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早稲田大学大学院理工学研究科

博 士 論 文 概 要

論 文 題 目

Study on Energy Saving in Electrical Drive System

電動機駆動システムの
省エネルギー化に関する研究

申 請 者

フェリ ユシバル
Feri Yusivar

電気工学専攻 電磁応用研究

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1. Background of the thesis

Electrical drive systems as one of the basic technology has been put to the practical use to support the modern technology. The electrical drive system in electric vehicle is one of the representative objects. In present when the environmental energy problem becomes serious, the electrical power regenerative becomes the large strong point of the electrical drive system to be paid attention. Especially, by adopting the electrical power regenerative brake system, a large contribution on energy saving can be expected from the electrical drive system of the electric vehicle with big inertia load. Based on this background, in this thesis the energy saving in electrical drive system for electric vehicle application is studied with a focus on the alternating-current (AC) motor that has advantage of less maintenance than the direct-current (DC) motor.

From the viewpoint of electric power source, electric vehicle can be classified to electric car (EC) and electric railway vehicle (ER). The electric power source of EC is stored in batteries those are carried onboard, while the electric power source of ER is provided by substation via a transmission cable along the railway path. The capacity of storage batteries of EC is limited with the restriction of the loading space and mass. This limitation results in a limit driving distance of EC with the once charged storage batteries. On the other hand, although there is no problem with the driving distance of ER, a method to save energy in a battery that is mounted on the vehicle onboard or placed at the power substation is considered for energy conservation purpose, e.g., a method to reuse the regenerative power in a DC supplied ER. Thus similar to the EC system, it is believed that in the future the capacity problem of storage battery becomes obvious existence in the ER system. From now on, it is thought that the importance of storing electricity rises further in addition to machine loss cutting down when it aims at the energy saving in the electric vehicle drive system.

With this background, various energy saving efforts in electrical drive system are attempted. It is important to recover the kinetic energy as much as possible for decreasing the total energy consumption by enhancing the effectiveness of the regenerative brake control system and increasing the regenerative braking power with a high-speed operation. Then, to make the regenerative energy effectively, the regenerative electric power should be adjusted corresponding to the condition of the storage battery. Therefore, a proper grasping of the charging condition of the storage battery becomes indispensable. Furthermore, it is also important to decrease the energy loss in the drive system. Concretely, by turning off the electric power while the vehicle is moving promptly for coasting operation after it reaches a speed, the occurrences of inverter switching loss and magnetic excitation loss (in case of induction motor) are prevented. It can be concluded that energy can be saved through the reuse of regenerative energy and the efficiency on consuming energy.

Based on the above background, the research-works of this thesis, in the area of electrical drive system, includes: (1) the investigation of a combination of an maximizing DC voltage utility strategy in the asynchronous PWM inverter and a novel field weakening scheme as to aim the increase of the regenerative electric power in the high-speed operation, (2) the investigation of the restarting capability of the induction motor under the speed sensorless control condition, (3) the proposal of the elucidation and solution of the electrical oscillation phenomenon in the permanent magnet synchronous motor drive system with a light load energy consumption, and (4) the investigation of the modeling technique for lead-acid storage battery characteristics.

Through the investigation and verification of the above research-works, this thesis contributes to energy saving in the electric vehicle drive system.

2. Outline of the thesis

(1) Chapter 1: Introduction Chapter 1 outlines some backgrounds that motivate the works in this thesis. The problems related to energy saving in electrical drive system are formulated. The solutions to these problems are also briefly described. Outlining the topics of the remaining chapters ends this chapter.

(2) Chapter 2: Field-weakening scheme in combine with saturated voltage control strategy If the DC voltage utility can be improved as to improve the output power in the high speed motor operation, a larger kinetic energy can also be recovered. In this chapter, to combine the maximizing DC voltage utility of the asynchronous PWM inverter using a saturation voltage strategy, a novel field-weakening scheme corresponding to the torque improvement is proposed. It is difficult to do so in the previous field-weakening scheme, since a Proportional-Integral (PI) controller controls the motor voltage not to exceed its limit. Instead using PI controller, to make it possible to implement a voltage saturation technique, the proposed scheme uses only a Proportional controller with low-pass filter. Experimental results and performance comparisons are presented to show the proposed scheme has an improved torque capability in comparison to the previous one.

(3) Chapter 3: Motor restarting capability of speed sensorless drive As for an energy saving effort, the energy loss decrease due to the electric power of the inverter is turned off in the motor coasting operation. Then the motor should be restarted when the acceleration or the regenerative braking is needed. Therefore, the restarting capability is one of essential technology for energy saving in electrical drive system. For this research purpose, chapter 3 deals with the preliminary investigation of the induction motor restarting capability under the speed sensorless control condition. The speed sensorless scheme in this chapter utilizes a reduced order observer. The initial value problem of speed estimation that occurs when restarting the motor after coasting is emphasized. The initial estimated speed selection for a successful motor restarting operation is studied further.

(4) Chapter 4: Anti oscillation strategy for the regenerative braking control In this chapter the analysis of the oscillation phenomenon, when the regenerative braking control is applied into the PMSM drive system with a light-load energy consumption, is presented and an anti oscillation strategy is proposed to overcome this stability problem. First, the oscillation phenomenon, which occurred in the actual electric vehicle, is confirmed through the experiment and the simulation. The mathematical model of investigated system, which divided into four operation conditions, is derived. The cause of the oscillation phenomenon is then clarified by solving each steady state solution and pole analyzing. Based on the analytical results, a new regenerative braking control method in purpose to eliminate the oscillation is proposed. Finally, the validity of the effectiveness of the proposed control technique is verified through the experiment according to the mini model of the investigated system.

(5) Chapter 5: Storage battery modeling In this chapter, the new technique to model the transient characteristic of the lead-acid storage battery is proposed. First, the frequency-response of battery in the discharge state is measured. The concept of transfer function to decide the admittance value of battery is introduced. Then the equivalent circuit of battery is estimated from the obtained admittance value. The variation of circuit-constant values with the battery residual capacity is investigated. The frequency characteristic of series and parallel batteries model, which provides high voltage and power capacity, is calculated mathematically from a single battery model. This mathematical model is confirmed by comparing its frequency characteristic with the measured one from the experimental system. It is verified that the battery modeling can be done easily by using a proposal technique. The storage battery modeling contributes to the optimization of the regenerative energy usage.

(6) Chapter 6: Conclusions and Recommendations Chapter 6 gives a summary of the overall results from the former chapters, identifies the main conclusions of this research works, and provides some directions to continue and to extend the research works in the future.