicative of the measured position of the shift lever. The changeable position of the shift lever selects one of drive ranges of the vehicle **10**, which include, for example, Drive range and Reverse range, and other drive ranges.
(47) The acceleration sensor **62** is configured to measure an acceleration of the vehicle **10** in a traveling direction thereof, and output, to the EV ECU **70**, a measurement signal indicative of the measured acceleration of the vehicle **10**. The acceleration sensor **62** measures a positive value of the acceleration of the vehicle **10** when the vehicle **10** is accelerating in the forward direction, and measures a negative value of the acceleration of the vehicle **10** when the vehicle **10** is decelerating in the forward direction.
(48) The vehicle speed sensor **63** is configured to measure a speed of the vehicle **10** in the traveling direction, and output, to the EV ECU **70** and ACC ECU **71**, a measurement signal indicative of the measured speed of the vehicle **10**.
(49) The preceding-vehicle detection sensor **64** is configured to detect a preceding vehicle traveling in front of the vehicle **10**, and output, to the ACC ECU **71**, information indicative of the detected preceding vehicle. An image capturing device and/or a millimeter-wave radar device can be used as the preceding-vehicle detection sensor **63**. The image capturing device captures images of a forwarding region of the vehicle **10**, and analyzes the captured images to thereby detect a preceding vehicle traveling in front of the vehicle **10**. The millimeter-wave radar device is configured to emit millimeter radio waves, and analyze echoes resulting from the emitted millimeter radio waves to thereby detect a preceding vehicle traveling in front of the vehicle **10**.
(50) The operation unit **65** is a device which a driver operates to input various information items to the ACC ECU **71**. The information items include an information item indicative of enabling/disabling an ACC function that automatically controls the speed of the vehicle **10** to cause

the vehicle **10** to follow the preceding vehicle. The information items include an information item indicative of a constant speed of the vehicle **10** when the ACC function is enabled. The operation unit **65** is configured to output, to the ACC ECU **71**, information items inputted by driver's operation of the operation unit **65**.

(51) The brake position sensor **66** is configured to measure a current position of a brake pedal of the vehicle **10** operable by a driver and output, to the brake ECU **72**, a measurement signal indicative of the measured position of the brake pedal.

(52) Each of the ECUs **70** to **72** includes a microcomputer as its essential component; the microcomputer is comprised of at least one CPU and at least one memory. Each of the ECUs **70** to **72** is configured to transmit, through an in-vehicle network, such as a CAN network, various information items to external devices, and receive, from external devices, various information items through the in-vehicle network.

(53) The ACC ECU **71**, i.e., its CPU, runs program instructions stored in its memory to thereby perform an ACC task. Specifically, the ACC ECU **71** is programmed to perform the ACC task in response to receiving of the information item indicative of enabling the ACC function from the operation unit **65**.

(54) For example, when the ACC function is enabled, the ACC ECU **71** sets an ACC flag Fa to on, and transmits the ACC flag Fa to the EV ECU **70**. Otherwise, when the ACC function is disabled, the ACC ECU **71** sets the ACC flag Fa to off, and transmits the ACC flag Fa to the EV ECU **70**. This enables the EV ECU **70** to determine whether the ACC function is enabled or disabled in accordance with the on state or off state of the ACC flag Fa.

(55) The ACC ECU **71** transmits, to the EV ECU **70**, a first ACC torque command T**21*** together with the ACC flag Fa upon determination that no preceding vehicles are detected by the preceding-vehicle detection sensor **64** while the ACC function is enabled. The first ACC torque command T**21*** represents a target value for first total torque that should be outputted by each of the motor-generator **31***a* and **31***b* of the in-wheel motors **30***a* and **30***b* in order to cause the vehicle **10** to travel at the constant speed set through the operation unit **65**.

(56) The EV ECU **70** is configured to control, based on the first ACC torque command T**21***, each of the motor-generators **31***a* and **31***b* of the in-wheel motors **30***a* and **30***b* to thereby cause the vehicle **10** to travel at the constant speed set through the operation unit **65**.

(57) When a preceding vehicle traveling in front of the vehicle **10** is detected by the preceding-vehicle detection sensor **71** while the ACC function is enabled, the ACC ECU **71** calculates, based on the information indicative of the preceding vehicle outputted from the preceding-vehicle detection sensor **64**, a relative speed and a relative distance of the preceding vehicle relative to the vehicle **10**. Then, the ACC ECU **71** calculates, based on the relative speed and relative distance of the preceding vehicle relative to the vehicle **10**, a second ACC torque command T**22***, and transmits, to the EV ECU **70**, the second ACC torque command T**22*** together with the ACC flag Fa.

(58) The second ACC torque command T**22*** represents a target value for second total torque that should be outputted by each of the motor-generator **31***a* and **31***b* of the in-wheel motors **30***a* and **30***b* in order to maintain the relative distance of the preceding vehicle relative to the vehicle **10** at a predetermined distance. The second ACC torque command T**22*** is set to a positive value in case of acceleration of the vehicle **10**, or a negative value in case of deceleration of the vehicle **10**.

(59) The EV ECU **70** is configured to control, based on the second ACC torque command T**22***, each of the motor-generators **31***a* and **31***b* of the in-wheel motors **30***a* and **30***b* to thereby cause the vehicle **10** to follow the preceding vehicle while maintaining a predetermined following distance between the preceding vehicle and the vehicle **10**.

(60) As described above, the ACC ECU **71** is configured to transmit, to the EV ECU **70**, the first ACC torque command T**21*** or the second ACC torque command T**22*** together with the ACC flag Fa set to the on state when the ACC function is enabled.

(61) In contrast, the ACC ECU **71** is configured to transmit, to the EV ECU **70**, the ACC flag Fa set to the off state when the ACC function is disabled.
(62) The EV ECU **70**, i.e., its CPU, runs program instructions stored in its memory to thereby perform overall control of the traveling condition of the vehicle **10**. Specifically, the EV ECU **70** includes, as illustrated in FIG. **3**, a normal torque command calculator **700**, a torque command moderator **701**, a stop controller **702**, and a torque command distributor **703**.
(63) The normal torque command calculator **700** is configured to receive the measurement signals outputted from the respective accelerator position sensor **60**, shift position sensor **61**, and vehicle speed sensor **62**.
(64) The normal torque command calculator **700** is configured to obtain, based on the received measurement signals, the current position, which will be referred to as AP, of the accelerator pedal, the current position, which will be referred to as shift position SP, of the shift lever, and the speed of the vehicle **10**, which will be referred to as a speed VC of the vehicle **10**.
(65) Then, the normal torque command calculator **700** is configured to calculate a normal torque command T**10*** based on maps related to the measured current position AP of the accelerator pedal, the measured shift position SP of the shift lever, and the measured speed VC of the vehicle **10**. The normal torque command T**10*** represents a target value of normal total torque that should be outputted by each of the motor-generator **31***a* and **31***b* of the in-wheel motors **30***a* and **30***b*. If the normal torque command T**10*** is set to a positive value, the target value of the normal total torque that should be outputted by each of the motor-generator **31***a* and **31***b* represents a target value of torque in an acceleration direction of the vehicle **10**. Otherwise, if the normal torque command T**10*** is set to a negative value, the target value of the normal total torque that should be outputted by each of the motor-generator **31***a* and **31***b* represents a target value of torque in a deceleration direction of the vehicle **10**.
(66) The normal torque command calculator **700** is configured to output, to the torque command moderator **701**, the calculated normal torque command T**10***.
(67) The torque command moderator **701** is configured to receive (i) the normal torque command T**10*** outputted from the normal torque command calculator **700**, (ii) the ACC flag Fa transmitted from the ACC ECU **71**, and (iii) the first ACC torque command T**21*** or the second ACC torque command T**22*** transmitted from the ACC ECU **71**.
(68) The torque command moderator **701** is configured to transmit, to the stop controller **702**, the normal torque command T**10*** as a base torque command T**30*** if the ACC flag Fa is set to the off state, that is, the ACC function is disabled.
(69) Otherwise, the torque command moderator **701** is configured to transmit, to the stop controller **702**, the first ACC torque command T**21*** or the second ACC torque command T**22*** transmitted from the ACC ECU **71** as the base torque command T**30*** if the ACC flag Fa is set to the on state, that is, the ACC function is enabled.
(70) The stop controller **702** is configured to receive (i) the base torque command T**30*** transmitted from the torque command moderator **702**, (ii) the ACC flag Fa transmitted from the ACC ECU **71**, and (iii) the measurement signals outputted from the respective acceleration sensor **62** and the vehicle speed sensor **63**.
(71) The stop controller **702** is configured to obtain, based on the received measurement signals, acceleration measured by the acceleration sensor **62**, which will be referred to as measured acceleration, i.e., second acceleration, AS of the vehicle **10**, and the speed VC of the vehicle **10** measured by the vehicle speed sensor **63**.
(72) Additionally, the stop controller **702** is configured to receive (I) The output torque and the rotational speed of the motor-generator **31***a* of the in-wheel motor **30***a*, which are outputted from the MG ECU **33***a* (II) The output torque and the rotational speed of the motor-generator **31***b* of the in-wheel motor **30***b*, which are outputted from the MG ECU **33***b*
(73) The output torque of the motor-generator **31***a* will be referred to as output torque TMa, the

output torque of the motor-generator **31***b* will be referred to as output torque TMb, the rotational speed of the motor-generator **31***a* will be referred to as a rotational speed ωMa, and the rotational speed of the motor-generator **31***b* will be referred to as a rotational speed ωMb.
(74) The stop controller **702** is configured to transmit, upon determination that the base torque command T**30*** is a positive value, i.e., acceleration of the vehicle **10** is needed, the base torque command T**30*** to the torque command distributor **703** as a final torque command T**40*** independently of whether the ACC flag Fa is set to the on state or the off state.
(75) The stop controller **702** is similarly configured to transmit, upon determination that both the base torque command T**30*** is a negative value, i.e., deceleration of the vehicle **10** is needed, and the ACC flag Fa is set to the off state, the base torque command T**30*** to the torque command distributor **703** as the final torque command T**40***.
(76) In contrast, the stop controller **702** is configured to perform a correction task of correcting, upon determination that both the base torque command T**30*** is a negative value and the ACC flag Fa is set to the on state, the base torque command T**30*** in accordance with (i) the measured acceleration AS and speed VC of the vehicle **10**, (ii) the output torque TMa and rotational speed w Ma of the motor-generator **31***a*, and (iii) the output torque TMb and rotational speed ωMb of the motor-generator **31***b*. This correction of the base torque command T**30*** aims to suppress shock generated at the stop of the vehicle **10**. The stop controller **702** is configured to transmit, to the torque command distributor **703**, the corrected base torque command T**30*** as the final torque command T**40***.
(77) The torque command distributor **703** is configured to receive the final torque command T**40*** transmitted from the stop controller **702**, and calculate, based on the received final torque command T**40***, a first torque command T**51*** and a second torque command T**52***. The first torque command T**51*** represents a target value of torque that should be outputted from the motor-generator **31***a* of the in-wheel motor **30***a*, and the second torque command T**52*** represents a target value of torque that should be outputted from the motor-generator **31***b* of the in-wheel motor **30***b*.
(78) For example, the torque command distributor **703** distributes the final torque command T**40*** equally into the first torque command T**51*** and the second torque command T**52*** upon determination that the steering angle of the steering wheel **21** is an angle of 0 degrees, i.e., the vehicle **10** is traveling in a straight line.
(79) As another example, the torque command distributor **703** calculates, upon determination that the steering angle of the steering wheel **21** is an angle of any degrees other than 0 degrees, a torque distribution ratio of the final torque command T**40*** between the motor-generator **31***a* and the motor-generator **31***b* in accordance with the steering angle of the steering wheel **21**. Then, the torque command distributor **703** distributes, based on the calculated torque distribution ratio, the final torque command T**40*** into the first torque command T**51*** and the second torque command T**52*** such that the distributed first and second torque commands T**51*** and T**52*** satisfy the calculated torque distribution ratio therebetween.
(80) Following the determination of the first torque command T**51*** and the second torque command T**52***, the torque command distributor **703** transmits the first torque command T**51*** and the second torque command T**52*** to the respective MG ECU **33***a* and **33***b* of the in-wheel motors **30***a* and **30***b*.
(81) The MG ECU **33***a* of the in-wheel motor **30***a* is configured to receive the first torque command T**51*** transmitted from the torque command distributor **703**, and calculate, based on the received first torque command T**51***, energization control information indicative of how the inverter **32***a* energizes the motor-generator **31***a*. Then, the MG ECU **33***a* is configured to cause the inverter **32***a* to supply, to the motor-generator **31***a*, electric power that is based on the energization control information. This results in the motor-generator **31***a* outputting torque that is based on the first torque command T**51***.
(82) The MG ECU **33***b* of the in-wheel motor **30***b* performs the same control operations as those

performed by the MG ECU **33***a* of the in-wheel motor **30***a*. This therefore results in the motor-generator **31***b* outputting torque that is based on the second torque command T**52***.
(83) As described above, the EV ECU **70** of the vehicle **10** according to the first embodiment serves as a first controller for determining a torque command, and each of the MG ECUs **33***a* and **33***b* serves as a second controller for controlling energization of the corresponding one of the motor-generators **31***a* and **31***b*. The EV ECU **70**, the MG ECU **33***a*, and the MG ECU **33***b* serve as a motor controller for controlling the output torque of the motor-generator **31***a* and the output torque of the motor-generator **31***b*.
(84) The brake ECU **72**, i.e., its CPU, runs program instructions stored in its memory to thereby control each of the braking devices **40***a* to **40***d*. Specifically, the brake ECU **72** is programmed to activate each of the braking devices **40***a* to **40***d* in response to detecting, based on the current position of the brake pedal measured by the brake position sensor **66**, driver's depression of the brake pedal, thus causing the corresponding one of the braking devices **40***a* to **40***d* to apply braking force to the corresponding one of the wheels **11** to **14**.
(85) The brake ECU **72** is also programmed to transmit, to the torque command moderator **701** of the EV ECU **70**, a braking torque command T**60*** (see FIG. **3**) in response to detecting driver's depression of the brake pedal. The braking torque command T**60*** represents a target value of total torque that should be outputted by each of the motor-generator **31***a* and **31***b* of the in-wheel motors **30***a* and **30***b* in order to decelerate the vehicle **10** in a predetermined braking direction of the vehicle **10**.
(86) When receiving the braking torque command T**60*** transmitted from the brake ECU **72**, the torque command moderator **701** is configured to transmit, to the stop controller **702**, the braking torque command T**60*** as the base torque command T**30*** in priority to the normal torque command T**10*** and the first ACC torque command T**21*** or the second ACC torque command T**22***. The stop adjuster **703** is configured to receive the braking torque command T**60*** transmitted from the torque command attributor **701** as the base torque command T**30***, and transmit, to the torque command distributor **703**, the base torque command T**30***, i.e., the braking torque command T**60***.
(87) The torque command distributor **703** is configured to receive the base torque command T**30***, i.e., the braking torque command T**60***, transmitted from the torque command attributor **701**, and transmit the first and second torque commands T**51*** and T**52***, which are each based on the braking torque command T**60***, to the respective MG ECU **33***a* and **33***b* of the in-wheel motors **30***a* and **30***b*.
(88) The MG ECU **33***a* of the in-wheel motor **30***a* is configured to control, based on the first torque command T**51*** transmitted from the torque command distributor **703**, energization of the motor-generator **31***a* through the inverter **32***a* to thereby cause the motor-generator **31***a* to operate in a regenerative mode to apply braking force based on the braking torque command T**60*** to the driving wheel **11**. Similarly, the MG ECU **33***b* of the in-wheel motor **30***b* is configured to control, based on the second torque command T**52*** transmitted from the torque command distributor **703**, energization of the motor-generator **31***b* through the inverter **32***b* to thereby cause the motor-generator **31***b* to operate in the regenerative mode to apply braking force based on the braking torque command T**60*** to the driving wheel **12**.
(89) As described above, the brake ECU **72** is configured to cause (i) each of the braking devices **40***a* to **40***d* to apply braking force to the corresponding one of the wheels **11** to **14**, and (ii) each of the motor-generators **31***a* and **31***b* to apply braking force to the corresponding one of the driving wheels **11** and **12**, thus stopping the vehicle **10**. The brake ECU **72** of the first embodiment serves as a brake controller.
(90) Next, the following describes an exemplary principle of how the stop controller **702** corrects the base torque command T**30*** while the ACC function is enabled.
(91) As illustrated in FIG. **5**A, let us consider a case of stopping the vehicle **10** on the surface of an uphill road with a gradient of 0 degrees with respect to a flat road. In this case, because force,

which has the backward direction opposite to the traveling direction of the vehicle **10**, is applied to the vehicle **10** due to gravity of the vehicle **10**, it is difficult to hold the vehicle **10** to be stopped on the surface of the uphill road unless predetermined offset torque is applied to each wheel **11** to **14** in the traveling direction of the vehicle **10**.

(92) Similarly, let us consider a case of stopping the vehicle **10** on the surface of a downhill road with a negative gradient of 0 degrees with respect to a flat road. In this case, because force, which has the traveling direction of the vehicle **10**, is applied to the vehicle **10** due to gravity of the vehicle **10**, it is difficult to hold the vehicle **10** to be stopped on the surface of the uphill road unless predetermined offset torque is applied to each wheel **11** to **14** in the backward direction opposite to the traveling direction of the vehicle **10**.

(93) Such a road surface having a gradient of 0 degrees with respect to a flat road, which is illustrated in FIG. **5**A or FIG. **5**B, will be referred to as a sloping road, i.e., an upslope road or a downslope road. The gradient θ of an upslope road relative to a flat road with the 0-degree gradient can be expressed as a positive angle of degrees, and the gradient θ of a downslope road relative to a flat road with the 0-degree gradient can be expressed as a negative angle of degrees.

(94) That is, in order to stop the vehicle **10** on the surface of an upslope road (see FIG. **5**A) or a downslope road (see FIG. **5**B), it is necessary to apply predetermined offset torque to each wheel **11** to **14** of the vehicle **10**.

(95) From this viewpoint, the stop controller **702** of the first embodiment is configured to learn a value of the offset torque for a corresponding value of the gradient θ of a sloping road while the vehicle **10** is traveling on the surface of the sloping road with the corresponding value of the gradient θ; the learned value of the offset torque is capable of reliably stopping the vehicle **10** on the corresponding value of the gradient θ of the sloping road.

(96) Then, when stopping the vehicle **10** on the surface of a sloping road having a value of the gradient θ, the EV ECU **70** causes each of the motor-generators **31***a* and **31***b* to operate in the regenerative mode and apply braking torque to a corresponding one of the driving wheels **11** and **12** to thereby brake the vehicle **10** while the stop controller **702** corrects the final torque command T**40*** such that the braking torque applied to each of the driving wheels **11** and **12** becomes gradually closer to the learned value of the offset torque corresponding to the value of the gradient θ of the sloping road.

(97) This configuration enables the braking torque applied to each of the driving wheels **11** and **12** to have closely approached the value of the offset torque corresponding to the value of the gradient θ of the sloping road at the stop of the vehicle **10** on the surface of the sloping road. This therefore makes it possible to reliably hold or maintain the vehicle **10** in a stopped state on the surface of the sloping road.

(98) Because the EV ECU **70** causes the braking torque applied to each of the driving wheels **11** and **12** to become gradually closer to the value of the offset torque corresponding to the value of the gradient θ of the sloping road, it is possible to suppress shock generated at the stop of the vehicle **10** on the surface of the sloping road.

(99) As described above, in order to stop the vehicle **10** on the surface of an upslope road as illustrated in, for example, FIG. **5**A, it is necessary to apply predetermined offset torque to each of the driving wheels **11** and **12** in the traveling direction, so that the offset torque to be applied to each of the driving wheels **11** and **12** has a positive value.

(100) In contrast, in order to stop the vehicle **10** on the surface of a downslope road as illustrated in, for example, FIG. **5**B, it is necessary to apply predetermined offset torque to each of the driving wheels **11** and **12** in the direction opposite to the traveling direction, so that the offset torque to be applied to each of the driving wheels **11** and **12** has a negative value.

(101) In particular, the offset torque to be applied to the vehicle **10** on a sloping road with the gradient θ has a correlation with the gradient θ such that an absolute value of the offset torque increases with an increase in an absolute value of the gradient θ of the sloping road.

(102) Next, the following describes an exemplary principle of how the stop controller **702** calculates the offset torque.
(103) The following relational expression (f1) can be established assuming that the vehicle **10** is traveling on the surface of a sloping road as illustrated in FIG. **5**A or **5**B:
$TM-W.Math.g.\mathrm{Math.sin}\ \theta-TL=I.Math.AC$ (f1) where: TM represents the total output torque of the motor-generators **31***a* and **31***b;* W represents the weight of the vehicle **10**; g represents acceleration of gravity; TL represents a rolling resistance of a flat road; I represents the inertia of the vehicle **10**; and AC represents acceleration of the vehicle **10** in the traveling direction.
(104) The weight W of the vehicle **10** includes not only the weight of the vehicle **10** itself but also the total weight of at least one occupant in the vehicle **10**. The acceleration AC of the vehicle **10** represents acceleration, i.e., first acceleration, of the vehicle **10** in the traveling direction.
(105) Because the vehicle **10** is estimated to travel at a low speed just before a stop, the rolling resistance TL on a flat road can be deemed to be zero. Additionally, the term "W.Math.g.Math.sin θ" in the relational expression (f1) corresponds to a value of the offset torque required to hold the vehicle **10** in a stopped state on the sloping road with the gradient θ.
(106) From the above relational expression (f1), the following expression (f2) can be derived;
$T0=TM-I.Math.AC$ (f2) where T**0** represents the offset torque "W.Math.g.Math.sin θ".
(107) Let us assume a situation where the vehicle **10** is stopped or is traveling just before a stop. In this assumption, the total output torque TM of the motor-generators **31***a* and **31***b* can be deemed to be substantially zero, and the rolling resistance TL on a flat road can also be deemed to be zero. It therefore can be deemed that gravity is only applied to the vehicle **10**. For these reasons, the following relational expression (f3) can be established in the situation where the vehicle **10** is stopped or is traveling just before a stop:
$-W.Math.g.\mathrm{Math.sin}\ \theta=I.Math.AG$ (f3) where AG represents a component of the acceleration of gravity g in the traveling direction of the vehicle **10**.
(108) This therefore makes it possible to calculate a value of the offset torque T**0** in the situation where the vehicle **10** is stopped or is traveling just before a stop in the following expression (f4):
$T0=-I.Math.AG$ (f4)
(109) The measured acceleration AS of the vehicle **10** includes not only an acceleration component of the vehicle **10** in the traveling direction of the vehicle **10** but also the component AG of the acceleration of gravity g in the traveling direction of the vehicle **10**. In the situation where the vehicle **10** is stopped or is traveling just before a stop, the acceleration component of the vehicle **10** in the traveling direction of the vehicle **10** can be deemed to be zero. For this reason, the measured acceleration AS of the vehicle **10** becomes only the component AG of the acceleration of gravity g in the traveling direction of the vehicle **10**. This therefore enables the measured acceleration AS of the vehicle **10** to be directly used as the component AG of the acceleration of gravity g in the traveling direction of the vehicle **10** in the expression (f4). The measured acceleration AS of the vehicle **10** corresponds to a second acceleration that is the component AG of the acceleration of gravity g in the traveling direction of the vehicle **10** according to the first embodiment. The acceleration sensor **62** serves as a second acceleration determiner.
(110) The acceleration of the vehicle **10** has a correlation relationship with a rotational acceleration of each of the motor-generators **31***a* and **31***b*. The amount of change of at least one of the rotational speeds ωMa and ωMb of the motor-generators **31***a* and **31***b*, which are measured by the respective rotation sensors **35***a* and **35***b*, per unit of time enables the acceleration AC of the vehicle **10** to be determined. In other words, a differential value of at least one of the rotational speeds ωMa and ωMb of the motor-generators **31***a* and **31***b* enables the acceleration AC of the vehicle **10** to be determined. For example, the EV ECU **70** can be configured to determine the acceleration AC of the vehicle **10** as a function of at least one of the rotational speeds ωMa and ωMb of the motor-generators **31***a* and **31***b*.
(111) Each of the rotation sensors **35***a* and **35***b* serves as a rotational speed measuring unit. The

acceleration AC of the vehicle **10** that can be determined by the differential value of at least one of the rotational speeds ωMa and ωMb of the motor-generators **31***a* and **31***b* serves as a first acceleration. The EV ECU **70** serves as a first acceleration determiner for determining, based on at least one of the rotational speeds ωMa and ωMb of the motor-generators **31***a* and **31***b*, the acceleration AC of the vehicle **10**.

(112) Next, the following describes a learning routine of the offset torque T**0** carried out by the stop controller **702** based on the above principles with reference to FIG. **6**. The stop controller **702** is programmed to iterate a cycle of the learning routine.

(113) Referring to FIG. **6**, the stop controller **702** determines whether the speed VC of the vehicle **10** measured by the vehicle speed sensor **63** is higher than or equal to a predetermined first threshold speed Vth**10** in step S**10**. The first threshold speed Vth**10** is previously set to a value that enables whether the vehicle **10** is stopped or is traveling just before a stop or is traveling normally to be determined. The first threshold speed Vth**10** is set to, for example, 1 km/h.

(114) Upon determination that the speed VC of the vehicle **10** measured by the vehicle speed sensor **63** is higher than or equal to the first threshold speed Vth**10** (YES in step S**10**), the stop controller **702** performs a traveling-vehicle learning subroutine in S**11**.

(115) Specifically, the stop controller **702** calculates the acceleration AC of the vehicle **10** as a function of at least one of the rotational speeds ωMa and ωMb of the motor-generators **31***a* and **31***b*, which are measured by the respective rotation sensors **35***a* and **35***b* in step S**11**. For example, the stop controller **702** calculates the acceleration AC of the vehicle **10** in accordance with, for example, an arithmetic expression or a map representing a correlative relationship between the acceleration AC of the vehicle **10** and the at least one of the rotational speeds ωMa and ωMb of the motor-generators **31***a* and **31***b*.

(116) Next, the stop controller **702** calculates the sum of the output torque TMa of the motor-generator **31***a* measured by the torque sensor **34***a* and the output torque TMb of the motor-generator **31***b* measured by the torque sensor **34***b* to thereby calculate the total output torque TM of the motor-generators **31***a* and **31***b* in step S**11**. Then, the stop controller **702** calculates a value of the offset torque T**0** at a value of the gradient θ of a road on which the vehicle **10** is traveling in accordance with (i) the relational expression (f2), (ii) the calculated acceleration AC of the vehicle **10**, (iii) the calculated total output torque TM of the motor-generators **31***a* and **31***b*, and (iv) a value of the inertia I of the vehicle **10** stored in the memory of the EV ECU **70** in step S**11**.

(117) Otherwise, upon determination that the speed VC of the vehicle **10** measured by the vehicle speed sensor **63** is lower than the first threshold speed Vth**10** (NO in step S**10**), the stop controller **702** performs a stopped-vehicle learning subroutine in S**12**.

(118) Specifically, the stop controller **702** calculates a value of the offset torque T**0** at a value of the gradient θ of a road on which the vehicle **10** is stopped in accordance with the relational expression (f4) and the measured acceleration AS that is the component AG of the acceleration of gravity g in the traveling direction of the vehicle **10** in step S**12**.

(119) Following the operation in step S**11** or S**12**, the stop controller **702** performs a filtering task that passes the value of the offset torque T**0** through a lowpass filter with a predetermined time constant of, for example, 1 second in step S**13**. Then, the stop controller **702** stores the filtered value of the offset torque T**0** at the value of the gradient θ of the road on which the vehicle **10** is traveling or is stopped in the memory of the EV ECU **70** in step S**13**.

(120) The stop controller **702** serves as an offset torque calculator for calculating the offset torque T**0** according to the first embodiment.

(121) Next, the following describes a stop control routine carried out by the stop controller **702** with reference to FIGS. **7** and **8**. The stop controller **702** is programmed to iterate a cycle of the stop control routine.

(122) Referring to FIG. **6**, when starting a current cycle of the stop control routine, the stop controller **702** deter mines whether the ACC function is enabled based on the ACC flag Fa

transmitted from the ACC ECU **71** in step S**20**.

(123) Upon determination that the ACC function is disabled (NO in step S**20**), the stop controller **702** determines that there is no need of performing a stop control task of the vehicle **10** on a sloping road, and performs the following operations in steps S**32** to S**35**.

(124) Specifically, the stop controller **702** cancels a braking request for activation of each braking device **40***a* to **40***d*, which has been issued to the brake ECU **72** in step S**32**. Next, the stop controller **702** sets a previously prepared stop-control mode M to 0 in step S**33**, and initializes a count value of a previously prepared counter C to 0 in step S**34**.

(125) Following the operation in step S**34**, the stop controller **702** sets a stop torque command TS* to a current value of the base torque command T**30*** in step S**35**. Next, the stop controller **702** determines whether the value of the stop-control mode M is more than or equal to 1 ($M \geq 1$) in step S**36** of FIG. **8**. Because the stop-control mode M has been set to 0 in step S**33**, the stop controller **702** determines that the value of the stop-control mode M is less than 1 ($M<0$) (NO in step S**36**). Then, the stop controller **702** determines the base torque command T**30*** as the final torque command T**40*** in step S**38**. Thereafter, the stop controller **702** terminates the current cycle of the stop control routine illustrated in FIGS. **7** and **8**, returning to a next cycle of the stop control routine illustrated in FIGS. **7** and **8**.

(126) Otherwise, upon determination that the ACC function is enabled (YES in step S**20**), the stop controller **702** determines whether the base torque command T**30*** is lower than or equal to a predetermined threshold value Tth in step S**21**. The predetermined threshold value Tth is previously determined to enable determination of whether deceleration of the vehicle **10** is requested, and is stored in the memory of the EV ECU **70**.

(127) Upon determination that the base torque command T**30*** is higher than the predetermined threshold value Tth, i.e., that deceleration of the vehicle **10** is not requested (NO in step S**21**), the stop controller **702** performs the operations in steps S**32** to S**36** and S**38**.

(128) Otherwise, upon determination that the base torque command T**30*** is lower than or equal to the predetermined threshold value Tth, i.e., that deceleration of the vehicle **10** is requested (YES in step S**21**), the stop controller **702** determines whether the speed VC of the vehicle **10** is lower than a predetermined second threshold speed Vth**11** in step S**22**. The second threshold speed Vth**11** is previously set to a value that enables whether the vehicle **10** is traveling at a low speed or is traveling at a speed higher than the low speed to be determined. The second threshold speed Vth**11**, which is stored in the memory of the EV ECU **70**, is set to, for example, 3 km/h. The second threshold speed Vth**11** corresponds to a predetermined control start speed.

(129) Upon determination that the speed VC of the vehicle **10** is higher than or equal to the second threshold speed Vth**11** (NO in step S**22**), the stop controller **702** performs the operations in steps S**32** to S**36** and S**38**.

(130) As described above, execution of the operation in step S**38** enables the base torque command T**30*** to be determined as the final torque command T**40*** upon determination that (I) the ACC function is disabled, (II) deceleration of the vehicle **10** is not requested, or (III) the vehicle **10** is traveling at a speed higher than or equal to the second threshold speed Vth**11**

(131) This results in each of the motor-generators **31***a* and **31***b* applying, to the corresponding one of the driving wheels **11** and **12**, drive power or braking force based on the base command torque T**30***.

(132) Otherwise, the stop controller **702** performs the operation in step S**23** and the subsequent operations as long as all the following conditions (I) to (III) are satisfied, i.e., all the determinations in steps S**20** to S**22** are affirmative: (I) The ACC function is enabled. (II) Deceleration of the vehicle **10** is requested. (III) The speed VC of the vehicle **10** is lower than the second threshold speed Vth**11**.

(133) Specifically, the stop controller **702** sets the stop-control mode M to 1 in step S**23**, and corrects a current value of the stop torque command TS* in accordance with the following

expression (f5) in step S**24**:

$TS^*=TS(i-1)+\Delta T$ (f5) where: TS (i−1) represents an immediately previous value of the stop torque command TS*; and ΔT represents a parameter stored in the memory of the EV ECU **70**.

(134) Following the operation in step S**24**, the stop controller **702** determines whether the current value of the stop torque command TS* is higher than or equal to the offset torque T**0** stored in the memory of the EV ECU **70** in step S**25**.

(135) Upon determination that the current value of the stop torque command TS* is lower than the offset torque T**0** (NO in step S**25**), the stop controller **702** deter mines whether the value of the stop-control mode M is more than or equal to 1 (M≥1) in step S**36** of FIG. **8**. Because the stop-control mode M has been set to 1 in step S**23**, the stop controller **702** determines that the value of the stop-control mode M is more than or equal to 1 (M≥1) (YES in step S**36**). Then, the stop controller **702** determines the stop torque command TS* as the final torque command T**40*** in step S**37**. Thereafter, the stop controller **702** terminates the current cycle of the stop control routine illustrated in FIGS. **7** and **8**, returning and subsequently performs a next cycle of the stop control routine illustrated in FIGS. **7** and **8**.

(136) That is, the stop controller **702** iterates a cycle of the stop control routine including the operation in step S**24** until the determination in step S**25** is affirmative, i.e., the stop torque command TS* has reached the offset torque T**0**. The performed cycles of the stop control routine including the operation in step S**24** enable the stop torque command TS* to gradually increase toward the offset torque T**0**. Because the stop controller **702** determines the stop torque command TS* as the final torque command T**40*** in each of the performed cycles of the stop control routine, the total output torque TM of the motor-generators **31***a* and **31***b* changes toward the offset torque T**0**.

(137) Thereafter, when the current value of the stop torque command TS* has reached the offset torque T**0**, so that it is determined that the current value of the stop torque command TS* is higher than or equal to the offset torque T**0** (YES in step S**25**). Then, the stop controller **702** determines the stop torque command TS* as the offset torque T**0** in step S**26**, and increments the count value of the counter C by 1 in step S**27**.

(138) Following the operation in step S**27**, the stop controller **702** determines whether the count value of the counter C is more than or equal to a first threshold Cth**11** in step S**28**. The first threshold Cth**11** is determined to a value that enables determination of whether a first predetermined time T**11** has elapsed since the stop torque command TS* was determined as the offset torque T**0** in step S**26**; the first threshold Cth**11** is stored in the memory of the EV ECU **70**. The first predetermined time T**11** is set to, for example, 1 second.

(139) Upon determination that the count value of the counter C is less than the first threshold Cth**11**, i.e., that the first predetermined time has not elapsed since the stop torque command TS* was determined as the offset torque T**0** (NO in step S**28**), the stop controller **702** performs negative determination in step S**36** of FIG. **8**, and thereafter performs the operation in step S**37**. This enables the stop torque command TS* and the final torque command T**40*** to be maintained at the offset torque T**0** until the first predetermined time T**11** has elapsed since the stop torque command TS* was determined as the offset torque T**0**.

(140) Thereafter, when the first predetermined time has elapsed since the stop torque command TS* was determined as the offset torque T**0**, the stop controller **702** performs affirmative determination in step S**28**, and thereafter sets the stop-control mode M to 2 in step S**29**. Following the operation in step S**29**, the stop controller **702** issues a braking request to the brake ECU **72** for activation of each braking device **40***a* to **40***d* in step S**30**. This causes the brake ECU **72** to activate each braking device **40***a* to **40***d*, thus applying braking force generated by each braking device **40***a* to **40***d* to the corresponding one of the wheels **11** to **14**. This therefore makes it possible to hold the vehicle **10** in the stopped state on the surface of a sloping road.

(141) Following the operation in step S**30**, the stop controller **702** determines whether the count

value of the counter C is more than or equal to a predetermined second threshold Cth**2**. The second threshold Cth**12** is determined to a value that enables determination of whether a second predetermined time T**12** has elapsed since the operation in step S**30** was performed, i.e., the braking request to the brake ECU **72** was issued; the second threshold Cth**12** is stored in the memory of the EV ECU **70**.
(142) The second predetermined time T**12** is determined to permit a time lag required until a sufficient amount of braking force has been applied to each wheel **11** to **14** since the issuance of the braking request to the brake ECU **72**, which is set to, for example, 2 seconds.
(143) Upon determination that the count value of the counter C is less than the second threshold Cth**12**, i.e., that the second predetermined time has not elapsed since the braking request to the brake ECU **72** was issued (NO in step S**31**), the stop controller **702** performs negative determination in step S**36** of FIG. **8**, and thereafter performs the operation in step S**37**. This enables the stop torque command TS* and the final torque command T**40*** to be maintained at the offset torque T**0** until the second predetermined time T**12** has elapsed since the braking request to the brake ECU **72** was issued.
(144) Thereafter, when the second predetermined time has elapsed since the braking request to the brake ECU **72** was issued, the stop controller **702** performs affirmative determination in step S**31**, and thereafter performs the operation in step S**33** and the subsequent operations.
(145) Specifically, the stop controller **702** sets the stop-control mode M to 0 in step S**33**, and initializes the count value of the counter C to 0 in step S**34**.
(146) Following the operation in step S**34**, the stop controller **702** sets the stop torque command TS* to the current value of the base torque command T**30*** in step S**35**. At that time, because the current value of the base command torque T**30*** has become zero or a value adjacent to zero, the stop torque command T is set to zero or a value close to zero.
(147) Next, the stop controller **702** determines whether the value of the stop-control mode M is more than or equal to 1 (M≥1) in step S**36** of FIG. **8**. Because the stop-control mode M has been set to 0 in step S**33**, the stop controller **702** deter mines that the value of the stop-control mode M is less than 1 (M<0) (NO in step S**36**). Then, the stop controller **702** determines the base torque command T**30*** as the final torque command T**40*** in step S**38**. Thereafter, the stop controller **702** terminates the current cycle of the stop control routine illustrated in FIGS. **7** and **8**, returning to a next cycle of the stop control routine illustrated in FIGS. **7** and **8**.
(148) Next, the following describes a first example of how selected operation parameters of the vehicle **10** change over time with reference to FIGS. **9**A to **9**D, and a second example of how selected operation parameters of the vehicle **10** change over time with reference to FIGS. **10**A to **10**D.
(149) As illustrated in FIGS. **9**A to **9**D, in the first example, the vehicle **10** travels on a downslope road within a period from time t**10** to time t**11**, and thereafter travels on a flat road within a period from the time t**11** to time t**12**, and thereafter travels on an upslope road from the time t**12**.
(150) Let us assume that the accelerator pedal of the vehicle **10** is maintained at a position corresponding to a constant operated amount of the accelerator pedal from the time t**10**.
(151) In this assumption, as illustrated in FIG. **9**B, the total output torque TM of the motor-generators **31***a* and **31***b* is maintained at a constant value. This results in the speed VC of the vehicle **10** changes as illustrated in FIG. **9**A. Specifically, while the vehicle **10** travels on the downslope road within the period from the time t**10** to the time t**11**, the speed VC of the vehicle **10** gradually increases, because gravity acts on the vehicle **10** in the traveling direction. While the vehicle **10** travels on the flat road within the period from the time t**11** to the time t**12**, the speed VC of the vehicle **10** is maintained at a constant speed, because gravity acts on the vehicle **10** in a direction perpendicular to the traveling direction.
(152) While the vehicle **10** travels on the upslope road from the time t**12**, the speed VC of the vehicle **10** gradually decreases, because gravity acts on the vehicle **10** in the backward direction

opposite to the traveling direction.

(153) The change of the speed VC of the vehicle **10** as illustrated in FIG. **9**A results in the acceleration AC of the vehicle **10** in the traveling direction remaining over zero within the period from the time t**10** to the time t**11**, and remaining at zero within the period from the time t**11** to the time t**12** (see dash-dot-dash line in FIG. **9**C). From the time t**12**, the acceleration AC of the vehicle **10** in the traveling direction remains below zero (see dash-dot-dash line in FIG. **9**C). Because the measured acceleration AS of the vehicle **10** includes not only the acceleration AC of the vehicle **10** in the traveling direction but also the acceleration of gravity, the measured acceleration AS of the vehicle **10** changes over time (see solid line in FIG. **9**C).

(154) When learning the offset torque T**0** in accordance with the acceleration AC of the vehicle **10** in the traveling direction (see FIG. **9**B), the total output torque TM of the motor-generators **31***a* and **31***b* (see FIG. **9**C), and the above expression (f2), the stop controller **702** obtains the offset torque T**0** as illustrated in FIG. **9**D.

(155) Next, the following describes the second example of how selected operation parameters of the vehicle **10** change over time when the vehicle **10**, whose ACC function is enabled, traveling on an upslope road is stopped on the upslope road with reference to FIGS. **10**A to **10**D.

(156) Let us assume a situation where, while the vehicle **10** is traveling on the upslope road, the ACC ECU **71** analyzes the condition of the preceding vehicle in front of the vehicle **10** to accordingly transmit, to the EV ECU **70**, the second ACC torque command T**22*** having a negative value in order to stop the vehicle **10**.

(157) In this situation, the second ACC torque command T**22*** is determined as the base torque command T**30***, and the base torque command T**30***, i.e., the second ACC torque command T**22***, is used as the final torque command T**40***. This results in the second ACC torque command T**22*** being determined as the final torque command T**40*** at time t**20** (see FIGS. **10**A to **10**D).

(158) At the time t**20**, as illustrated in FIG. **9**C, the final torque command T**40*** is set to a negative value. This causes the motor-generators **31***a* and **31***b* to operate in the regenerative mode to accordingly apply braking force to the respective driving wheels **11** and **12**. This results in the speed VC of the vehicle **10** gradually decreasing as illustrated in FIG. **10**A while the stop-control mode M being maintained at **0**.

(159) Thereafter, when the speed VC of the vehicle **10** decrease down to the second threshold speed Vth**11** at time t**21**, the stop-control mode M is set to 1 at the time t**21** as illustrated in FIG. **10**B. At the time t**21**, the stop torque command TS* is calculated in accordance with the expression (f5), and the calculated stop torque command TS* is used as the final torque command T**40***. This results in, as illustrated in FIG. **10**C, the final torque command T**40*** gradually increasing toward the offset torque T**0** at the inclination of the parameter ΔT from the time t**21**.

(160) When the stop torque command TS* has reached the offset torque T**0** at time t**22**, the stop torque command TS* is fixed to the offset torque T**0**, and the stop torque command TS*, i.e., the offset torque T**0**, is used as the final torque command T**40***. This results in, as illustrated in FIG. **10**C, the final torque command T**40*** being maintained at the offset torque T**0**.

(161) Thereafter, when the first predetermined time T**11** has elapsed since the time t**22**, the stop-control mode M is set to 2 at time t**23** (see FIG. **10**B). At the time t**23**, the braking request is issued from the stop controller **702** to the braking ECU **72** for activation of each braking device **40***a* to **40***d*. This results in, as illustrated in FIG. **10**D, the braking force applied to each wheel **11** to **14** from the corresponding braking device **40***a* to **40***d* gradually increasing. When the second predetermined time T**12** has elapsed since the time t**23**, the final torque command T**40*** is returned to the base torque command T**30*** at time t**24**, resulting in, as illustrated in FIG. **10**D, the final torque command T**40*** being set to, for example, 0. That is, the braking force applied to each driving wheel **11**, **12** from the corresponding motor-generator **31***a*, **31***b* is cancelled at the time t**24**. At the time t**24**, the braking force applied from each braking device **40***a* to **40***d* to the corresponding wheel **11** to **14** makes it possible to hold the vehicle **10** in the stopped state.

(162) The control apparatus **80** of the vehicle **10** according to the first embodiment achieves the following first to sixth advantageous benefits:
(163) The first advantageous benefit is as follows. Specifically, the EV ECU **70** and MG ECU **33***a* and **33***b* are configured to cooperatively control, when stopping the vehicle **10** on the surface of a sloping road having a gradient of θ degrees, the total output torque TM of the motor-generators **31***a* and **31***b* to asymptotically approach the offset torque T**0**. This configuration causes the total output torque TM of the motor-generators **31***a* and **31***b* to gradually change toward the offset torque T**0**, making it possible to prevent the occurrence of shock at the stop of the vehicle **10**.
(164) This configuration additionally causes each of the motor-generators **31***a* and **31***b* to apply the offset torque T**0** to the corresponding one of the driving wheels **11** and **12** at the stop of the vehicle **10** on the surface of the sloping road having the gradient of 0 degrees, making it possible to hold the vehicle **10** in a stopped state on the surface of the sloping road having the gradient of θ degrees.
(165) This therefore enables the vehicle **10** to stop on such a sloping road more smoothly.
(166) The second advantageous benefit is as follows.
(167) The stop controller **702** is configured to calculate the offset torque T**0** in accordance with the expression (f2), the total output torque TM of the motor-generators **31***a* and **31***b*, and the calculated acceleration AC of the vehicle **10** in the traveling direction upon determination that the speed VC of the vehicle **10** is higher than or equal to the first threshold speed Vth**11** (see the operations in steps S**10** and S**11** in FIG. **6**). Alternatively, the stop controller **702** is configured to calculate the offset torque T**0** in accordance with the expression (f4) and the measured acceleration AS upon determination that the speed VC of the vehicle **10** is lower than the first threshold speed Vth**11** (see the operations in steps S**10** and S**12** in FIG. **6**).
(168) This therefore enables the stop controller **72** to easily obtain the offset torque T**0**.
(169) The third advantageous benefit is as follows.
(170) The EV ECU **70** is configured to calculate the acceleration AC of the vehicle **10** in the traveling direction in accordance with the rotational speeds ωMa and ωMb of the motor-generators **31***a* and **31***b* measured by the respective rotation sensors **35***a* and **35***b*. This configuration therefore enables the EV ECU **70** to easily obtain the acceleration AC of the vehicle **10** in the traveling direction.
(171) The fourth advantageous benefit is as follows.
(172) The stop controller **702** is configured to perform, every predetermined cycle, calculation of a value of the offset torque T**0** (see FIG. **6**), and perform the filtering task that passes the value of the offset torque T**0** calculated for each cycle through the lowpass filter.
(173) This configuration enables the values of the offset torque T**0** calculated for the respective cycles to be smoothed, making it possible to obtain the values of the offset torque T**0** from which disturbance factors have been eliminated.
(174) The fifth advantageous benefit is as follows.
(175) Specifically, the EV ECU **70** and MG ECU **33***a* and **33***b* are configured to cooperatively start a task of causing the total output torque TM of the motor-generators **31***a* and **31***b* to asymptotically approach the offset torque T**0** in response to determination that the speed VC of the vehicle **10** becomes lower than the first threshold Vth**11**.
(176) This configuration performs the task of causing the total output torque TM of the motor-generators **31***a* and **31***b* to asymptotically approach the offset torque T**0** in a situation where the vehicle **10** is likely to stop, making it possible to perform, at more appropriate timing, the task of causing the total output torque TM of the motor-generators **31***a* and **31***b* to asymptotically approach the offset torque T**0**.
(177) The sixth advantageous benefit is as follows.
(178) Continuous application of braking force from each of the motor-generators **31***a* and **31***b* to the corresponding one of the driving wheels **11** and **12** for holding the vehicle **10** in a stopped state may result in an increase in power consumption of the vehicle **10**.

(179) From this viewpoint, the EV ECU **70** according to the first embodiment is configured to (1) Request, after the output torque TMa of the motor-generator **31***a* and the output torque TMb of the motor-generator **31***b* have reached the offset torque T**0**, the brake ECU **72** to cause each of the braking devices **40***a* to **40***d* to apply braking force to the corresponding one of the wheels **11** to **14** (2) Deactivate the motor-generators **31***a* and **31***b*
(180) This configuration makes it possible to hold, based on the braking force applied to each wheel **11** to **14** from the corresponding braking device **40***a* to **40***d*, the vehicle **10** in a stopped state while deactivating the motor-generators **31***a* and **31***b* to accordingly reduce power consumption of the vehicle **10**.
Second Embodiment
(181) The following describes the control apparatus **80** of the vehicle **10** according to the second embodiment of the present disclosure while focusing on different points of the control apparatus **80** second embodiment from that of the first embodiment.
(182) Referring to FIG. **11**, the EV ECU **70** of the second embodiment is configured such that the base torque command T**30*** calculated by the torque command moderator **701** is inputted to the torque command distributor **703**.
(183) The torque command distributor **703** is configured to receive the base torque command T**30*** inputted thereto from the torque command attributor **701**, and calculate, based on the received base torque T**30***, the first torque command T**51*** and the second torque command T**52***. The first torque command T**51*** represents the target value of torque that should be outputted from the motor-generator **31***a* of the in-wheel motor **30***a*, and the second torque command T**52*** represents the target value of torque that should be outputted from the motor-generator **31***b* of the in-wheel motor **30***b*.
(184) The torque command distributor **703** is additionally configured to transmit the first torque command T**51*** and the second torque command T**52*** to the respective MG ECU **33***a* and **33***b* of the in-wheel motors **30***a* and **30***b*.
(185) The MG ECU **33***a* for the in-wheel motor **30***a* includes a stop controller **330***a* and an energization controller **331***a*. Similarly, the MG ECU **33***b* for the in-wheel motor **30***b* includes a stop controller **330***b* and an energization controller **331***b*.
(186) The stop controller **330***a* is configured to receive (i) the first torque command T**51*** transmitted from the torque command distributor **703**, (ii) the ACC flag Fa transmitted from the ACC ECU **71**, and (iii) the measurement signals outputted from the respective acceleration sensor **62**, the vehicle speed sensor **63**, the torque sensors **34***a* and **34***b*, and the rotation sensor **35***a*.
(187) The stop controller **330***a* is configured to obtain, based on the received measurement signals, the acceleration AS measured by the acceleration sensor **62**, i.e., the measured acceleration AS, the speed VC of the vehicle **10** measured by the vehicle speed sensor **63**, the output torque TMa of the motor-generator **31***a*, the output torque TMb of the motor-generator **31***b*, and the rotation speed ωMa of the motor-generator **31***a*.
(188) Then, the stop controller **330***a* is configured to (1) Perform, based on the obtained information items, which include the measured acceleration AS, the speed VC of the vehicle **10**, the output torque TMa, the output torque TMb, and the rotation speed co M, a correction task, which is identical to that performed by the stop controller **702** of the first embodiment (2) Transmit, to the energization controller **331***a*, corrected first torque command T**30***
(189) The energization controller **331***a* is configured to controllably drive the inverter **32***a*, thus controlling how the motor-generator **31***a* is energized.
(190) This enables the motor-generator **31***a* to output torque corresponding to the corrected first torque command T**51***.
(191) Because operations of each of the stop controller **330***b* and the energization controller **311***b* provided for the in-wheel motor **30***b* are substantially identical to those of the corresponding one of the stop controller **330***a* and the energization controller **331***a* provided for the in-wheel motor **30***a*,

detailed descriptions of the operations of each of the stop controller **330***b* and the energization controller **311***b* are omitted.
(192) The controller **80** of the second embodiment, which is configured set forth above, makes it possible to cause, when stopping the vehicle **10** that is traveling on the surface of a sloping road with a gradient of 0 degrees, the total output torque TM of the motor-generators **31***a* and **31***b* to asymptotically approach the offset torque T**0**.
(193) The control apparatus **80** of the vehicle **10** according to the second embodiment achieves the following seventh advantageous benefit:
(194) Specifically, the MG ECU **33***a* and **33***b* are configured to cooperatively control, when stopping the vehicle **10** on the surface of a sloping road having a gradient of θ degrees, the total output torque TM of the motor-generators **31***a* and **31***b* to asymptotically approach the offset torque T**0**.
(195) This configuration of the control apparatus **80** is configures such that the MG ECU **33***a* and **33***b* take on the control of causing the total output torque TM of the motor-generators **31***a* and **31***b* to asymptotically approach the offset torque T**0**. This configuration of the control apparatus **80** according to the second embodiment therefore makes it possible to reduce processing load of the EV ECU **70** to be lower as compared with that of the EV ECU **70** of the control apparatus **80** according to the first embodiment.
Modifications
(196) The above first and second embodiments can be variably modified as follows:
(197) The stop controller **702** can be configured to calculate the offset torque T**0** in accordance with a differential value between the acceleration AC of the vehicle **10** in the traveling direction and the acceleration AS measured by the acceleration sensor **62** in place of the expression (f2).
(198) The stop controller **702** can be configured to change the parameter ΔT employed in the expression (f5) in accordance with maps illustrated in FIG. **12**; each map represents a relationship between (1) Values of the parameter ΔT (2) Values of the offset torque T**0** (3) Values of the speed VC of the vehicle **10**
(199) Because values of the offset torque T**0** have correlations with respective values of the gradient θ of a road surface, changing the parameter ΔT using the maps illustrated in FIG. **12** enables the parameter ΔT to change based on change of the gradient θ of a road surface.
(200) The control apparatus **80** according to each of the first and second embodiments can be applied to a vehicle including a one-pedal driving configuration that enables a driver to an acceleration operation and a braking operation using one pedal.
(201) Specifically, the one-pedal driving configuration installed in a vehicle enables the vehicle to (i) accelerate when a driver depresses one pedal, and (ii) decelerate the vehicle when the driver releases the one pedal to return its original position.
(202) Applying the control apparatus **80** according to each of the first and second embodiments to such a vehicle including the one-pedal driving configuration enables the control apparatus **80** to perform the task of causing the total output torque TM of the motor-generators **31***a* and **31***b* to asymptotically approach the offset torque T**0** during release of the depressed pedal for deceleration of the vehicle **10**. This therefore results in the vehicle **10** being more smoothly stopped on a sloping road.
(203) The control apparatuses **80** and control methods described in the present disclosure can be implemented by a dedicated computer including a memory and a processor programmed to perform one or more functions embodied by one or more computer programs.
(204) The control apparatuses **80** and control methods described in the present disclosure can also be implemented by a dedicated computer including a processor comprised of one or more dedicated hardware logic circuits.
(205) The control apparatuses **80** and control methods described in the present disclosure can further be implemented by a processor system comprised of a memory, a processor programmed to

perform one or more functions embodied by one or more computer programs, and one or more hardware logic circuits.

(206) The one or more programs can be stored in a non-transitory storage medium as instructions to be carried out by a computer. Each dedicated hardware logic circuit or hardware logic circuit can be implemented by one or more digital circuits including plural logic gates or one or more analog circuits.

(207) The present disclosure is not limited to the above embodiments. The design of at least one of the embodiments, which has been modified by a skilled person in the art, can be within the scope of the present disclosure as long as the modified design of the at least one of the embodiments includes the features of the present disclosure.

(208) Appropriate modifications can be made to the components of the embodiments and the arrangements, conditions, and shapes thereof. Appropriate changes can be made to the combination of the components of the embodiments unless a technical inconsistency arises therefrom. disclosure.

Claims

1. A control apparatus for causing a motor-generator of a vehicle to apply drive power to at least one wheel of the vehicle, and operate, at a stop of the vehicle, in a regenerative mode to apply braking force to the at least one wheel of the vehicle, the control apparatus comprising: an offset torque calculator configured to calculate offset torque to be applied to the at least one wheel of the vehicle, the offset torque being required to stop the vehicle on a sloping road having a predetermined gradient; and a motor controller configured to, in stopping of the vehicle on the sloping road having the predetermined gradient, cause output torque of the motor-generator to gradually approach the offset torque while maintaining a deceleration of the vehicle to be substantially constant.
2. The control apparatus according to claim 1, further comprising: a torque measuring unit configured to measure the output torque of the motor-generator; and an acceleration measuring unit configured to measure acceleration of the vehicle in a traveling direction thereof, wherein: the offset torque calculator is configured to calculate the offset torque in accordance with the output torque of the motor-generator and the acceleration of the vehicle in the traveling direction.
3. The control apparatus according to claim 2, wherein: the acceleration measuring unit is a first acceleration unit configured to measure first acceleration that is the acceleration of the vehicle in the traveling direction, the control apparatus further comprising: a second acceleration measuring unit configured to measure, as second acceleration of the vehicle, an acceleration component of acceleration gravity in the traveling direction, the offset torque calculator being configured to: calculate the offset torque in accordance with the output torque of the motor-generator and the first acceleration of the vehicle in the traveling direction upon determination that a speed of the vehicle in the traveling direction is higher than or equal to a predetermined threshold speed; and calculate the offset torque in accordance with the output torque of the motor-generator and the second acceleration of the vehicle in the traveling direction upon determination that the speed of the vehicle in the traveling direction is lower than the predetermined threshold speed.
4. The control apparatus according to claim 1, further comprising: a first acceleration measuring unit configured to measure first acceleration of the vehicle in a traveling direction thereof; and a second acceleration measuring unit configured to measure, as second acceleration of the vehicle, an acceleration component of acceleration gravity in the traveling direction, wherein: the offset torque calculator is configured to perform the calculation of the offset torque in accordance with a differential value between the first acceleration and the second acceleration.
5. The control apparatus according to claim 3, further comprising: a rotational speed measuring unit configured to measure a rotational speed of the motor-generator, wherein: the first acceleration unit

is configured to calculate the first acceleration in accordance with the rotational speed of the motor-generator.

6. The control apparatus according to claim 4, further comprising: a rotational speed measuring unit configured to measure a rotational speed of the motor-generator, wherein: the first acceleration unit is configured to calculate the first acceleration in accordance with the rotational speed of the motor-generator.

7. The control apparatus according to claim 1, wherein: the offset torque calculator is configured to: calculate, every predetermined cycle, a value of the offset torque; and pass the value of the offset torque calculated for each cycle through a lowpass filter.

8. The control apparatus according to claim 1, wherein: the motor controller comprises: a first control unit configured to determine a torque command representing a target value of the output torque of the motor-generator; and a second control unit configured to control energization of the motor-generator in accordance with the torque command to accordingly cause the output torque of the motor-generator to asymptotically approach the offset torque.

9. The control apparatus according to claim 1, wherein: the motor controller is configured to start to cause the output torque of the motor-generator to gradually approach the offset torque in response to determination that a speed of the vehicle in a traveling direction thereof becomes lower than a predetermined control start speed.

10. The control apparatus according to claim 1, further comprising: a brake controller configured to control a braking device that applies, to the at least one wheel, the braking force in accordance with hydraulic pressure, wherein: the motor controller is configured to request the brake controller to cause the braking device to apply the braking force to the at least one wheel after the output torque of the motor-generator has reached the offset torque.

11. The control apparatus according to claim 1, wherein: the motor controller is configured to, in stopping of the vehicle on the sloping road, cause the output torque of the motor-generator to gradually approach the offset torque while maintaining the deceleration of the vehicle to be substantially zero.

12. The control apparatus according to claim 1, wherein: the motor controller is configured to increase a deceleration of the vehicle while maintaining the output torque of the motor-generator substantially at the offset torque.