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Charging through electric drive system with minimum torque disturbance

Abstract

An electric vehicle includes a system performing a method of charging a battery of the electric vehicle. The system includes an electrical motor having a rotor and a plurality of windings. The vehicle is turned off to allow the rotor to come to rest at an initial rotor position. The processor controls a current through the motor to rotate the rotor to locate a boundary of an electrical lash region associated with the rotor, determines a selected winding of the plurality of windings having a phase vector located close to the electrical lash region, deactivates the selected winding, controls flow of a first current through the motor with the selected winding deactivated to rotate the rotor towards a direction of the selected winding, and controls flow of a second current from a charging station to the battery through the electric motor with the rotor rotated towards the selected winding.

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Background/Summary

INTRODUCTION

(1) The subject disclosure relates to charging an electric vehicle through a motor and drive system of the electric vehicle and, in particular, to a method of arranging a rotor of the motor prior to charging to prevent a torque occurring at the motor during a charging operation.

(2) Charging stations for electric vehicles generally have enough power to charge currently available electric vehicle. Thus, a charging station for electric vehicles that operate off of a predetermined voltage has the capacity to charge at that voltage. Newer electric vehicles are being considered that operate at higher voltages. In order for current charging stations to be compatible with these newer electric vehicles, a circuit can be designed to allow additionally charging through the electric motor of the vehicle. However, when doing so, the charging current passing through the motor can create a magnetic torque that causes the rotor to rotate, which can result in an unwanted jerking of the vehicle. Accordingly, it is desirable to provide a system and method for charging the battery through the motor without generating a torque at the rotor.

SUMMARY

(3) In one exemplary embodiment, a method of charging a battery of an electric vehicle is disclosed. The electric vehicle is turned off to allow a rotor of an electric motor of the electric vehicle to come to rest at an initial rotor position, the electric motor including a plurality of windings. A boundary of an electrical lash region associated with the rotor is located. A selected winding of the plurality of windings is determined, the selected winding having a phase vector located close to the electrical lash region. The selected winding is deactivated. A current is flowed through the electric motor with the selected winding deactivated to rotate the rotor towards a

direction of the selected winding. The battery is charged through the electric motor with the rotor rotated towards the selected winding.

(4) In addition to one or more of the features described herein, locating the boundary of the electrical lash region further includes flowing the current through the electric motor to rotate the rotor. For the electric motor including three windings, the method further includes flowing the current through the three windings to rotate the rotor to locate the boundary of the electrical lash region. An angular range of the electrical lash region is related to a free rotation region allowed by a gear mesh of a transmission and a number of pole pairs at the electric motor. The method further includes measuring an angular location of the rotor using a rotor position sensor. The method further includes rotating the rotor into alignment with the deactivated winding using the current from at least one of the battery and a charging station. The method further includes charging the battery via a direct connection between a charging station and the battery and an indirect connection between the charging station and the battery via the electric motor.

(5) In another exemplary embodiment, a system for charging a battery of an electric vehicle is disclosed. The system includes an electric motor having a rotor and a plurality of windings, wherein the rotor comes to rest at an initial rotor position when the electric vehicle is turned off, and a processor. The processor is configured to control a current through the electric motor to rotate the rotor to locate a boundary of an electrical lash region associated with the rotor, determine a selected winding of the plurality of windings, the selected winding having a phase vector located close to the electrical lash region, deactivate the selected winding, control flow of a first current through the electric motor with the selected winding deactivated to rotate the rotor towards a direction of the selected winding, and control flow of a second current from a charging station to the battery through the electric motor with the rotor rotated towards the selected winding.

(6) In addition to one or more of the features described herein, the processor is further configured to locate the boundary of the electrical lash region by observing a location at which the rotor stops rotation without an increase in the first current through the electric motor. For the electric motor including three windings, the processor is further configured to control flow of the first current through the three windings to rotate the rotor to locate the boundary of the electrical lash region. An angular range of the electrical lash region is related to a free rotation region allowed by a gear mesh of a transmission and a number of pole pairs at the electric motor. The system further includes a rotor position sensor configured to measure an angular location of the rotor. The processor is further configured to rotate the rotor into alignment with the selected winding using the first current from at least one of the battery and the charging station. The charging station is configured to charge the battery via a direct connection between the charging station and the battery and an indirect connection between the charging station and the battery via the electric motor.

(7) In yet another exemplary embodiment, an electric vehicle is disclosed. The electric vehicle includes a battery, an electric motor having a rotor and a plurality of windings, wherein the rotor comes to rest at an initial rotor position when the electric vehicle is turned off, and a processor. The processor is configured to control a current through the electric motor to rotate the rotor to locate a boundary of an electrical lash region associated with the rotor, determine a selected winding of the plurality of windings, the selected winding having a phase vector located close to the electrical lash region, deactivate the selected winding, control flow of a first current through the electric motor with the selected winding deactivated to rotate the rotor towards a direction of the selected winding, and control flow of a second current from a charging station to the battery through the electric motor with the rotor rotated towards the direction of the selected winding.

(8) In addition to one or more of the features described herein, the processor is further configured to locate the boundary of the electrical lash region by observing a location at which the rotor stops rotation without an increase in the first current through the electric motor. For the electric motor including three windings, the processor is further configured to control flow of the first current through the three winding to rotate the rotor to locate the boundary of the electrical lash region. An

angular range of the electrical lash region is related to a free rotation region allowed by a gear mesh of a transmission and a number of pole pairs at the electric motor. The electric vehicle further includes a rotor position sensor configured to measure an angular location of the rotor. The processor is further configured to rotate the rotor into alignment with the deactivated winding at least one of the first current from the battery and the second current from the charging station.
(9) The above features and advantages, and other features and advantages of the disclosure are readily apparent from the following detailed description when taken in connection with the accompanying drawings.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) Other features, advantages and details appear, by way of example only, in the following detailed description, the detailed description referring to the drawings in which:
(2) FIG. **1** shows an electric vehicle in accordance with an exemplary embodiment;
(3) FIG. **2** is a circuit diagram showing a circuit that allows charging of the electrical drive system of the electric vehicle;
(4) FIG. **3** shows a phase diagram showing the phase vectors for the windings of the electric motor shown in FIG. **2**;
(5) FIG. **4** shows the phase diagram illustrating stable phase location of a rotor during a charging operation under different winding configuration;
(6) FIG. **5** shows a graph illustrating a relation of rotation angle for a wheel of the electric vehicle and a torque applied at the wheel;
(7) FIG. **6** shows a schematic diagram of a torque transmission system;
(8) FIG. **7** shows a phase diagram illustrating an initial rotor position of the rotor and an electrical lash region associated with the rotor;
(9) FIG. **8** shows a flowchart of a method for detecting a boundary of the electrical lash region; and
(10) FIG. **9** shows a flowchart of a method for charging the battery through the electric motor.
DETAILED DESCRIPTION
(11) The following description is merely exemplary in nature and is not intended to limit the present disclosure, its application or uses. It should be understood that throughout the drawings, corresponding reference numerals indicate like or corresponding parts and features.
(12) In accordance with an exemplary embodiment, FIG. **1** shows an electric vehicle **100**. The electric vehicle **100** includes an electrical system **102** including an electrical drive system **104** which controls operation of the electric vehicle to cause the electric vehicle to move. The electrical system **102** can also include an electrical load **106** which operates using power provided by the electrical system **102**. The electrical load **106** can include accessory loads, such as radio, air conditioning, power windows, etc. As shown in FIG. **1**, the electric vehicle is plugged into a charging station **110** which charges a battery of the electrical drive system **104**.
(13) The electric vehicle **100** further includes a controller **112**. The controller **112** may include processing circuitry that may include an application specific integrated circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group) and memory that executes one or more software or firmware programs, a combinational logic circuit, and/or other suitable components that provide the described functionality. The controller **112** may include a non-transitory computer-readable medium that stores instructions which, when processed by one or more processors of the controller **112**, implement a method of controlling a charging operation for the electrical drive system **104**.
(14) FIG. **2** is a circuit diagram **200** showing a circuit that allows charging of the electrical drive system **104** of the electric vehicle **100**. The electrical drive system **104** includes a battery **202**, an

electric motor **204** and an inverter **206** that couples the battery **202** to the electric motor **204**. During normal operation of the electric vehicle, the battery **202** provides power through the inverter **206** to the electric motor **204**. The electric motor **204** can have a plurality of windings. For illustrative purposes, the electric motor **204** is a four-terminal motor including three windings and a neutral point **214**. The three windings include a first winding **208** (an A winding), a second winding **210** (a B winding) and a third winding **212** (a C winding). The first winding **208**, second winding **210** and third winding **212** connect between the inverter **206** and the electric motor **204** to provide a three-phase current to the motor.

(15) The electric vehicle **100** connects to the charging station **110** via positive bus line **216** and negative bus line **218**. The positive bus line **216** and the negative bus line **218** connect the charging station **110** directly to the positive and negative terminals of the battery **202**, respectively. A positive line switch **220** and a negative line switch **222** can be closed at the beginning of the charging operation and opened at the end for the charging operation. An auxiliary charging line **224** connects from the positive bus line **216** to the neutral point **214** of the electric motor **204** and creates an indirect connection between the charging station **110** and the battery **202** via the electric motor **204** and the inverter **206**. An auxiliary charging switch **226** is located on the auxiliary charging line **224** and can be closed at the beginning of the auxiliary charging operation and opened at the end of the auxiliary charging operation, as discussed herein.

(16) During a charging operation, one of the windings can be disconnected or deactivated. The winding can be deactivated by controlling the switches of the inverter associated within the winding. For illustrative purposes, the first winding **208** has been selected to be deactivated during the charging operation. The first winding **208** is deactivated by closing switches **230** and **232**. Subsequent charging then occurs through the remaining active windings (e.g., second winding **210** and third winding **212**).

(17) FIG. **3** shows a phase diagram **300** showing the phase vectors (or phasors) for the windings of the electric motor **204** shown in FIG. **2**. Three active phase vectors A+, B+ and C+ are shown which represent the phase vector locations of the first winding **208**, second winding **210**, and third winding **212**, respectively. Each winding carries current with a same magnitude but out of phase with each other by 120 degrees. For illustrative purposes, the active phase vector A+ is located at 0°, the active phase vector B+ is located at 120° and the active phase vector C+ is located at 240°. The active phase vectors A+, B+, C+ represent the phases of current in each winding during a normal or active operating mode for the electric vehicle in which current is supplied from the battery **202** to the electric motor **204**. For each active phase vector, there is a corresponding passive phase vector indicating the phases of current through each of the windings during charging of the battery through the motor, (i.e., with current flowing the opposite direction as for the active mode). Passive phase vector A− is related to charging through the A winding, passive phase vector B− is related to charging through the B winding, and passive phase vector C− is related to charging through the C winding. Each passive phase vector is 180 degrees opposite its corresponding active phase vector on the phase diagram **300**.

(18) The phase diagram **300** further shows a torque resulting from operation of the electric motor in a passive phase. For illustrative purposes, the A winding is deactivated, and the B winding and C winding are active. By flowing current through the B winding during a charging operation, a first torque **302** is generated in the direction of the passive phase vector B−. Similarly, by flowing current through the C winding during the charging operation, a second torque **304** is generated in the direction of the passive phase vector C−. The combination of the first torque **302** and the second torque **304** creates in an active torque **306** along the direction of the active phase vector A+. This active torque **306** can produce a torque at the wheel, resulting in a jerking of the automobile.

(19) FIG. **4** shows the phase diagram **400** illustrating the stable phase location of a rotor during a charging operation under a different winding configuration. An initial angular position **402** of the rotor is shown. In a configuration in which the A winding is disabled (i.e., B winding and C

winding are active), the flow of current through the active windings results in the rotor settling at a first stable location **404** in the vicinity of the A− axis. Similarly, in a configuration in which the B winding is disabled (i.e., A winding and C winding are active), the flow of current through the active windings results in the rotor settling at a second stable location **406** in the vicinity of the B− axis. Finally, in a configuration in which the C winding is disabled (i.e., A winding and B winding are active), the flow of current through the active windings results in the rotor settling at a third stable location **408** in the vicinity of the C− axis.

(20) FIG. **5** shows a graph **500** illustrating a relation of rotation angle for a wheel of the electric vehicle **100** and a torque applied at the wheel. Rotation angle is shown (in degrees) along the abscissa and applied torque is shown (in Newton-meters) along the ordinate axis. At a present location of the wheel (i.e., rotation angle=0), there is a free rotation region **502** in which the wheel is able to rotate without any or with very little torque applied. Rotation of the wheel outside of this region requires either increasing positive torque **504** (e.g., in a forward rotation) or increasing negative torque **506** (e.g., in a backward rotation). For illustrative purposes, the free rotation region **502** is about 2.2 degrees.

(21) FIG. **6** shows a schematic diagram **600** of a torque transmission system. The torque transmission system includes the rotor **602** of the electric motor **204** and a shaft **604** that connects to a wheel of the electric vehicle. A rotor position sensor **606** can be used to measure an angular position or angular location of the rotor **602**. A gear system **608** includes two or more gears that transfer the torque from the rotor **602** to the shaft **604** to rotate the wheel. For illustrative purposes, a gear ratio of the gear system **608** is R.sub.gear=13.26. The gear ratio can be associated with one or more gear meshes of the torque transmission system. The gear system **608** translates the free rotation region **502** of the wheel to a mechanical lash region at the rotor **602**, as shown in Eq. (1):

(22) $\text{lash}_{\text{mech}} = (\text{freerotationregion}) \times R \quad \text{Eq. (1)}$

The mechanical lash region is an angular range of free rotation for the rotor **602**. For the free rotation region shown in FIG. **5**, the mechanical lash region for the rotor **602** has an angular range equal to (2.2°)(13.26)=29.172°.

(23) FIG. **7** shows a phase diagram **700** illustrating an initial rotor position **702** of the rotor **602** and an electrical lash region **704** associated with the rotor **602**. The electrical lash region **704** is a range of free motion for the rotor as represented in the phase diagram **700** and is related to the mechanical lash region of the rotor **602** by the number of pole pairs in the motor, as shown in Eq. (2):

(24) $\text{lash}_{\text{elec}} = (\#\text{polepairs}) \times \text{lash}_{\text{mech}} \quad \text{Eq. (2)}$

For illustrative purposes, the motor includes four pole pairs. Thus, for a mechanical lash region having about 30 degrees, the angular range for the electrical lash region is about 120 degrees.

(25) The initial rotor position **702** is a location at which the rotor comes to rest when the electric vehicle or electric motor is turned off. The electrical lash region **704** surrounds the initial rotor position **702** at all times. The placement of the electric lash diagram within the phase diagram **700** is generally unknown once the motor comes to a stop. The methods disclosed herein determine the angular boundaries of the electrical lash region **704** and therefore determine which active phase vector (i.e., A+, B+ or C+) lies within the electrical lash region.

(26) For illustrative purposes, the initial rotor position **702** is at about 90 degrees. A small current can be passed through the electric motor to generate a torque on the rotor **602**, causing the rotor to rotate. The rotor position and applied current are measured during the rotation. During a counterclockwise rotation, the rotor runs up against a first angular boundary **706** of the electrical lash region **704**. The first angular boundary **706** can be detected by observing a resistance to motion although current is increased. Similarly, during a clockwise rotation, the rotor runs up against a second angular boundary **708**, which can be detected using a similar observation. Once the boundaries of the electrical lash region **704** have been located, it can be determined which of the active phase vectors (A+, B+, C+) lies within the electrical lash region. The winding associated

with the active phase vector that lies within the electrical lash region **704** (e.g., the A winding) can then be selected and deactivated.

(27) FIG. **8** shows a flowchart **800** of a method for detecting a boundary of the electrical lash region. In box **802**, the motor is turned off, allowing the rotor to come to rest at an initial rest position. In box **804**, a small current is run through the motor to rotate the rotor clockwise and counterclockwise to locate the angular boundaries of an electrical lash region associated with the rotor. In box **806**, an active phase vector that lies within the electrical lash region or close to the electrical lash region is selected. The phase vector that is considered to be close to the electrical lash region is the phase vector that is closest to the electrical lash region (of all of the phase vectors). In an embodiment, the selected phase vector is an active phase vector. In box **808**, a winding associated with the selected phase vector is deactivated.

(28) FIG. **9** shows a flowchart **900** of a method for charging the battery through the electric motor **204**. In box **902**, with the selected winding deactivated, an electrical current is run through the active windings to cause the rotor to rotate to towards the direction of the deactivated winding. Rotating the rotor toward the direction of the deactivated winding can include rotating the rotor close to or into a vicinity of the deactivated winding, rotating the rotor to settle at a stable location associated with the deactivated winding, rotating the rotor to within +−5°, +−10° or +−20° of the direction of the deactivated winding, etc. Rotating the rotor can include ramping up a first current from the battery in the active windings from zero to produce the rotation at the rotor. In box **904**, the auxiliary charging switch **226** is closed. In box **906**, the charging current is ramped up slowly to produce a second current through the motor from the charging station. If the rotor is not completely aligned with the deactivated winding, this ramping up of the second current produces small, if any, torque or rotation of the rotor. In box **908**, the charging current is increased to a desired charging power level.

(29) The terms “a” and “an” do not denote a limitation of quantity, but rather denote the presence of at least one of the referenced item. The term “or” means “and/or” unless clearly indicated otherwise by context. Reference throughout the specification to “an aspect”, means that a particular element (e.g., feature, structure, step, or characteristic) described in connection with the aspect is included in at least one aspect described herein, and may or may not be present in other aspects. In addition, it is to be understood that the described elements may be combined in any suitable manner in the various aspects.

(30) When an element such as a layer, film, region, or substrate is referred to as being “on” another element, it can be directly on the other element or intervening elements may also be present. In contrast, when an element is referred to as being “directly on” another element, there are no intervening elements present.

(31) Unless specified to the contrary herein, all test standards are the most recent standard in effect as of the filing date of this application, or, if priority is claimed, the filing date of the earliest priority application in which the test standard appears.

(32) Unless defined otherwise, technical and scientific terms used herein have the same meaning as is commonly understood by one of skill in the art to which this disclosure belongs.

(33) While the above disclosure has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from its scope. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the disclosure without departing from the essential scope thereof. Therefore, it is intended that the present disclosure not be limited to the particular embodiments disclosed, but will include all embodiments falling within the scope thereof.

Claims

1. A method of charging a battery of an electric vehicle, comprising: turning off the electric vehicle to allow a rotor of an electric motor of the electric vehicle to come to rest at an initial rotor position, the electric motor including a plurality of windings; locating a boundary of an electrical lash region associated with the rotor; determining a selected winding of the plurality of windings, the selected winding having a phase vector located close to the electrical lash region; deactivating the selected winding; flowing a current through the electric motor with the selected winding deactivated to rotate the rotor towards a direction of the selected winding; and charging the battery through the electric motor with the rotor rotated towards the selected winding.
2. The method of claim 1, wherein locating the boundary of the electrical lash region further comprises flowing the current through the electric motor to rotate the rotor.
3. The method of claim 1, wherein the electric motor includes three windings, further comprising flowing the current through the three windings to rotate the rotor to locate the boundary of the electrical lash region.
4. The method of claim 1, wherein an angular range of the electrical lash region is related to a free rotation region allowed by a gear mesh of a transmission and a number of pole pairs at the electric motor.
5. The method of claim 1, further comprising measuring an angular location of the rotor using a rotor position sensor.
6. The method of claim 1, further comprising rotating the rotor into alignment with the deactivated winding using the current from at least one of: (i) the battery; and (ii) a charging station.
7. The method of claim 1, further comprising charging the battery via a direct connection between a charging station and the battery and an indirect connection between the charging station and the battery via the electric motor.
8. A system for charging a battery of an electric vehicle, comprising: an electric motor having a rotor and a plurality of windings, wherein the rotor comes to rest at an initial rotor position when the electric vehicle is turned off; a processor configured to: control a current through the electric motor to rotate the rotor to locate a boundary of an electrical lash region associated with the rotor; determine a selected winding of the plurality of windings, the selected winding having a phase vector located close to the electrical lash region; deactivate the selected winding; control flow of a first current through the electric motor with the selected winding deactivated to rotate the rotor towards a direction of the selected winding; and control flow of a second current from a charging station to the battery through the electric motor with the rotor rotated towards the selected winding.
9. The system of claim 8, wherein the processor is further configured to locate the boundary of the electrical lash region by observing a location at which the rotor stops rotation without an increase in the first current through the electric motor.
10. The system of claim 8, wherein the electric motor includes three windings, and the processor is further configured to control flow of the first current through the three windings to rotate the rotor to locate the boundary of the electrical lash region.
11. The system of claim 8, wherein an angular range of the electrical lash region is related to a free rotation region allowed by a gear mesh of a transmission and a number of pole pairs at the electric motor.
12. The system of claim 8, further comprising a rotor position sensor configured to measure an angular location of the rotor.
13. The system of claim 8, wherein the processor is further configured to rotate the rotor into alignment with the selected winding using the first current from at least one of: (i) the battery; and (ii) the charging station.
14. The system of claim 8, wherein the charging station is configured to charge the battery via a direct connection between the charging station and the battery and an indirect connection between the charging station and the battery via the electric motor.

15. An electric vehicle, comprising: a battery; an electric motor having a rotor and a plurality of windings, wherein the rotor comes to rest at an initial rotor position when the electric vehicle is turned off; a processor configured to: control a current through the electric motor to rotate the rotor to locate a boundary of an electrical lash region associated with the rotor; determine a selected winding of the plurality of windings, the selected winding having a phase vector located close to the electrical lash region; deactivate the selected winding; control flow of a first current through the electric motor with the selected winding deactivated to rotate the rotor towards a direction of the selected winding; and control flow of a second current from a charging station to the battery through the electric motor with the rotor rotated towards the direction of the selected winding.
16. The electric vehicle of claim 15, wherein the processor is further configured to locate the boundary of the electrical lash region by observing a location at which the rotor stops rotation without an increase in the first current through the electric motor.
17. The electric vehicle of claim 15, wherein the electric motor includes three windings, and the processor is further configured to control flow of the first current through the three winding to rotate the rotor to locate the boundary of the electrical lash region.
18. The electric vehicle of claim 15, wherein an angular range of the electrical lash region is related to a free rotation region allowed by a gear mesh of a transmission and a number of pole pairs at the electric motor.
19. The electric vehicle of claim 15, further comprising a rotor position sensor configured to measure an angular location of the rotor.
20. The electric vehicle of claim 15, wherein the processor is further configured to rotate the rotor into alignment with the deactivated winding at least one of: (i) the first current from the battery; and (ii) the second current from the charging station.
