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Design of Flywheel Batteries for Vehicles

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Abstract: Flywheel battery is a new concept battery for mechanical energy storage. It provides some attractive advantages compared with chemical batteries for electric vehicles, such as power efficiency and high energy, long cycle life and maintenance reduction.This work developed an integrated flywheel battery with an axial-flux motor and generator that integrates rotor with the flywheel.This paper presents a new control method for the energy storage (FBES) device for flywheel batteries. The proposed method adopts a double closed-loop control structure based on an external DC bus voltage loop cascaded with an internal current loop and an additional loop for speed control.It can accomplish the charging and discharge cycle of the flywheel battery by regulating the speed of the flywheel without altering the controlling object of the outer loop.The DC bus voltage is fully determined by the power system during the charge process, and the speed control loop limits the speed of the flywheel to avoid overcharging. Accordingly, the flywheel battery must maintain the stability of the DC bus voltage during the discharge cycle.To complete the simulation of charge and discharge control and the sudden simulation of loading during discharge, an FBES system is created.

Keywords: Battery, Charge and Discharge Control,Energy, FBES,Flywheel.

INTRODUCTION

The steady charge is provided by an internal combustion engine driving an electric generator. The power requirements of acceleration or regenerative braking can be controlled by batteries or flywheels[1].A flywheel is an electromechanical Energy Storage approach. To store electricity, the electrical energy from an external source is converted into a flywheel's rotational energy by a motor.Use the motor as a generator and collecting energy removes the energy extracted and slows the flywheel. A flywheel battery system consists of the flywheel, magnetic bearings, a motor and generator, electrical power, and electronic control.High energy density flywheel systems are made of composite material because of the high strength demands. For small flywheels the requirement for high strength is fundamental.The flywheel battery is a novel concept battery for the mechanical storage of energy, not by chemical process[2]. The flywheel battery's energy density and power density are greater than that of chemical batteries.The character of high power density, short charge, high energy density, and discharge time, long cycle life and environment friendly make the flywheel battery useful.High battery density and high flywheel battery power density, this paper proposed complex battery-based energy sources for EVs (lead-acid) and flywheel batteries[3].

The functions of flywheel battery are given below:

The flywheel battery discharges rapidly during the acceleration or hill-climbing condition in order to improve the vehicle's drivability and prolong the life cycle of the battery, as it cannot discharge at high current.The flywheel battery charges rapidly during deceleration or downhill condition in order to improve the efficiency of absorbing the regenerative energy[4].

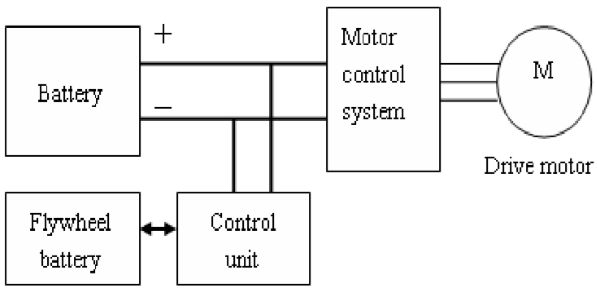

Figure 1: Block Diagram of Complex Energy Sources for EVs

FLYWHEEL BATTERY ENERGY STORAGE SYSTEM

Squirrel-cage type induction motor is used as the motor and generator with features of simple structure, high reliability and wide range of speeds.Three-phase full-bridge converter acted as the induction motor controls the electronic power device. It's the important approach for connecting bidirectional energy flow to the parallel DC bus.Mechanical bearings and permanent magnetic bearings (PMB) form the mixed supporting system to reduce friction losses, thus increasing the FBES system's energy conversion efficiency[5].

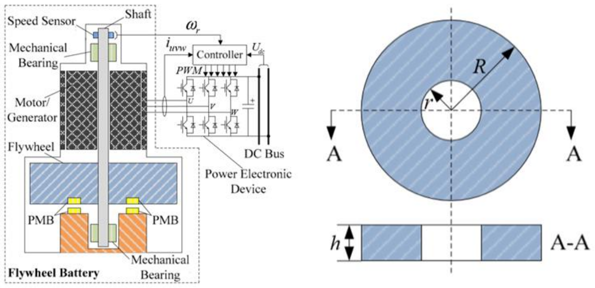

Figure 2: Structure Diagram of the FBES System

The energy stored depends on the product of the square of the speed and the inertia of the flywheel. Increasing them both will be able to increase the amount of energy stored. The higher speed of the flywheel typically has special requirements for battery design[6].Figure 2 is expressed in equation as:

$$J = \frac{\rho h \pi}{2}\left(R^4 - r^4\right)$$

Where, ρ is the flywheel density.

1. *Working Mode:*

FBES operation is usually accompanied by control of the speed of the flywheel. There are three working modes of the FBES system according to the flywheel speed changes and each of them is listed as below.

2. *Charging Mode:*

By increasing the speed of the flywheel, the electrical energy is converted into mechanical energy. The power conversion system acts as an inverter that controls the induction motor as a generator.

3. *Standby Mode:*

If no energy conversion is required flywheel speed is kept constant. The FBES system only needs less electrical energy to make up for its own losses. The electric energy is stored in mechanical energy form.

4. *Discharging Mode:*

The mechanical energy is converted into the electrical energy to keep the important loads working normal. The induction motor functions as a generator, and the speed of the flywheel decreases. Meanwhile the device operates as a rectifier for power conversion.The essence of FBES system control is to achieve a reasonable energy flow by quickly and accurately regulating the flywheel speed with the power electronic device[7].

FLYWHEEL CHARGE AND DISCHARGE CONTROL

The main circuit of flywheel battery is shown in figure 3.

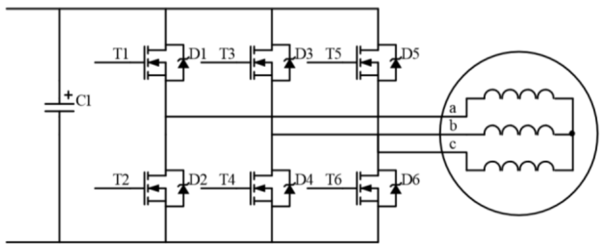

Figure 3: Electrical Model of Flywheel Battery

The C1 capacitor filters the current inverter and acts to stiffen the voltage of the DC bus. During the charging model the inverter works as the flywheel driver motor, the inverter works as the controlled rectification to control the flywheel battery output voltage at the discharge model.The controller allows the flywheel to operate in both charging and discharge modes, and the algorithm is based on careful regulation of the permanent

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electric motor and generator magnet connected to the flywheel.The flywheel battery is charged rapidly during deceleration or downhill condition to accommodate the regenerating electricity[8]. The built-in motor and generator acts as the engine at this stage.The flywheel battery has an uncertain and nonlinear character, and a combined Fuzzy-PI control strategy is adopted during charging.The Fuzzy control is used at the large error range because it is few sensitive to parameter uncertainties and nonlinear, and the PI control was used to reduce the static error at the small error range.During the flywheel battery discharge cycle it has variable flywheel speed and load character, a slide mode controller is adopted to regulate the discharge voltage of the flywheel battery[9].

FRAMEWORK OF FLYWHEEL BATTERY

The battery on the flywheel stores energy to a rotating mass.A given amount of kinetic energy is stored as rotational energy, depending on the inertia and the speed of the rotating mass.The flywheel is mounted inside a vacuum enclosure to remove friction-loss from the air and to be suspended for steady operation by bearings.Kinetic energy is transferred in and out of the flywheel with an electrical system that can act either as a motor or as a generator Apart from the flywheel, additional power electronics are needed to control power in and output, rpm, frequency etc.The flywheel battery consists of a high-speed flywheel, high-speed bearings, an integrated motor or generator, an auxiliary system and an energy transfer mechanism.The energy is stored as the mechanical form (E=1/2Jω2 where J is the moment of inertia and ω is the rotational speed) in the high-speed flywheel[10].The control system for the energy transfer controls the energy input charge or output discharge. The permanent magnet motor of the disk-type functions as the integrated motor or generator.

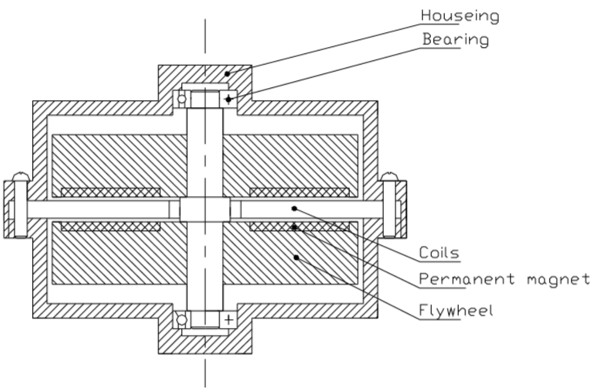

Figure 4: Flywheel Battery

The flywheel itself is made of high-resistance steel and High-energy permanent magnets are recessed into the top of the flywheel in the shape of a thick cylinder.The flywheel battery's motor or generator is an axial flux mechanism consisting of permanent magnets mounted in the top of the flywheel, and windings as well as Hall Effect sensors in the top part of the stator.Figure 4 and Figure 5 show the configuration of windings, magnets, and sensors[11].

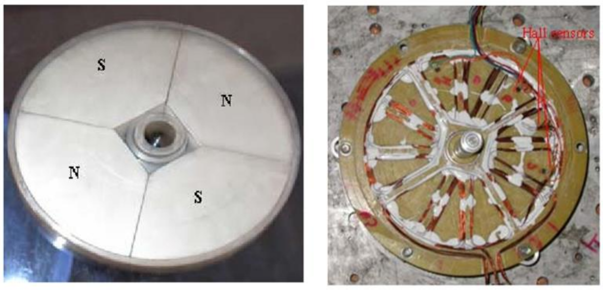

Figure 5: Flywheel Recessed With Permanent Magnets

CONCLUSION

A novel flywheel battery design for electric vehicles, the flywheel battery consists mainly of four parts, a flywheel recessed with permanent magnets, two bearings, a motor or generator disk type and a controller. New control method is proposed for the FBES system. This adopts a double closed-loop structure based on a cascaded outer DC bus voltage loop with an inner current loop. In addition, a speed control loop is used to restrict the speed of the flywheel during charge mode to prevent overload.

It can easily accomplish the FBES system's charge and discharge process without altering the control structure according to the working mode. It lays the groundwork for applying the FBES system to the distributed generation domain. Mechanical bearings and permanent magnetic bearings (PMB) form the mixed supporting system to reduce friction losses, thus increasing the FBES system's energy conversion efficiency. Flywheel battery has an uncertain and nonlinear character, and a combined Fuzzy-PI control strategy is adopted during charging. The Fuzzy control is used at the large error range because it is few sensitive to parameter uncertainties and nonlinear, and the PI control was used to reduce the static error at the small error range.

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