

METHOD FOR ENERGY RECOVERY OF ELECTRIC VEHICLE

FIELD OF THE DISCLOSURE

The present disclosure relates to the field of motor vector control, and in particular, to a method for energy recovery of an electric vehicle.

BACKGROUND OF THE DISCLOSURE

With growing depletion of non-renewable resources such as petroleum as well as worsening of atmospheric environment, two-wheel electric vehicles are popular to people for their characteristics of small in size, quick, green and low pollution, and thus quickly become one of necessary transportation means for people. However, the cruising power of the two-wheel electric vehicles is generally not high due to the low energy density of batteries. How to efficiently recover and use regeneration energy to increase the endurance mileage becomes the focus of research on the two-wheel electric vehicles.

At present, the application of the energy recovery technology to the field of two-wheel electric vehicle is seriously inadequate. The existing energy recovery strategy for two-wheel electric vehicles is mainly that the motor works in a power generation state to recover the energy into an energy storage device while a driver operates a brake handle switch or the vehicle is in a free sliding state. However, it is found through research that the energy recovery method in this strategy has the disadvantages that the recovery efficiency is relatively low, and the driver cannot control the energy recovery power and braking intensity.

SUMMARY OF THE DISCLOSURE

An objective of the present disclosure is to provide a simple and quick method for energy recovery of an electric vehicle for solving the problems above.

5 To achieve the foregoing objective, the technical solution of the disclosure is as follows:

A method for energy recovery of an electric vehicle, including the following steps:

S1, obtaining a handle opening L and a rotation speed n of a motor by
10 sampling, and determining the handle opening L ;

S2, calculating a current handle target torque T^{**} by a handle-torque control algorithm according to the handle opening L ;

S3, calculating a current target braking torque T by a speed-torque control algorithm according to the rotation speed n of the motor; and

15 S4, controlling the motor torque to change from a current value to a target value according to the current target braking torque T , to complete an energy recovery operation.

Furthermore, step S1 includes the following steps:

S11, obtaining the handle opening L and the rotation speed n of the motor
20 by sampling, and performing filter processing;

S12, determining whether the handle opening L is smaller than an energy recovery exit threshold L_0 or not, and if the handle opening L is smaller than the energy recovery exit threshold L_0 , clearing an energy recovery enable flag $F1$, otherwise, executing step S13; and

25 S13, determining whether the handle opening L is greater than an energy

recovery enable threshold L2 or not, and if the handle opening L is greater than the energy recovery enable threshold L2, setting up the energy recovery enable flag F1.

Furthermore, step S2 includes the following steps:

5 S21, determining whether the energy recovery enable flag F1 is set up or not; if the energy recovery enable flag F1 is not set up, setting an effective interval for handle driving as the energy recovery exit threshold L0 to a maximum handle opening value L3, obtaining, by the motor, a positive torque through a current drive torque Map and making a vehicle enter an acceleration
10 state from a stationary state or a deceleration state; and if the energy recovery enable flag F1 is set up, setting an effective interval for handle braking as the energy recovery exit threshold L0 to a preset handle threshold L1, and setting the effective interval for handle driving as the preset handle threshold L1 to the maximum handle opening value L3, and then executing step S22;

15 S22, determining whether the handle opening L is greater than the preset handle threshold L1 or not; if the handle opening L is greater than the preset handle threshold L1, obtaining, by the motor, a positive torque through the current drive torque Map and keeping the vehicle to move forward; and if the handle opening L is smaller than the preset handle threshold L1, executing step
20 S23;

S23, calculating a current maximum handle braking torque T*, a calculation formula of which is as follows:

$$T^*(L) = \frac{(L_0 - L) \times T_{max}}{L_0} ;$$

where L0 is the energy recovery exit threshold, L is the handle opening
25 obtained by sampling, and Tmax is the maximum braking torque of the motor;

and

S24, performing weighted summation on the current maximum handle braking torque value T^* and a torque value obtained by the current drive torque Map, to obtain the current handle target torque T^{**} .

5 Furthermore, step S3 includes the following steps:

S31, determining whether the current handle target torque T^{**} is greater than 0 or not; if the current handle target torque T^{**} is greater than 0, keeping the vehicle to move forward; and if the current handle target torque T^{**} is smaller than 0, performing energy feedback braking, and executing step S32;

10 S32, determining whether the rotation speed n of the motor is greater than a lower rotation speed limit n_1 ; if the rotation speed n of the motor is smaller than the lower rotation speed limit n_1 , defining the current target braking torque T to be 0; and if the rotation speed n of the motor is greater than the lower rotation speed limit n_1 , executing step S33;

15 S33, determining whether the rotation speed n of the motor is greater than an upper rotation speed limit n_2 or not; if the rotation speed n of the motor is greater than the upper rotation speed limit n_2 , defining the current target braking torque T to be equal to the current handle target torque T^{**} ; and if the current target braking torque T is smaller than the upper rotation speed limit n_2 ,
20 executing step S34; and

S34, calculating the current target braking torque T , a calculation formula of which is as follows:

$$T(L) = \frac{(n-n_1) \times T^{**}}{n_1-n_2} ;$$

where T is the current target braking torque, T^{**} is the current handle
25 target torque, n is the rotation speed of the motor obtained by sampling, n_1 is

the lower rotation speed limit, and n_2 is the upper rotation speed limit.

Furthermore, the braking current or a braking current instruction adopted in a permanent magnet synchronous motor has the same implementation effect as the braking torque or a braking torque instruction used in this embodiment. A calculation formula of an electromagnetic torque is as follows:

$$T_e = \frac{3}{2}p[\varphi_f i_q + (L_d - L_q)i_d i_q];$$

where T_e is the motor electromagnetic torque, φ_f is a rotor flux generated by a permanent magnet, i_d and i_q are dq-axis magnitudes of current, and L_d and L_q are a direct-axis inductance and a quadrature-axis inductance, respectively.

Compared with the prior art, the present disclosure has the following advantages and positive effects.

According to the present disclosure, the handle opening state of the electric vehicle and the rotation speed of the motor are obtained, and the current handle target torque is calculated by the handle-torque control algorithm according to the handle opening state. If the current handle target torque value is smaller than 0, we believe that the driver is intended to decelerate. The current target braking torque is calculated according to the rotation speed of the motor in conjunction with the operating characteristic curve of the motor to control the motor to operation, so that energy recovery is accomplished simply and quickly.

The present disclosure can determine the driver's demand for braking intensity according to the handle opening and the speed at which the driver releases the handle, and therefore, the energy recovery power and the braking intensity can be regulated according to the handle opening state in a case that the driver does not operate the brake handle, thereby reducing the operation process of the driver and improving the driving experience of the driver while

reducing operation fatigue.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to more clearly describe the technical solutions in embodiments of
5 the present disclosure or in the prior art, the drawings required in the description
of the embodiments or the prior art are briefly described below. It is apparent
that the drawings described below are merely some embodiments of the present
disclosure, and those of ordinary skill in the art can obtain other drawings
according to these drawings without involving an inventive effort.

- 10 FIG 1 is a frame structure diagram of the present disclosure;
FIG 2 is a frame flowchart of step S101;
FIG 3 is a frame flowchart of step S102;
FIG 4 is a curve relation diagram of the handle opening and the drive
torque;
15 FIG 5 is a fame flowchart of step S103; and
FIG 6 is a block diagram of a torque-current calculation module.

DETAILED DESCRIPTION OF THE EXEMPLARY EMBODIMENTS

- 20 The technical solutions in the embodiments of the present disclosure are
clearly and completely described below in conjunction with the drawings in the
embodiments of the present disclosure. It is apparent that the described
embodiments are merely some embodiments of the present disclosure, instead
of all embodiments. Based on the embodiments of the present disclosure, all
25 other embodiments obtained by those of ordinary skill in the art without

involving an inventive effort, any modifications, equivalent substitutions, improvements and the like shall fall within the protection scope of the present disclosure.

In this embodiment, disclosed is a method for energy recovery of an electric vehicle. For the sake of illustration, it is unified that the handle opening state is set as L , which is a numerical value obtained after normalization of voltage range of the handle; the energy recovery exit threshold is set as L_0 , which is a preset numerical value; the preset handle threshold is set as L_1 , which is a preset numerical value; the energy recovery enable threshold is set as L_2 , which is a preset numerical value; the maximum handle opening value is set as L_3 , which is a numerical value obtained after normalization of the voltage range in the maximum handle opening state; the calibration values L_0 , L_1 , L_2 and L_3 are calibrated according to different handle ranges, where $L_0 < L_1 < L_2 < L_3$; the energy recovery enable flag is set as F_1 , the rotation speed of the motor is set as n , the lower rotation speed limit is set as n_1 , the upper rotation speed limit is set as n_2 , the current maximum handle braking torque is set as T^* , the current handle target torque is set as T^{**} , and the current target braking torque is set as T .

The specific implementation steps of the present disclosure include four steps, as shown in FIG 1.

I. Step S101, the handle opening L and the rotation speed n of the motor are obtained by sampling, and the handle opening L is determined. The specific flowchart is as shown in FIG 2:

1, first, obtaining the handle opening and the rotation speed of the motor by sampling, and filtering to obtain the handle opening L and the rotation speed n

of the motor, where for the data sampling frequency, data sampling is generally performed every multiple of 62.5 us in consideration of the processing capacity of the sensor and response time of the speed change that people can perceive, and the value is the optimal when the interval time is 62.5-2000 us;

5 2, determining whether the handle opening L is smaller than the energy recovery exit threshold L0 or not, and if the handle opening L is smaller than L0, clearing the energy recovery enable flag F1, otherwise, performing a third logic judgment operation; and

 3, determining whether the handle opening L is greater than the energy
10 recovery enable threshold L2 or not, and if the handle opening L is greater than L2, setting up the energy recovery enable flag F1.

II. Step S102, the current handle target torque is calculated by the handle-torque control algorithm according to the handle opening state. The specific flowchart is as shown in FIG 3:

15 1, first, determining whether the energy recovery enable flag F1 is set up or not; if the energy recovery enable flag F1 is not set up, indicating that the driver is intended to accelerate, setting an effective interval for handle driving to be L0-L3, and in this case, the handle opening L is within a handle braking interval (L0-L1), not performing feedback braking, and calculating, by the motor, a
20 positive torque through the drive torque Map to make the vehicle enter an acceleration process from a stationary state or a deceleration state; and if the energy recovery enable flag F1 is set up, setting an effective interval for handle braking to be L0-L1, setting the effective interval for handle driving to be L1-L3, and executing a second logic judgment operation;

25 2, determining whether the handle opening L is greater than the preset

handle threshold L1; if the handle opening L is greater than L1, calculating, by the motor, a positive torque through the drive torque Map to keep the vehicle move forward; and if the handle opening L is smaller than L1, performing the third operation; and

- 5 3, making the handle opening L be within the effective interval for handle braking (L0-L1), and in this case, the handle opening L reflects the driver's demand for braking intensity to a certain extent, and we can calculate the current maximum handle braking torque T* according to the following formula:

$$T^*(L) = \frac{(L_0 - L) \times T_{max}}{L_0} ;$$

- 10 where T*(L) is the current maximum handle braking torque, L0 is the energy recovery exit threshold, L is the handle opening obtained by sampling for controlling the electronic braking force and the energy recovery power, and Tmax is the maximum braking torque of the motor, corresponding to the electronic braking force in the program.

- 15 Moreover, the energy recovery power is different since the handle opening L is different. After considering the motor stator rotor resistance, copper loss, heat loss and other factors that have lost part of the electric energy, the maximum powder P_{chg} of the motor's actual braking feedback is as follows:

$$P_{chg}(L) = \frac{T_{mot} \times n \times \eta}{9550} ;$$

- 20 where Tmot is the motor braking torque, n is the rotation speed of the motor, and η is motor feedback braking power generation efficiency of the motor after loss is taken into consideration.

At the end of step S102, in order to make the motor torque change smoothly, the vehicle does not generate obvious braking impact and sense of

frustration in the energy recovery process, and weighted summation is performed on the calculated maximum handle braking torque value T^* and the torque value obtained by the current drive torque Map to finally obtain the current handle target torque T^{**} . As shown in FIG 4, curve L^+ in the schematic
5 diagram is the torque value obtained by the drive torque Map, curve L^- is the current maximum handle braking torque value T^* , curve L^* is the current handle target torque T^{**} obtained after the weighted summation.

III. Step S103, the current target braking torque is calculated by the speed-torque control algorithm according to the rotation speed of the motor. The
10 specific flowchart is as shown in FIG 5:

1, first, determining whether the current handle target torque T^{**} is greater than 0 or not; if the current handle target torque T^{**} is greater than 0, controlling, by the motor, the vehicle to move forward according to a given value of the positive torque; and if the current handle target torque T^{**} is
15 smaller than 0, performing energy feedback braking, and executing the second operation;

2, making the motor recover slide kinetic energy of the vehicle within the reasonable range as the feedback braking capacity of the two-wheel electric vehicle has a strong relationship with the operation characteristics of the motor
20 in the practical riding process, so as to prevent the driver feeling uncomfortable due to energy recovery, and further regulating the motor braking intensity according to the rotation speed of the motor; presetting the lower rotation speed limit n_1 , selecting the calibration value according to the motor parameters, and exiting energy recovery when the calibration value is lower than the lower
25 rotation speed limit n_1 ; presetting the upper rotation speed limit n_2 , and

calibrating the calibration value according to the motor parameters, where the current target braking torque T is equal to the current handle target torque T^{**} when the calibration value is higher than the upper rotation speed limit n_2 ;

3, determining whether the rotation speed of the motor is greater than the lower rotation speed limit n_1 or not; if the rotation speed of the motor is smaller than n_1 , defining the current target braking torque to be 0; and if the rotation speed of the motor is greater than n_1 , performing the fourth logic judgment operation;

4, determining whether the rotation speed of the motor is greater than the upper rotation speed limit n_2 or not; if the rotation speed of the motor is greater than n_2 , making the current target braking torque T equal to the current handle target torque T^{**} ; and if the rotation speed of the motor is smaller than n_2 , performing the fifth operation; and

5, calculating the current target braking torque T according to the following formula:

$$T(L) = \frac{(n-n_1) \times T^{**}}{n_1-n_2};$$

where T is the current target braking torque, T^{**} is the current handle target torque and is obtained in step S102, n is the rotation speed of the motor obtained by sampling, n_1 is the lower rotation speed limit, and n_2 is the upper rotation speed limit.

IV. Step S104, the motor torque is controlled to change from the current value to the target value according to the current target braking torque T calculated in step S103, to complete an energy recovery operation of the motor.

Particularly, the electromagnetic torque equation is indicated as follows under dq coordinates of the permanent magnet synchronous motor:

$$T_e = \frac{3}{2}p[\phi_f i_q + (L_d - L_q)i_d i_q]$$

where T_e is the motor electromagnetic torque, ϕ_f is the rotor flux generated by the permanent magnet, i_d and i_q are dq-axis magnitudes of current, and L_d and L_q are a direct-axis inductance and a quadrature-axis inductance, respectively.

The braking torque or the braking torque instruction (the current maximum handle braking torque T^* , the current handle target torque T^{**} , the current target braking torque T , and the like) in this embodiment can be obtained through the torque-current calculation module (as shown in FIG 6) for the embodiments which adopt the braking current or the braking current instruction, and therefore, the adopted braking current or the braking current instruction has the same implementation effect as the braking torque or the braking torque instruction used in this embodiment.

According to the present disclosure, the handle opening state of the electric vehicle and the rotation speed of the motor are obtained, and the current handle target torque is calculated by the handle-torque control algorithm according to the handle opening state. If the current handle target torque value is smaller than 0, we believe that the driver is intended to decelerate. The current target braking torque is calculated through the rotation speed of the motor in conjunction with the operation characteristic curve of the motor to control the motor to operate, so that energy recovery is accomplished simply and quickly.

The present disclosure can determine the driver's demand for braking intensity according to the handle opening and the speed at which the driver releases the handle, and therefore, the energy recovery power and the braking intensity can be regulated according to the handle opening state in a case that

the driver does not operate the brake handle, thereby reducing the operation process of the driver and improving the driving experience of the driver while reducing operation fatigue.

CLAIMS

What is claimed is:

1. A method for energy recovery of an electric vehicle, comprising the following steps:

S1, obtaining a handle opening L and a rotation speed n of a motor by sampling, and determining the handle opening L ;

S2, calculating a current handle target torque T^{**} by a handle-torque control algorithm according to the handle opening L ;

S3, calculating a current target braking torque T by a speed-torque control algorithm according to the rotation speed n of the motor; and

S4, controlling the motor torque to change from a current value to a target value according to the current target braking torque T , to complete an energy recovery operation.

2. The method for energy recovery of an electric vehicle according to claim 1, wherein step S1 comprises the following steps:

S11, obtaining the handle opening L and the rotation speed n of the motor by sampling, and performing filter processing;

S12, determining whether the handle opening L is smaller than an energy recovery exit threshold L_0 or not, and if the handle opening L is smaller than the energy recovery exit threshold L_0 , clearing an energy recovery enable flag F_1 , otherwise, executing step S13; and

S13, determining whether the handle opening L is greater than an energy recovery enable threshold L_2 or not, and if the handle opening L is greater than the energy recovery enable threshold L_2 , setting up the energy

recovery enable flag F1.

3. The method for energy recovery of an electric vehicle according to claim 2, wherein step S2 comprises the following steps:

S21, determining whether the energy recovery enable flag F1 is set up or not; if the energy recovery enable flag F1 is not set up, setting an effective interval for handle driving as the energy recovery exit threshold L0 to a maximum handle opening value L3, obtaining, by the motor, a positive torque through a current drive torque Map, and making a vehicle enter an acceleration state from a stationary state or a deceleration state; and if the energy recovery enable flag F1 is set up, setting an effective interval for handle braking as the energy recovery exit threshold L0 to a preset handle threshold L1, and setting the effective interval for handle driving as the preset handle threshold L1 to the maximum handle opening value L, and then executing step S22;

S22, determining whether the handle opening L is greater than the preset handle threshold L1; if the handle opening L is greater than the preset handle threshold L1, obtaining, by the motor, a positive torque through the current drive torque Map, and keeping the vehicle to move forward; and if the handle opening L is smaller than the preset handle threshold L1, executing step S23;

S23, calculating a current maximum handle braking torque T*, a calculation formula of which is as follows:

$$T^*(L) = \frac{(L_0 - L) \times T_{max}}{L_0};$$

wherein L0 is the energy recovery exit threshold, L is the handle

opening obtained by sampling, and $T_{\max}$ is the maximum braking torque of the motor; and

S24, performing weighted summation on the current maximum handle braking torque value T^* and a torque value obtained by the current drive torque Map , to obtain the current handle target torque T^{**} .

4. The method for energy recovery of an electric vehicle according to claim 3, wherein step S3 comprises the following steps:

S31, determining whether the current handle target torque T^{**} is greater than 0 or not; if the current handle target torque T^{**} is greater than 0, keeping the vehicle to move forward; and if the current handle target torque T^{**} is smaller than 0, performing energy feedback braking, and executing step S32;

S32, determining whether the rotation speed n of the motor is greater than a lower rotation speed limit n_1 ; if the rotation speed n of the motor is smaller than the lower rotation speed limit n_1 , defining the current target braking torque T to be 0; and if the rotation speed n of the motor is greater than the lower rotation speed limit n_1 , executing step S33;

S33, determining whether the rotation speed n of the motor is greater than an upper rotation speed limit n_2 or not; if the rotation speed n of the motor is greater than the upper rotation speed limit n_2 , defining the current target braking torque T to be equal to the current handle target torque T^{**} ; and if the rotation speed n of the motor is smaller than the upper rotation speed limit n_2 , executing step S34; and

S34, calculating the current target braking torque T , a calculation

formula of which is as follows:

$$T(L) = \frac{(n-n_1) \times T^{**}}{n_1-n_2} ;$$

wherein T is the current target braking torque, T^{**} is the current handle target torque, n is the rotation speed of the motor obtained by sampling, n_1 is the lower rotation speed limit, and n_2 is the upper rotation speed limit.

5. The method for energy recovery of an electric vehicle according to claim 4, wherein:

in a permanent magnet synchronous motor, a calculation formula of an electromagnetic torque is as follows:

$$T_e = \frac{3}{2}p[\varphi_f i_q + (L_d - L_q)i_d i_q] ;$$

wherein T_e is the motor electromagnetic torque, φ_f is a rotor flux generated by a permanent magnet, i_d and i_q are the dq-axis magnitudes of current, and L_d and L_p are a direct-axis inductance and a quadrature-axis inductance, respectively.