Mathematical Modeling of Lithium/Silver Vanadium Oxide Batteries

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Introduction

Implantable Cardioverter-Defibrillators (ICDs) are designed to detect and treat potentially lethal cardiac arrhythmias by administering high-voltage electrical shocks directly to the heart. Lithium/silver vanadium oxide (Li/SVO) batteries are the most frequently used power source for ICDs.

Mathematical models can be used to tailor a battery design to a specific application and simulate accelerated testing. Since the application involves a low rate background discharge, the time consuming, conventional build and test approach for whether a particular design can meet a new set of requirements is not practical. In addition to enabling faster design development and gaining better component reliability, battery model is also employed in conjunction with other component models to expedite the device (ICD) development.

ICD batteries are designed to achieve a balance between device size, longevity and charge time. Following detection of ventricular fibrillation, the device charges a capacitor, then, if needed, delivers a shock as large as 25-40 joules directly to the right ventricle to restore the heart to normal rhythm. Minimizing the time a patient remains in fibrillation is an important goal for this therapy. Time to charge the capacitor (charge time) is the main determinant of the interval between detection and delivery of therapy. The charge time depends on the internal resistance of the battery, hence the reliability of the performance model of a Li/SVO battery will depend on the ability to predict the resistance of the battery.

The mathematical model presented in this paper is based on a semi-empirical approach to predict the charge time for various cell designs and application conditions for various cells designed by Medtronic, Inc. for use in ICDs. The effect of change in anode area due to lithium thinning in the newer charge time-optimized design is also discussed in this paper.

Model Development

A design independent model[1] has been developed to predict the performance of Li/SVO batteries. The cells are subjected to a background load (equivalent to few μA current) and a pulse train consisting of four high current pulses is applied periodically. The resistive pulse load is adjusted based on the battery area and the device configuration (single or dual cell). .

An increase in the pulse resistance (R_{dc}) is observed when the state of discharge is about 45% (x = 2.8 in xLi:$Ag_2V_4O_{11}$. This continuing increase in resistance is proportional to the duration of discharge, *i.e.*, the resistance is higher for slower discharges (see Figure 1). A first-order kinetic model is used to model the time-dependent resistance, and the background voltage was obtained by averaging the discharge curves over various rates and designs. An area-normalized resistance, AR_{dc}, is employed in the model, and the model does a very good job of predicting the charge time behavior for various designs.

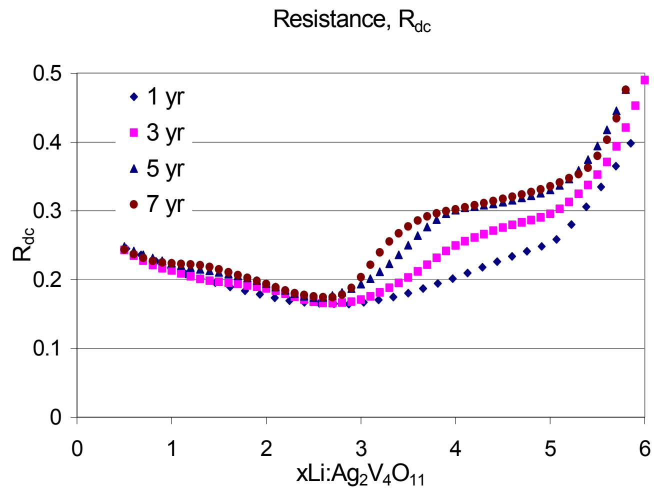

Figure 1. Time-dependent resistance for Li/SVO cells.

Conventionally, the Li/SVO batteries have been cathode limited, *i.e.,* the end of life of the cell has been determined by the SVO capacity. Recently, the anode to cathode capacity was rebalanced[2] to optimize the charge time by limiting the discharge to about x = 3 equivalents on Figure 1 by reducing the amount of lithium in the cell. As the cell is discharged, the anode area changes due to lithium thinning, and this behavior must be included in the model to accurately predict the resistance. This effect has been incorporated into the model empirically, and will be discussed in this paper.

References

[1] A. M. Crespi, C. L. Schmidt, J. Norton, K. Chen, and P. M. Skarstad, **JECS**, 148(1), A30-A37 (2001).
[2] Ann M. Crespi et al, Abstract No. 73, 202nd ECS Meeting, Salt Lake City, Oct 2002.