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SIMULATION FOR CHARGING OF ULTRA CAPACITOR

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ABSTRACT

For the short-term ultracapacitor models, first-, second-, third- and fourth-order transfer functions consistent with an RC ladder model are assumed. The transfer function coefficients are identified by a least squares algorithm based on experimental data consisting of time-varying current excitations and the resulting terminal voltage responses. A long-term model with six RC branches is developed by fitting the terminal voltage transient response to an impulse charging current. Hundreds of thousands of terminal voltage data points are recorded and least squares identification is employed to determine the optimal values of the unknown parameters in the long-term model.

From the ultracapacitor models derived, terminal voltages under different current profiles can be determined accurately over the time frame of one hour with an error less than 0.1 V, the impulse charging and discharging response over a time frame of two months can be simulated with an error less than 0.08 V, and the instantaneous power available can be calculated.

1. INTRODUCTION

Ultracapacitors were first used in military projects to start the engines of battle tanks and submarines and to replace batteries in missiles. With the maturity of the manufacturing and nano-material technology, the cost of ultracapacitors has fallen, and the nominal capacitances have increased significantly. As a result, ultracapacitors have begun to appear in more applications, such as diesel engine starting, railroad locomotives, actuators and memory backup. More recently, ultracapacitors have become a topic of some interest in the green energy world, where their ability to soak up energy quickly makes them particularly suitable for regenerative braking applications [1,2,3]; in contrast, batteries have difficulty in this application due to their lower rated charging current and shorter cycle life.

2. BACKGROUND AND RELATED WORK

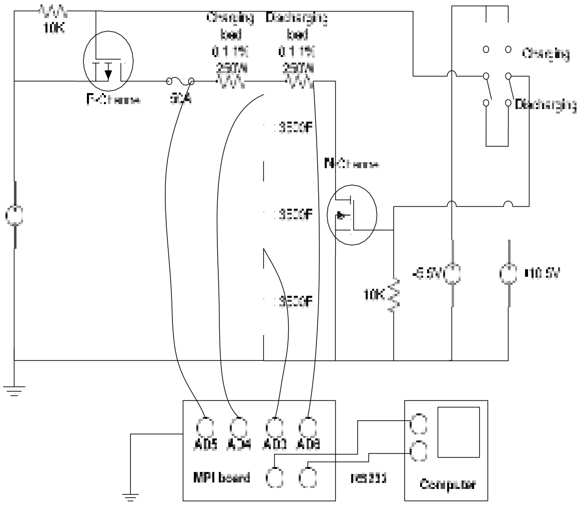
Theoretical lumped parameter models may be developed based on ultracapacitors' physical structure. Although this kind of model represents the ultracapacitor structure, it may include a large number of parameters as well as non-linear characteristics that make it difficult to implement in practice. As a result, a lot of published work to model ultracapacitors tries to derive simple models to represent the dynamic behavior and voltage dependence of ultracapacitors.

3. EXPERIMENTAL SET-UP

Determining the parameters of an ultracapacitor model requires first that current and voltage information be captured from the ultracapacitor under test, and then that least squares identification be done using that current and voltage data. In this chapter, the experimental set-up used to capture the data is described. This includes circuitry to control the charging and discharging of the ultracapacitor, as well as the program to measure and record the voltage and current information.

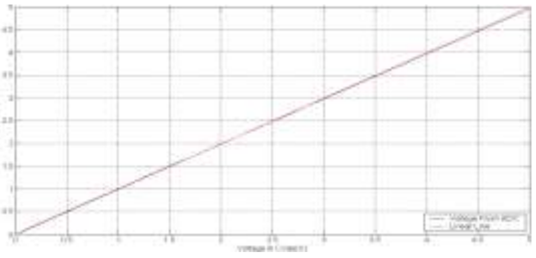
Test Circuit

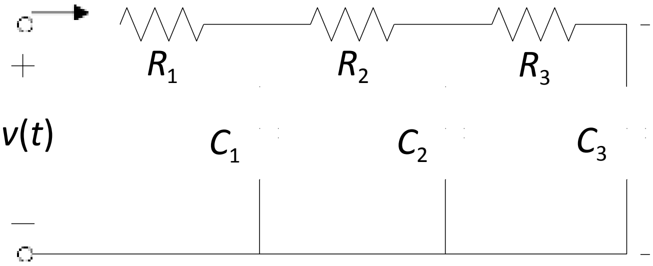
The test circuit, shown in Figure 3.1, consists of three NESSCAP3500P ultracapacitors in series excited by a 5-V, 1100-W power supply. A 50-A fuse is connected in the test circuit to protect the power supply. The rated voltage for each ultracapacitor cell is 2.7 V. To avoid exceeding the rated terminal voltages, three identical ultracapacitor cells are connected in series and their initial voltages are made equal. Two kinds of MOSFET switches are employed so that the charging and discharging processes can be controlled separately. Five p-channel MOSFETs, each of which can pass a maximum of 13 A of current, are employed in parallel as the charging switch; when charging, their gates are connected together to the preset -5.5-V constant voltage supply through a three-position switch.



Data Acquisition

A microcontroller board (dsPICDEM2) was employed for the terminal voltage and current measurements. The charging current is measured indirectly by measuring the voltage across the power resistor in series with the charging source; similarly, the discharging current is measured indirectly by measuring the voltage across the power resistor . that serves as the discharging load. This is done by measuring the potentials of both terminals of the power resistor with respect to the ground, subtracting the potentials to find the voltage difference across the resistor, and converting to current through the resistor by dividing the voltage by the resistance





Flow Chart

The flow chart for the program in the dsPIC30F4013 on the dsPICDEM2 MPI board that samples, measures and records data.

4. SHORT-TERM MODEL

A simple first-order *RC* model was used to estimate the available energy in the ultracapacitor bank that serves as the main electrical energy storage system for the University of Akron's Challenge X vehicle. A higher-order model would allow for better control.where the sections are organized such that the fastest time constant is associated with the *R* and *C* closest to the terminals, and the time constants get longer and longer for sections further from the terminals. This accurately models the behavior seen on the bench: when an ultracapacitor is charged, the terminal voltage rises quickly, but once the charging current is cut off, the terminal voltage slowly drops, as charge

5. LONG-TERM MODEL

These models fit the dynamic behavior of the ultracapacitor over a time frame of around one hour. While the short-term models are sufficient for simulating charging and discharging of the ultracapacitor, which are fast phenomena, they cannot be used to accurately simulate long-term behavior. An understanding of long-term behavior is important, for example, to estimate the terminal voltage of the ultracapacitor or the instantaneous available energy from the ultracapacitor after it has been relaxed for two months. Thus, long-term models are needed for implementation of control strategies for some practical cases.

6. CONCLUSIONS

Ultracapacitors are attracting more and more people's attention as efficient and environmentally friendly energy storage devices. In this thesis we present short-term and long-term linear models to predict the dynamic voltage and current response of an ultracapacitor cell. The models could be useful in the design of a control strategy for ultracapacitors as an energy storage system.For the short-term model we use a third-order transfer function to represent the dynamic behavior of ultracapacitor within a time frame of around one hour. The data for the model identification are produced using a dynamic current excitation and measured using only ordinary laboratory instruments such as an oscilloscope and multimeters. As far as the long-term model is concerned, we want to know the terminal voltage and instantaneous available power information for the ultracapacitor if we settle it for a long time. We use six *RC* branches to describe the behavior of the ultracapacitor within a time frame of around two months. In order to make it possible to calculate the instantaneous power we design the long-term model to have real poles and zeros; as for the short-term models, this time we use least squares identification to search for the optimal coefficients, based on two months of data.

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