United States Patent Application Publication	20250263107
Kind Code	A1
Publication Date	August 21, 2025
Inventor(s)	SATOU; Atsushi et al.

STEERING SYSTEM

Abstract

In a two-system steering system, a power supply system includes: first and second buses that are communicated with each other via a circuit breaker; first and second power supplies that are connected to the first and second buses, respectively; and a backup power supply including a battery to allow electric power to be supplied to both of first and second systems, and is configured such that, when one of the first and second buses has a ground fault, the circuit breaker cuts off the communication between the first and second buses, and the backup power supply supplies the electric power to both of the first and second systems. The backup power supply can suppress a situation where, during a time lag from detection of the ground fault to actuation of the circuit breaker, both of the first and second systems cannot be normally actuated.

Inventors: **SATOU; Atsushi (Toyota-shi, JP), ITAZURI; Kazuki (Toyota-shi, JP), SATO; Fumihiko (Okazaki-shi, JP), HIBINO; Tokuaki (Toyota-shi, JP), NITTA; Hiroki (Okazaki-shi, JP), KAJISAWA; Yuuta (Okazaki-shi, JP)**

Applicant: **TOYOTA JIDOSHA KABUSHIKI KAISHA** (Aichi-ken, JP); **JTEKT CORPORATION** (Aichi-ken, JP)

Family ID: **1000008438769**

Appl. No.: **19/045553**

Filed: **February 05, 2025**

Foreign Application Priority Data

JP	2024-020886	Feb. 15, 2024

Publication Classification

Int. Cl.: **B62D5/00** (20060101); **B62D5/04** (20060101)

U.S. Cl.:

CPC **B62D5/005** (20130101); **B62D5/0409** (20130101); **B62D5/0421** (20130101);

Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to Japanese Patent Application No. 2024-020886 filed on Feb. 15, 2024, incorporated herein by reference in its entirety.

BACKGROUND

1. Technical Field

[0002] The disclosure relates to a steering system to be mounted on a vehicle.

2. Description of Related Art

[0003] Regarding a power supply system for various devices such as a steering device to be mounted on a vehicle, for example, there is a technology described in Japanese Unexamined Patent Application Publication No. 2023-32346 (JP 2023-32346 A). In this technology, a main power supply system including a normal load group including some devices and an auxiliary power supply, and a backup power supply system including a backup load group including some devices are provided. At the time of failure of the main power supply system, after a converter that is a main power supply is stopped, a connection line connecting both the systems to each other at normal times is cut off, and the backup power supply system is used to actuate the devices of the backup load group by supplying electric power from a converter that is a backup power supply.

SUMMARY

[0004] In the technology described in JP 2023-32346 A, at the time of failure of the main power supply, the connection line is cut off, but there may occur a time lag from the detection of the failure of the main power supply system until the cut-off of the connection line. When the time lag occurs, there may be provided a state in which no electric power is supplied to both of the normal load group and the backup load group. When this state occurs, there is also expected a situation where, after the connection line is cut off, the backup load unit cannot be normally actuated. With such a situation being avoided, the practicality of a system including devices to be mounted on the vehicle, for example, a steering system can be improved. The disclosure has been made in view of such circumstances, and has an object to provide a highly practical steering system.

[0005] In order to achieve the above-mentioned object, a steering system of the disclosure is a steering system to be mounted on a vehicle, the steering system including: [0006] a steering device including two systems of a first system and a second system, the two systems each including a power source; [0007] a control drive device including two systems of a first system and a second system to control and drive the first system and the second system of the steering device, respectively, the two systems of the control drive device each including a driver that drives the power source and a controller that controls the driver; [0008] two electric power supply buses connected in series to each other, the two electric power supply buses including a first bus to which the first system of the control drive device is connected to supply electric power to the first system of the control drive device, and a second bus to which the second system of the control drive device is connected to supply electric power to the second system of the control drive device; [0009] a circuit breaker that disconnects the first bus and the second bus; [0010] a first power supply connected to the first bus and a second power supply connected to the second bus; and [0011] a backup power supply device that includes a battery and is configured to supply electric power from the battery, in which [0012] the steering system is configured such that, at normal times, in a state in which the first bus and the second bus are communicated with each other, electric power is supplied from at least one of the first power supply and the second power supply, and, when one of the first bus and the second bus has a ground fault, the circuit breaker disconnects the first bus and the second bus such that the electric power is supplied via another one of the first bus and the second bus from a corresponding one of the first power supply and the second power supply connected to the other one of the first bus and the second bus to a corresponding one of the first system and the second system of the control drive device connected to the other one of the first bus and the second bus, and [0013] the backup power supply device is configured to cause the electric power supplied from at least one of the first bus and the second bus to pass through itself, and, when supply of the electric power is cut off, automatically supply the electric power from the battery included in itself to at least the controllers of both of the first system and the second system of the control drive device.

[0014] The term “ground fault” means that a bus has a short circuit with a component having a ground potential. At normal times, when the ground fault occurs in one of the first bus and the second bus, since the first bus and the second bus are communicated with each other, the ground fault occurs in the other one of the first bus and the second bus as well. As a result, there is provided a state in which no electric power is supplied to any of the first system and the second system of the control drive device from any of the first power supply and the second power supply. In order to avoid such a situation, when the ground fault occurs in one of the first bus and the second bus, the circuit breaker cuts off the communication between the first bus and the second bus, and the electric power of a corresponding one of the first power supply and the second power supply is supplied via the other one of the first bus and the second bus to a corresponding one of the first system and the second system of the control drive device.

[0015] However, when the ground fault occurs in one of the first bus and the second bus, a time lag occurs from the detection of the ground fault until cut-off of the communication between the first bus and the second bus by the circuit breaker. Although the time lag is a short time, there is provided a state in which no electric power is supplied to both of the first system and the second system of the control drive device. In particular, when the controller is brought to a state of not being supplied with the electric power, the control by the controller is reset, and, even after the electric power is supplied again, both of the first system and the second system of the steering device fall into a state of not being able to be normally actuated.

[0016] The term “backup power supply device” refers to a device provided for avoiding this state, and the backup power supply device makes it possible to suppress a situation where no electric power is supplied to the controllers of both of the first system and the second system of the control drive device at a time point at which the ground fault has occurred. With the above-mentioned configuration, the steering system of the disclosure becomes highly practical.

[0017] The term “steering device” in the steering system of the disclosure (hereinafter sometimes referred to as “this steering system”) includes at least an actuator that turn a wheel or assists the turning of the wheel. The actuator is only required to include, for example, an electric motor or the like as the drive source. When the power source is the electric motor, for example, with the electric motor being a two-system motor, the steering device can be configured as a two-system device. Incidentally, when the electric motor is a DC brushless motor, for example, with a stator including two sets of coils, the electric motor is configured as a two-system motor.

[0018] The term “control drive device” refers to a device that controls and drives the steering device, and, in detail, refers to a device that controls the power source of the steering device. The two-system control drive device includes two drivers and two controllers so as to correspond to the two systems of the steering device. The “driver” can also be called a drive circuit, and, for example, an inverter may be adopted as the driver when the power source is a DC brushless motor. Further, the “controller” is only required to include, for example, a computer as a main component.

[0019] The term “first bus” and the term “second bus” both refer to electric power supply lines, that is, what are called electric wires, and may have a form of busbars. The first bus and the second bus respectively supply electric power to the first system and the second system of the control drive device, but other systems such as a brake system may be connected to the first bus and the second

bus so that the first bus and the second bus supply electric power to the other systems as well. The "circuit breaker" may be what is called a switch that switches between mutual communication and non-communication between the two buses.
[0020] Power supplies that function as the "first power supply" and the "second power supply" may each be, for example, in a case of electric vehicles such as a battery electric vehicle and a hybrid electric vehicle, a converter that converts, into low-voltage electric power, high-voltage electric power from a drive battery that supplies electric power to a drive motor provided for driving the vehicle to travel. Further, the power supplies may each be an auxiliary battery such as a lead battery that has been conventionally used. The "backup power supply device" includes the above-mentioned "battery" therein, and the battery may be what is called a capacitor that is an electricity storage device having a small electricity storage capacity. It is to be noted that two or more first power supplies and two or more second power supplies may be disposed.
[0021] The configuration of the "backup power supply device", in more detail, the configuration for automatically supplying electric power from the battery included in itself when the supply of the electric power from both of the first bus and the second bus is cut off is described in detail later.
[0022] It is to be noted that the backup power supply device may be configured to supply, with respect to both of the first system and the second system of the control drive device, the electric power from the battery to only the controller out of the driver and the controller. With such a configuration, it is possible to adopt a battery having a relatively small capacity. Further, the backup power supply device may be configured to supply, with respect to at least one of the first system and the second system of the control drive device, the electric power from the battery to both of the driver and the controller. When it is possible to supply the electric power to both of the driver and the controller, although a battery having a relatively large capacity is required, even during the above-mentioned time lag, the appropriate actuation of at least one of the first system and the second system of the steering device is ensured, and it is possible to further increase the reliability of the actuation of the steering system when the above-mentioned ground fault has occurred.
[0023] Further, the number of backup power supply devices to be disposed is not limited to one. For example, the backup power supply device may include a first backup power supply device configured to supply the electric power to the first system of the control drive device, and a second backup power supply device configured to supply the electric power to the second system of the control drive device.
[0024] This steering system may be what is called a steer-by-wire steering system. When the steer-by-wire steering system is employed, the steering system is only required to be configured such that each of the first system and the second system of the steering device includes a turning actuator including the power source to turn a wheel, and a reaction force actuator including the different power source to apply an operation reaction force to a steering operation member, and each of the first system and the second system of the control drive device includes the control drive device for the turning actuator and the control drive device for the reaction force actuator.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0025] Features, advantages, and technical and industrial significance of exemplary embodiments of the disclosure will be described below with reference to the accompanying drawings, in which like signs denote like elements, and wherein:
[0026] FIG. **1**A is a diagram illustrating an overall configuration of a steering system of an embodiment;
[0027] FIG. **1**B is a diagram illustrating a configuration of an electronic control unit that is a drive

control device;
[0028] FIG. **2**A is a diagram schematically illustrating a power supply system of the steering system of the embodiment;
[0029] FIG. **2**B is a diagram schematically illustrating an internal configuration of a backup power supply device included in the power supply system;
[0030] FIG. **3**A is a diagram schematically illustrating a power supply system of the related art;
[0031] FIG. **3**B is a diagram schematically illustrating an internal configuration of a backup power supply device included in the power supply system of the related art;
[0032] FIG. **4**A is a diagram illustrating a power supply system of a first modification example that can be adopted in the steering system of the embodiment;
[0033] FIG. **4**B is a diagram illustrating a power supply system of a second modification example that can be adopted in the steering system of the embodiment;
[0034] FIG. **5**A is a diagram schematically illustrating a power supply system of a third modification example that can be adopted in the steering system of the embodiment;
[0035] FIG. **5**B is a diagram schematically illustrating an internal configuration of a backup power supply device included in the power supply system of the third modification example; and
[0036] FIG. **6** is a flowchart of an ending processing program to be executed for ending the actuation of the electronic control unit.
DETAILED DESCRIPTION OF EMBODIMENTS
[0037] Hereinafter, as a mode for carrying out the disclosure, a steering system according to an embodiment of the disclosure is described in detail with reference to the drawings. It is to be noted that, besides the following embodiment, the disclosure can be carried out in various forms including the forms described in the above section “SUMMARY” and various modified or improved forms that are made based on the knowledge of those skilled in the art.
[A] Overall Configuration of Steering System
[0038] A steering system according to an embodiment (hereinafter sometimes referred to as “this steering system”) to be mounted on a vehicle is, as schematically illustrated in FIG. **1**A, a system for turning two wheels (that are front wheels) **10** each being a turned wheel, and is a steer-by-wire steering system including a reaction force actuator **12** and a turning actuator **14** that are mechanically independent of each other.
[0039] The reaction force actuator **12** has a function of receiving an operation of a steering wheel **20** serving as an operation member on which a turning operation (steering operation) is performed by a driver, and includes: (a) a steering shaft **22** having the steering wheel **20** mounted at its distal end; (b) a steering column **24** that rotatably holds the steering shaft **22** and is supported by an instrument panel reinforcement (not illustrated); and (c) a reaction force applying mechanism **28** that is provided on the steering column **24** and applies an operation reaction force that is a reaction force against the steering operation to the steering wheel **20** via the steering shaft **22** with the use of a reaction force motor **26** that is an electric motor as a power source. The reaction force actuator **12** has a general structure, and hence the description of the specific structure of the reaction force actuator **12** is omitted.
[0040] The reaction force motor **26** is a three-phase brushless DC motor. Magnets are provided on an outer periphery of a rotary shaft, and coils are arranged on a housing so as to face those magnets. The reaction force motor **26** is a two-system motor in which two sets of coils are arranged for one magnet. Hereinafter, the two systems are sometimes referred to as “first reaction force motor **26***a*” and “second reaction force motor **26***b*”. That is, the reaction force actuator **12** is constituted of an actuator including two systems (that are hereinafter sometimes referred to as “first reaction force actuator **12***a*” and “second reaction force actuator **12***b*”) that become redundant systems of one another.
[0041] Each of the wheels **10** is supported by a vehicle body so that its direction is changeable via a steering knuckle **40** that is one component of a suspension device. The turning actuator **14** pivots

the steering knuckles **40** to integrally turn the two wheels **10**. The turning actuator **14** includes: (a) a steering rod (also sometimes called "rack bar") **46** coupled at both ends thereof to the right and left steering knuckles **40** via link rods **44**; (b) a housing **48** that supports the steering rod **46** such that the steering rod **46** is movable to right and left sides, and is fixedly held by the vehicle body; and (c) a rod moving mechanism **52** that uses a turning motor **50** that is an electric motor as a power source to move the steering rod **46** to the right and left sides. The rod moving mechanism **52** mainly includes a ball screw mechanism constituted of a ball groove threadedly provided in the steering rod **46**, and a nut that threadedly engages the ball groove via bearing balls and is rotated by the turning motor **50**. The turning actuator **14** has a general structure, and hence the description of the specific structure thereof is omitted.

[0042] The turning motor **50** is also a two-system three-phase brushless DC motor having a structure similar to that of the reaction force motor **26**. Hereinafter, the two systems are sometimes referred to as "first turning motor **50***a*" and "second turning motor **50***b*". Thus, the turning actuator **14** is constituted of an actuator including two systems (that are hereinafter sometimes referred to as "first turning actuator **14***a*" and "second turning actuator **14***b*") that become redundant systems of one another.

[0043] The control of the reaction force actuator **12**, in detail, the control of the operation reaction force, that is, the control of the reaction force motor **26** is executed by two reaction force electronic control units (hereinafter sometimes referred to as "reaction force ECUs") **60***a*, **60***b* that correspond to the two systems of the reaction force actuator **12** and are control drive devices for the two systems. In more detail, the control and drive of the first reaction force actuator **12***a* is performed by the first reaction force ECU **60***a*, and the control and drive of the second reaction force actuator **12***b* is performed by the second reaction force ECU **60***b*. Similarly, the control of the turning actuator **14**, in detail, the control regarding the turning of the wheels, that is, the control of the turning motor **50** is executed by two turning electronic control units (hereinafter sometimes referred to as "turning ECUs") **62***a*, **62***b* that correspond to the two systems of the turning actuator **14** and are control drive devices for the two systems. In more detail, the control and drive of the first turning actuator **14***a* is performed by the first turning ECU **62***a*, and the control and drive of the second turning actuator **14***b* is performed by the second turning ECU **62***b*. Incidentally, the first reaction force ECU **60***a* and the second reaction force ECU **60***b* are sometimes collectively referred to as "reaction force ECU **60**", and the first turning ECU **62***a* and the second turning ECU **62***b* are sometimes collectively referred to as "turning ECU **62**". It is to be noted that, in the drawings, the first reaction force ECU **60***a*, the second reaction force ECU **60***b*, the first turning ECU **62***a*, and the second turning ECU **62***b* are represented by C-ECU **60***a*, C-ECU **60***b*, S-ECU **62***a*, and S-ECU **62***b*, respectively.

[0044] As illustrated in FIG. **1**B, the reaction force ECU **60** and the turning ECU **62** (hereinafter sometimes collectively referred to as "ECUs **60**, **62**") each include an inverter **64** that is a driver (drive circuit), and a controller **66** that controls the inverter **64**. The controller **66** includes a computer constituted of a CPU, a ROM, a RAM, and the like as a main component. Electric power is supplied to the inverter **64** and the controller **66** from buses to be described later. In more detail, electric power (hereinafter sometimes referred to as "PIG electric power") is supplied to the inverter **64** via an electric power supply line indicated by "PIG" in the drawing, and electric power (hereinafter sometimes referred to as "IG electric power") is supplied to the controller **66** via an electric power supply line indicated by "IG" in the drawing. A control signal is transmitted from the controller **66** to the inverter **64**, and, based on the control signal, the inverter **64** is actuated so that a drive current I is supplied to the reaction force motor **26** or the turning motor **50**. It is to be noted that the PIG electric power and the IG electric power are supplied to the reaction force ECU **60** and the turning ECU **62**, respectively, at the same voltage, but the controller **66** is actuated at a relatively low voltage, and hence the IG electric power is supplied to the controller **66** via a step-down transformer **68**. It is to be noted that the PIG electric power becomes the drive electric power for the reaction force motor **26** or the turning motor **50**, and hence is larger than the IG electric power. That is, a current that is large to some extent is supplied to the inverter **64**.

[0045] This steering system is, when being considered as a whole, a two-system system in which the first reaction force actuator **12***a*, the first turning actuator **14***a*, the first reaction force ECU **60***a*, and the first turning ECU **62***a* configure the first system, and the second reaction force actuator **12***b*, the second turning actuator **14***b*, the second reaction force ECU **60***b*, and the second turning ECU **62***b* configure the second system. Further, from another viewpoint, the first reaction force actuator **12***a* and the second reaction force actuator **12***b* respectively function as a first system and a second system of one reaction force actuator **12**, and the first turning actuator **14***a* and the second turning actuator **14***b* respectively function as a first system and a second system of one turning actuator **14**. Moreover, it is possible to regard that the first reaction force actuator **12***a* and the first turning actuator **14***a* configure a first system of one steering device, and the second reaction force actuator **12***b* and the second turning actuator **14***b* configure a second system of the one steering device. It is to be noted that one of the first system and the second system may be referred to as "main system", and the other one thereof may be referred to as "sub-system".

[0046] As illustrated in FIG. **1**A, the first reaction force ECU **60***a* and the first turning ECU **62***a* are connected to each other by a first dedicated communication line **70***a*, and the second reaction force ECU **60***b* and the second turning ECU **62***b* are connected to each other by a second dedicated communication line **70***b*. In order to allow communication to the reaction force ECU **60** or the turning ECU **62** in a different system, and in order to allow communication to another system or the like, each reaction force ECU **60** and each turning ECU **62** are connected to a car area network or controllable area network (CAN) **72** serving as a common communication line. It is to be noted that the control of the operation reaction force by the reaction force ECU **60** and the control regarding the turning of the wheels by the turning ECU **62** are general types of control, and hence the description thereof is omitted here. Incidentally, at normal times, both of the first reaction force actuator **12***a* and the first turning actuator **14***a* are evenly responsible for the operation reaction force required as a whole, and the first turning actuator **14***a* and the second turning actuator **14***b* are evenly responsible for a turning force (a force exerted for turning the wheels) required as a whole.

[B] Power Supply System

[0047] This steering system includes a power supply system as illustrated in FIG. **2**A. In more detail, the power supply system includes a first bus **82***a* and a second bus **82***b* (hereinafter sometimes collectively referred to as "bus **82**") that are two electric power supply lines disposed in series to each other via a circuit breaker **80**. At normal times, the first bus **82***a* and the second bus **82***b* are communicated with each other, and the communication is cut off by the circuit breaker **80** when some kind of event occurs. It is to be noted that both of the first bus **82***a* and the second bus **82***b* are disposed in a form of busbars.

[0048] A first converter **84***a* that is a first power supply is connected to the first bus **82***a*, and a second converter **84***b* that is a second power supply is connected to the second bus **82***b*. The first converter **84***a* and the second converter **84***b* (that are respectively indicated by "DC-DCa" and "DC-DCb" in the drawing) each receive supply of electric power from a high-voltage drive battery mounted on the vehicle, and respectively supply electric power to the first bus **82***a* and the second bus **82***b*. Further, an auxiliary battery (that is indicated by "AB" in the drawing) **86** that functions as the second power supply is connected to the second bus **82***b*. The auxiliary battery **86** is what is called a lead battery. Although illustration is omitted in the drawing, other devices such as a brake device are also connected to the first bus **82***a* and the second bus **82***b*, and the first converter **84***a*, the second converter **84***b*, and the auxiliary battery **86** supply electric power to those other devices as well. Although a detailed description is omitted, the auxiliary battery **86** also has a function of storing regenerative electric power obtained from the steering device or other devices. It is to be noted that, in the following description, the first converter **84***a*, the second converter **84***b*, and the auxiliary battery **86** are sometimes collectively referred to as "normal power supply".

[0049] Although a detailed description is omitted, as compared to the voltage of the electric power from the first converter **84***a*, the voltage of the electric power from the second converter **84***b* is set to be slightly lower, and the electric power is normally supplied from the first converter **84***a*. When the communication between the first bus **82***a* and the second bus **82***b* is cut off by the circuit breaker **80**, electric power can be supplied to the first bus **82***a* from the first converter **84***a*, and electric power can be supplied to the second bus **82***b* from the second converter **84***b*.
[0050] The first reaction force ECU **60***a* and the first turning ECU **62***a* that are each the first system of the control drive device are connected to the first bus **82***a*, and the second reaction force ECU **60***b* and the second turning ECU **62***b* that are each the second system of the control drive device are connected to the second bus **82***b*. In more detail, the first reaction force ECU **60***a* and the first turning ECU **62***a* are connected to the first bus **82***a* such that the PIG electric power is directly input thereto from the first bus **82***a*, and the second reaction force ECU **60***b* and the second turning ECU **62***b* are connected to the second bus **82***b* such that the PIG electric power is directly input thereto from the second bus **82***b*.
[0051] Meanwhile, this power supply system includes a backup power supply device (that is indicated by "BPS" in the drawing) **88**. The first reaction force ECU **60***a* and the first turning ECU **62***a* are connected to the first bus **82***a* such that the IG electric power is input thereto from the first bus **82***a* via the backup power supply device **88**, and the second reaction force ECU **60***b* and the second turning ECU **62***b* are connected to the second bus **82***b* such that the IG electric power is input thereto from the second bus **82***b* via the backup power supply device **88**. In more detail, the backup power supply device **88** has an internal configuration as schematically illustrated in FIG. **2**B, and is configured such that the IG electric power from the first bus **82***a* passes through itself to be transmitted to the first reaction force ECU **60***a* and the first turning ECU **62***a* and the IG electric power from the second bus **82***b* passes through itself to be transmitted to the second reaction force ECU **60***b* and the second turning ECU **62***b*.
[0052] In further more detail, the backup power supply device **88** includes four rectifiers **90** and a capacitor (that is indicated by "CAP" in the drawing) **92**. The four rectifiers **90** each permit passage of a current in one direction, and each inhibit passage of a current in the opposite direction. The capacitor **92** is a battery having a relatively small capacity. In more detail, the four rectifiers **90** are each what is called a diode, and include a first main rectifier **90***am* provided on a first main path **94***a* provided for outputting the IG electric power from the first bus **82***a* to the first reaction force ECU **60***a* and the first turning ECU **62***a*, a second main rectifier **90***bm* provided in a second main path **94***b* provided for outputting the IG electric power from the second bus **82***b* to the second reaction force ECU **60***b* and the second turning ECU **62***b*, a first sub-rectifier **90***as* provided in a first sub-path **96***a* that provides connection between the capacitor **92** and a part of the first main path **94***a* on the downstream side of the first main rectifier **90***am*, and a second sub-rectifier **90***bs* provided in a second-sub path **96***b* that provides connection between the capacitor **92** and a part of the second main path **94***b* on the downstream side of the second main rectifier **90***bm*.
[0053] The capacitor **92** can supply electric power having a voltage slightly lower than the voltage of the IG electric power supplied from the first bus **82***a* and the second bus **82***b*. Accordingly, when the IG electric power is supplied from the first bus **82***a*, the IG electric power is supplied to the first reaction force ECU **60***a* and the first turning ECU **62***a*, and, when the IG electric power is supplied from the second bus **82***b*, the electric power is supplied to the second reaction force ECU **60***b* and the second turning ECU **62***b*. In addition, when the supply of the IG electric power from the first bus **82***a* is cut off, the electric power from the capacitor **92** is supplied as the IG electric power to the first reaction force ECU **60***a* and the first turning ECU **62***a*, and, when the supply of the IG electric power from the second bus **82***b* is cut off, the electric power from the capacitor **92** is supplied as the IG electric power to the second reaction force ECU **60***b* and the second turning ECU **62***b*. That is, the backup power supply device **88** is configured to cause the IG electric power supplied to the ECUs **60**, **62** of the first system and the second system from the first bus **82***a* and

the second bus **82***b* to pass through itself, and, when the supply of the IG electric power from both of the first bus **82***a* and the second bus **82***b* is cut off, supply the IG electric power to both of the ECUs **60**, **62** of the first system and the second system from the battery included in itself automatically, that is, without requiring any special control. In other words, the backup power supply device **88** is configured to use a voltage difference to switch the supply source of the electric power from the normal power supply to the battery included in itself instantly, that is, without a time lag. Incidentally, the backup power supply device may supply the PIG electric power as well, but the capacitor **92** has a small capacity, and hence, when the PIG electric power is supplied as well, the electric power can be supplied only for a relatively short time.

[0054] Incidentally, although the illustration is omitted in the drawing, the backup power supply device **88** includes a circuit that receives supply of electric power from at least one of the first bus **82***a* and the second bus **82***b* to charge the capacitor **92**, and, at normal times, the capacitor **92** maintains a charged state.

[0055] It is to be noted that, as illustrated in FIG. **2**A, switches (indicated by “SW” in the drawing) **98** that are switching devices are provided between the first bus **82***a* and each of the first converter **84***a*, the first reaction force ECU **60***a*, the first turning ECU **62***a*, and the backup power supply device **88** and between the second bus **82***b* and each of the second converter **84***b*, the second reaction force ECU **60***b*, the second turning ECU **62***b*, and the backup power supply device **88**. In simple terms, the switches **98** are brought to a closed state when an ignition switch of the vehicle is ON, and are brought to an open state when the ignition switch is OFF. Although a detailed description is omitted, the actuation of the switches **98** and the actuation of the circuit breaker **80** are controlled by a domain controller (that is indicated by “DCNT” in the drawing) **100** that is a control device.

[C] Problem that Occurs when Bus has Ground Fault And how to Address this Problem

[0056] In this steering system including the above-mentioned power supply system (hereinafter sometimes referred to as “the power supply system of the embodiment”), as described above, at normal times, the first bus **82***a* and the second bus **82***b* are communicated with each other, and the electric power is supplied from the first converter **84***a* to all of the first reaction force ECU **60***a*, the first turning ECU **62***a*, the second reaction force ECU **60***b*, and the second turning ECU **62***b*.

[0057] In this steering system, for example, there is considered a case in which, as indicated by the long dashed double-short dashed line in FIG. **2**A, a ground fault, that is, a short-circuit that drops a voltage to a ground potential occurs in the first bus **82***a*. In this case, since the first bus **82***a* and the second bus **82***b* are communicated with each other, no electric power is supplied from any of the first converter **84***a*, the second converter **84***b*, and the auxiliary battery **86** to any of the reaction force ECUs **60***a*, **60***b* and the turning ECUs **62***a*, **62***b*. In view of the foregoing, in this steering system, when the ground fault as described above occurs, the circuit breaker **80** cuts off the communication between the first bus **82***a* and the second bus **82***b* so that the supply of the electric power from the second converter **84***b* to the second reaction force ECU **60***b* and the second turning ECU **62***b* via the second bus **82***b* is ensured.

[0058] However, when the ground fault occurs, a time lag occurs to some extent from the detection of the occurrence of the ground fault until the actuation of the circuit breaker **80**. While the time lag is occurring, that is, until the supply of the electric power from the second converter **84***b* to the second reaction force ECU **60***b* and the second turning ECU **62***b* is recovered, there arises a problem that no electric power is supplied to any of the second reaction force ECU **60***b* and the second turning ECU **62***b*. In particular, when the supply of the IG electric power to the controller **66** of the ECU **60** is cut off even for a moment, the actuation of the controller **66** is reset. Thus, when the first bus **82***a* has a ground fault, even when the supply of the electric power to the second reaction force ECU **60***b* and the second turning ECU **62***b* is recovered, the second system of the steering device is not appropriately actuated. That is, there may arise a problem that both of the first system and the second system of the steering device are not appropriately actuated.

[0059] In order to address the above-mentioned problem, in this steering system, even during the time lag, the supply of the IG electric power is automatically continued from the backup power supply device **88** to the controllers **66** of the second reaction force ECU **60***b* and the second turning ECU **62***b*. Thus, after the supply of the electric power from the second converter **84***b* is recovered, the appropriate actuation of the second system of the steering device is ensured by the electric power.
[0060] The description above is description of a case in which the first bus **82***a* has a ground fault, but a similar problem arises even when the second bus **82***b* has a ground fault. Although a detailed description is omitted, even when the second bus **82***b* has a ground fault and a time lag occurs, during the time lag, the supply of the IG electric power is automatically continued from the backup power supply device **88** to the controllers **66** of the first reaction force ECU **60***a* and the first turning ECU **62***a*. Thus, after the supply of the electric power from the first converter **84***a* via the first bus **82***a* is recovered, the appropriate actuation of the first system of the steering device is ensured by the electric power. That is, in this steering system, even when the ground fault occurs in any of the first bus **82***a* and the second bus **82***b*, appropriate actuation of a corresponding one of the first system and the second system of the steering device is ensured.
[D] Regarding Power Supply System of Related Art
[0061] The power supply system of the related art is illustrated in FIG. **3**A. In the following description, the same components as the power supply system of the steering system of the embodiment are denoted by the same reference symbols, and a detailed description thereof is omitted.
[0062] In the power supply system of the related art, a backup power supply device **110** is configured to perform backup only for the first system. In more detail, when the supply of the electric power from the first bus **82***a* is cut off, the backup power supply device **110** supplies not only the IG electric power but also the PIG electric power from the capacitor **92** to the first reaction force ECU **60***a* and the first turning ECU **62***a*.
[0063] Incidentally, regarding the PIG electric power, relatively large current supply is caused, and hence the backup power supply device **110** can switch from the electric power supply from the first bus **82***a* to the electric power supply from the capacitor **92** by semiconductor switching elements **112** instead of the rectifiers **90**. Although a detailed description is omitted, the backup power supply device **110** has a built-in controller, and the actuation of the switching elements **112** is controlled by the controller depending on the electric power from the capacitor **92**.
[0064] According to the power supply system of the related art, for example, when a ground fault occurs in the second bus **82***b*, the circuit breaker **80** cuts off the communication between the first bus **82***a* and the second bus **82***b*. Thus, even during a period until the electric power supply from the first bus **82***a* is recovered, the backup power supply device **110** suppresses an interruption of the supply of the IG electric power to the first reaction force ECU **60***a* and the first turning ECU **62***a*. Further, after the electric power supply from the first bus **82***a* is recovered, the appropriate actuation of the first system of the steering device is maintained by the electric power. Incidentally, the second system of the steering device is not actuated from when the ground fault occurs.
[0065] In contrast, when the ground fault occurs in the first bus **82***a*, during a period from the time point at which the ground fault occurs to when the communication between the first bus **82***a* and the second bus **82***b* is cut off by the circuit breaker **80**, no electric power is supplied to the second reaction force ECU **60***b* and the second turning ECU **62***b*, and the actuation of the controllers **66** of the second reaction force ECU **60***b* and the second turning ECU **62***b* is reset. As a result, even when the supply of the electric power from the second bus **82***b* is recovered, the second system of the steering device is not actuated appropriately. Meanwhile, the first system of the steering device is actuated by receiving the electric power supply from the backup power supply device **110**, and cannot be actuated after the electricity amount stored in the capacitor **92** runs out. This time of actuation is relatively short. That is, in the power supply system of the related art, when the ground

fault occurs in the first bus **82**_a_, only the first system of the steering device is appropriately actuated, but the actuation does not always continue for a sufficient time. The power supply system of the related art experiences such a problem.

[0066] As described above, in the steering system of the embodiment, even when the ground fault occurs in any of the first bus **82**_a_ and the second bus **82**_b_, the appropriate actuation of a corresponding one of the first system and the second system of the steering device is ensured for a sufficient time, and the problem experienced by the power supply system of the related art is solved.

[E] Modification Examples of Power Supply System

[0067] The steering system of the embodiment can adopt some power supply systems other than the power supply system of the above-mentioned embodiment. In the following, some modification examples of the power supply system that can be adopted in the steering system of the embodiment are simply described.

[0068] A power supply system of a first modification example is a system in which, as illustrated in FIG. **4**A, where the backup power supply device **110** adopted in the power supply system of the related art is provided not only on the first system side but also on the second system side. With this system, although two backup power supply devices are required, even when the ground fault occurs in any of the first bus **82**_a_ and the second bus **82**_b_, during the time lag described above, also the IG electric power is supplied to all of the first reaction force ECU **60**_a_, the first turning ECU **62**_a_, the second reaction force ECU **60**_b_, and the second turning ECU **62**_b_. Accordingly, one of the first system and the second system of the steering device on the side without the ground fault is continuously actuated appropriately through recovery of the electric power supply from a corresponding one of the first bus **82**_a_ and the second bus **82**_b_. The other one of the first system and the second system of the steering device on the side with the ground fault is appropriately actuated although it is as long as the electric power stored in the capacitor **92** of the backup power supply device **110** continues. This power supply system requires two backup power supply devices, but a steering system having a higher reliability can be constructed.

[0069] It is to be noted that this power supply system can be considered to configure, by the two backup power supply devices, one backup power supply device that automatically supplies, when the supply of the electric power from both of the first bus **82**_a_ and the second bus **82**_b_ is cut off, the electric power from the battery included in itself to the controllers **66** of all of the first reaction force ECU **60**_a_, the first turning ECU **62**_a_, the second reaction force ECU **60**_b_, and the second turning ECU **62**_b_. It is to be noted that, in the backup power supply device **110**, the supply source of the PIG electric power may be automatically switched between the first bus **82**_a_ or the second bus **82**_b_ and the capacitor **92** by the rectifiers **90**, similarly to the IG electric power.

[0070] A power supply system of a second modification example is configured to supply, as illustrated in FIG. **4**B, the IG electric power also to the second reaction force ECU **60**_b_ and the second turning ECU **62**_b_ via the backup power supply device **110** adopted in the power supply system of the related art. Accordingly, unlike the power supply system of the related art, even when the ground fault occurs in the first bus **82**_a_, the above-mentioned time lag does not occur in the second system of the steering device, and the appropriate actuation of the second system of the steering device is maintained through the recovery of the electric power supply from the second bus **82**_b_.

[0071] A power supply system of a third modification example includes, as illustrated in FIG. **5**A, one backup power supply device **120**, and the backup power supply device **120** includes one capacitor **122**. As illustrated in FIG. **5**B, the backup power supply device **120** is configured to receive the IG electric power and the PIG electric power from each of the first bus **82**_a_ and the second bus **82**_b_, and to supply, when the electric power supply from the first bus **82**_a_ and the second bus **82**_b_ is cut off, the IG electric power and the PIG electric power from the capacitor **122** to the first reaction force ECU **60**_a_, the first turning ECU **62**_a_, the second reaction force ECU **60**_b_, and the second turning ECU **62***b*.

[0072] With this power supply system, similarly to the power supply system of the first modification example, even when the ground fault occurs in any of the first bus **82***a* and the second bus **82***b*, during the time lag described above, the IG electric power is supplied to all of the first reaction force ECU **60***a*, the first turning ECU **62***a*, the second reaction force ECU **60***b*, and the second turning ECU **62***b*. After the electric power supply from one of the first bus **82***a* and the second bus **82***b* without the ground fault is recovered, the appropriate actuation of a corresponding one of the first system and the second system of the steering device is maintained by the electric power. In addition, a corresponding one of the first system and the second system of the steering device on the side with the ground fault is also appropriately actuated although it is until the electric power stored in the capacitor **122** runs out. Incidentally, as compared to the capacitor **92** included in the backup power supply device **110** of the power supply system of the first modification example, the capacitor **122** included in the backup power supply device **120** of this power supply system has a larger capacity, and an appropriate actuation time of any of the first system and the second system of the steering device on the side with the ground fault is relatively long. It is to be noted that, in the backup power supply device **120** as well, the supply source of the PIG electric power may be automatically switched between a corresponding one of the first bus **82***a* and the second bus **82***b* and the capacitor **122** by the rectifiers **90**, similarly to the IG electric power.

[0073] Some power supply systems have been described above, but, in all of the power supply systems, the first converter **84***a* is connected to the first bus **82***a*, and the second converter **84***b* and the auxiliary battery **86** are connected to the second bus **82***b*. In the power supply system that can be adopted in the steering system of the embodiment, the auxiliary battery **86** may be connected to the first bus **82***a*. Further, both of the first converter **84***a* and the second converter **84***b* may be connected to one of the first bus **82***a* and the second bus **82***b*, and only the auxiliary battery **86** may be connected to the other one thereof.

[F] Ending Processing of Control Drive Device

[0074] Each of the first reaction force ECU **60***a*, the first turning ECU **62***a*, the second reaction force ECU **60***b*, and the second turning ECU **62***b* executes the processing for ending its own actuation. In a steering system including no backup power supply, its own actuation has been ended when, for example, two conditions are satisfied, that is, no electric power is actually supplied from the normal power supply, that is, the corresponding switch **98** is brought to a closed state and the electric power (voltage) supplied to itself is reduced. Incidentally, switch opening-closing information that is information about opening and closing of the corresponding switch **98** is transmitted by the domain controller **100** via the CAN **72**.

[0075] However, when the power supply system including the backup power supply device is adopted, the electric power is supplied from the backup power supply device even when no electric power is supplied from the normal power supply, and hence it is not preferred to end its own actuation when the above-mentioned two conditions are satisfied. In view of the foregoing, in the steering system of the embodiment, the backup power supply device **88**, **110**, **120** detects a BPS input voltage that is an input-side voltage and transmits a BPS input voltage signal that is a signal about the BPS input voltage to the ECUs **60**, **62** via the CAN **72**. The corresponding ECUs **60**, **62** end their own processing based on the signal.

[0076] Specifically, the controllers **66** of the ECUs **60**, **62** connected to the backup power supply device end their own actuation in accordance with the ending processing program shown in the flowchart of FIG. **6**. The ending processing is described along the flowchart. The controllers **66** of the ECUs **60**, **62** first acquire the switch opening-closing information in Step **1** (hereinafter abbreviated as "S**1**". The same holds true in the other steps.), and, in S**2**, receive the BPS input voltage signal. Then, when, in S**3**, two conditions of the closed state of the switch **98** and the reduction of the BPS input voltage of the backup power supply device **88**, **110**, **120** (for example, the BPS input voltage of substantially 0 V) are satisfied, in S**4**, the controllers **66** stop their own actuation. That is, the actuation of the reaction force actuator **12** and the turning actuator **14** that are controlled and driven by the ECUs **60**, **62** including the controllers **66** is stopped. It is to be noted that this ending processing program is repeatedly executed in a short time interval.

Claims

1. A steering system to be mounted on a vehicle, the steering system comprising: a steering device including two systems of a first system and a second system, the two systems each including a power source; a control drive device including two systems of a first system and a second system to control and drive the first system and the second system of the steering device, respectively, the two systems of the control drive device each including a driver that drives the power source and a controller that controls the driver; two electric power supply buses connected in series to each other, the two electric power supply buses including a first bus to which the first system of the control drive device is connected to supply electric power to the first system of the control drive device, and a second bus to which the second system of the control drive device is connected to supply electric power to the second system of the control drive device; a circuit breaker that disconnects the first bus and the second bus; a first power supply connected to the first bus and a second power supply connected to the second bus; and a backup power supply device that includes a battery and is configured to supply electric power from the battery, wherein the steering system is configured such that, at normal times, in a state in which the first bus and the second bus are communicated with each other, electric power is supplied from at least one of the first power supply and the second power supply, and, when one of the first bus and the second bus has a ground fault, the circuit breaker disconnects the first bus and the second bus such that the electric power is supplied via another one of the first bus and the second bus from a corresponding one of the first power supply and the second power supply connected to the other one of the first bus and the second bus to a corresponding one of the first system and the second system of the control drive device connected to the other one of the first bus and the second bus, and the backup power supply device is configured to cause the electric power supplied from at least one of the first bus and the second bus to pass through itself, and, when supply of the electric power is cut off, automatically supply the electric power from the battery included in itself to at least the controllers of both of the first system and the second system of the control drive device.
2. The steering system according to claim 1, wherein: the steering system is a steer-by-wire steering system; each of the first system and the second system of the steering device includes a turning actuator including the power source to turn a wheel, and a reaction force actuator including the different power source to apply an operation reaction force to a steering operation member; and each of the first system and the second system of the control drive device includes the control drive device for the turning actuator and the control drive device for the reaction force actuator.
3. The steering system according to claim 1, wherein the backup power supply device is configured to supply, with respect to both of the first system and the second system of the control drive device, the electric power from the battery to only the controller out of the driver and the controller.
4. The steering system according to claim 1, wherein the backup power supply device is configured to supply, with respect to at least one of the first system and the second system of the control drive device, the electric power from the battery to both of the driver and the controller.
5. The steering system according to claim 1, wherein the backup power supply device includes a first backup power supply device configured to supply the electric power to the first system of the control drive device, and a second backup power supply device configured to supply the electric power to the second system of the control drive device.