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FLIGHT EXPERIENCE OF SOLAR MESOSPHERE EXPLORER'S POWER SYSTEM OVER HIGH TEMPERATURES RANGES

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This paper summarizes the performance of the power system on the Solar Mesosphere Explorer (SME) satellite for the life of the mission and the techniques used to ensure power system health. Early in the mission high cell imbalances in one of the batteries resulted in a loading scheme which attempted to minimize the cell imbalances without causing an undervoltage condition. A short term model of the power system allowed planners to predict depth of discharge using the latest available data. Due to expected orbital shifts the solar arrays experience extended periods of no eclipse. This has required special conditioning schemes to keep the batteries healthy when the eclipses return. Analysis of the SME data indicates long term health of the SME power system as long as the conditioning scheme is continued.

INTRODUCTION

SME was launched 6 Oct 1981 into a nearly circular polar orbit at an altitude of 534 km. The satellite was injected at an inclination of 97.5 degrees to maintain a near 3AM-3PM sun-synchronous orbit. However, since SME has no onboard mechanism for adjusting its orbit the natural orbital perturbations have caused the orbit plane to precess out of

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the shadow of the earth. The duration of each orbits eclipse has varied from a high of 32 minutes to the current low of 0 minutes. This has caused fluctuations of electrical shelf temperatures, which have ranged from 20 to 60 degrees C.

DESCRIPTION OF SME'S POWER SYSTEM

SME has an unregulated, direct energy transfer power system. Power is generated by eleven parallel diode protected solar array panels, with three additional switchable panels. The energy is stored in two nickel-cadmium batteries containing 21 cells each. While charging to each battery can be disabled, both batteries can discharge through a diode even when commanded off line. Overcharge protection is provided by a shunt regulator that has been commanded to shunt at the lowest of four voltage-temperature (V/T) levels. Undervoltage protection is provided by logic that will turn off all nonessential loads if the voltage drops below 23.7 volts.

The batteries where build by SAFT in the spring of 1977 for use on the P-78 satellite. They were used during P-78 ground tests from Oct 1977 through Sep 1978 and then placed in cold storage. The batteries were tested on Sept 1979 and then returned to cold storage before being placed in SME on Sept 1980. Prior to launch the batteries were cycled approximately 100 times to less than 20% DOD and approximately 20 times to more than 50% DOD (ie. conditioning cycles). In all ground testing battery two was observed to have slightly higher capacity and better balance than battery one.

EARLY MISSION SUMMARY

During the first 4 years of the mission the battery temperatures varied between 15 and 30 degrees C (Fig. 1). Since the angle between the solar arrays and the sun has been kept at a constant 37 degrees the driver for this fluctuation was the yearly solar intensity (Fig. 2). The duration of eclipse has varied little during this period (Fig. 3). The cell imbalance monitors on board, which averages and compares the voltage on each half of each battery, began to rise in both batteries but especially in battery one. In late 1981 battery one was taken off line automatically by the cell monitor. Five days later, battery two was commanded off line to provide deeper conditioning than one eclipse could provide. During the remainder of the mission, on one eclipse per day, optional loads were commanded on to cause a 10% discharge of the batteries to 24.5 volts (Fig. 4). This was combined with some loading during charge to reduce the charge rate to C/10.

TEMPERATURE PROBLEMS WITH BATTERY ONE

During the fall of 1985 the duration of eclipse dropped to less than 20 minutes, for the first time in the mission, and the temperature of the electrical shelf began to rise. However,the temperature of battery one rose an additional 7 degrees C above the electrical shelf (Fig. 5). This additional temperature rise caused battery one to heat the shelf above that predicted for the observed duration of eclipse. Battery one had become a heat source for the electrical shelf. Also, cell imbalances in battery one began to rise during charge and the amount of heat generated by battery one continued to increase. By reducing the charge rate to c/10 the cell imbalances in battery one where brought under control and the temperatures stabilized. Consideration was given, at that time, to taking battery one off line. However, since it was not possible to accurately determine the sharing between the two batteries and since the temperatures where under control battery one was left on line.

NO ECLIPSE

As the first period of no eclipse approached, the temperature of battery one began to increase more rapidly than that of the other electrical shelf monitors. It was decided, at that time, to take battery one off line. The results of taking battery one off line where dramatic. Within 10 hours, the temperature of battery one dropped 18 degrees C and the temperature of battery two dropped 4 degrees C. At this time, the battery temperatures again matched the electrical shelf temperatures. The voltage of battery one dropped 5 volts during the next 30 hours. As the voltage of battery one continued to drop, a decision was made to leave it off-line for the remainder of the mission (Fig. 6).

After the satellite entered the period of no eclipse, battery two was also taken off line. At that time it became possible to recalibrate the current monitors of battery two. Recalibration confirmed the coefficients had been underestimating the share of discharge battery two provided at temperatures above 30 degrees C. It is estimated battery two will be able to supply adequate power to avoid undervoltage during the 1987 eclipses. During the current period of no eclipse, battery two is conditioned by being taken off line for 5-7 days at approximately c/1000 discharge, then recharged for 30 minutes at c/10. After the 30 minutes, the bus voltage reaches shunt and the shunt control trickle charges the battery for an additional four hours, after which the conditioning cycle is repeated. If trickle charge is allowed to continue for more than 4 hours a slight temperature increase is noted in battery two, indicating overcharge.

VOLTAGE PREDICTION

Prior to no eclipse, battery voltage was modeled as a function of the capacity removed from the battery. On a daily basis commands were loaded into the onboard memory. These commands controlled the times loads were turned on and off. Knowing the draw of each load and its duration, the capacity removed from the battery during each eclipse could be calculated and applied to the model to predict the battery voltage. During no eclipse, however, the battery trickle discharges, while offline. This trickle discharge is due to the small draw placed on the battery by the monitors. The value of this draw is unknown, since it is below the resolution of the monitors.

While battery two is offline, changes in voltage occur slowly. The slow change allows for accurate modeling of the battery's discharge curve (Fig. 7). In order to predicted the battery's voltage, over time, a simplification of the Shepherd equation was used.

$$E = E_s - K\left(\frac{Q}{Q - it}\right)i - Ni + Ae^{(-BQ^{-1}it)} \quad \text{(Shepherd equation)}$$

If the amount of current drawn from the battery is assumed constant, then the Shepherd equation (Ref. 1) can be simplified to give:

$$E = V - \frac{W}{1 - Xt} + Ye^{(-Zt)} \quad \text{(simplifed Shepherd equation)}$$

The coefficients (V-Z) are adjusted until the predicted voltage matches the observed voltage.

CONCLUSION

Battery one, which was the weaker of the two batteries, failed initially in 1985 when the increase in sunlight caused it to be overcharged. The battery went into a thermal runaway condition in 1986 and was taken off line. The rapid drop in the voltage of battery one, once off line, was an indication of its weak condition. The current conditioning of battery two will tend to create a soft battery, due to the low discharge rate to shallow depths. Alternate conditioning cycles, however, are being investigated to insure battery two will be able to provide sufficient energy during the eclipses of 1987.

REFERENCES

1. C. M. Shepherd, "Design of Primary and Secondary Cells; II. An Equation Describing Battery Discharge," J. of the Electrochemical Society, Vol.112, No.7, July 1965 pp.657-664

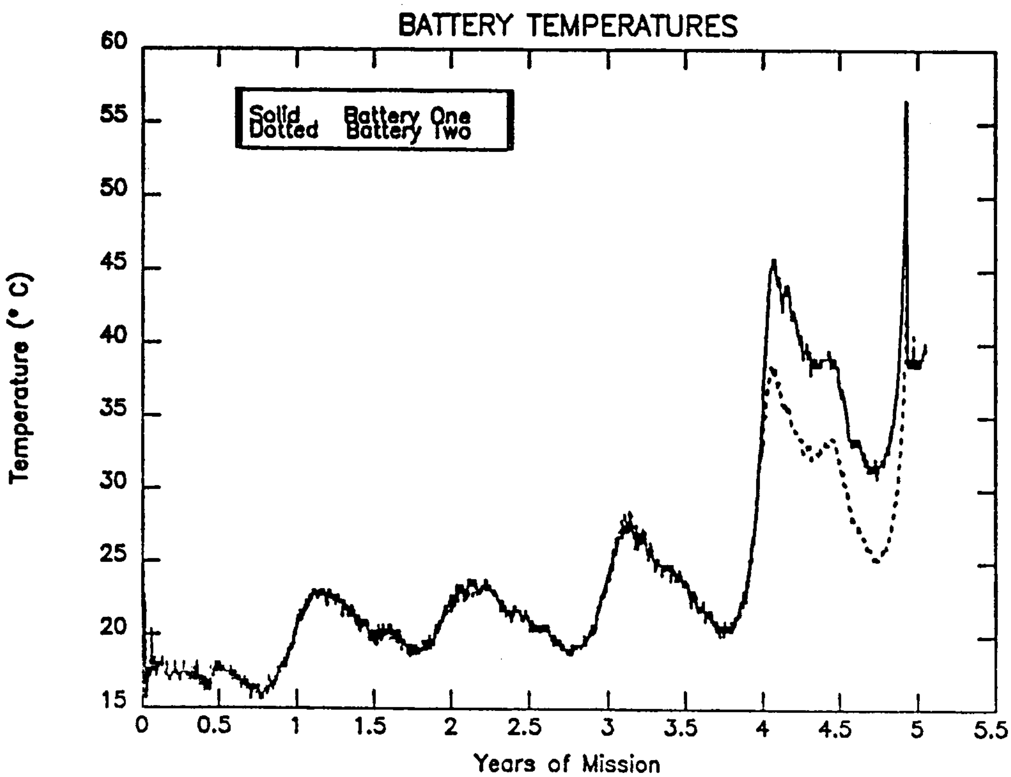
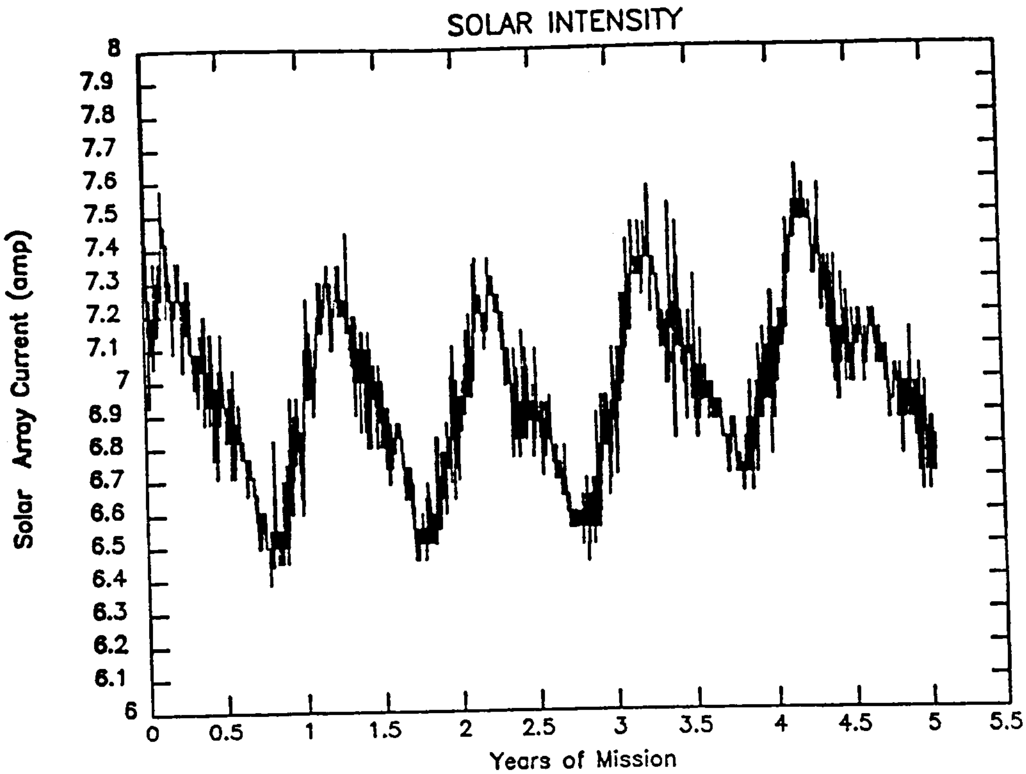


Figure 1.



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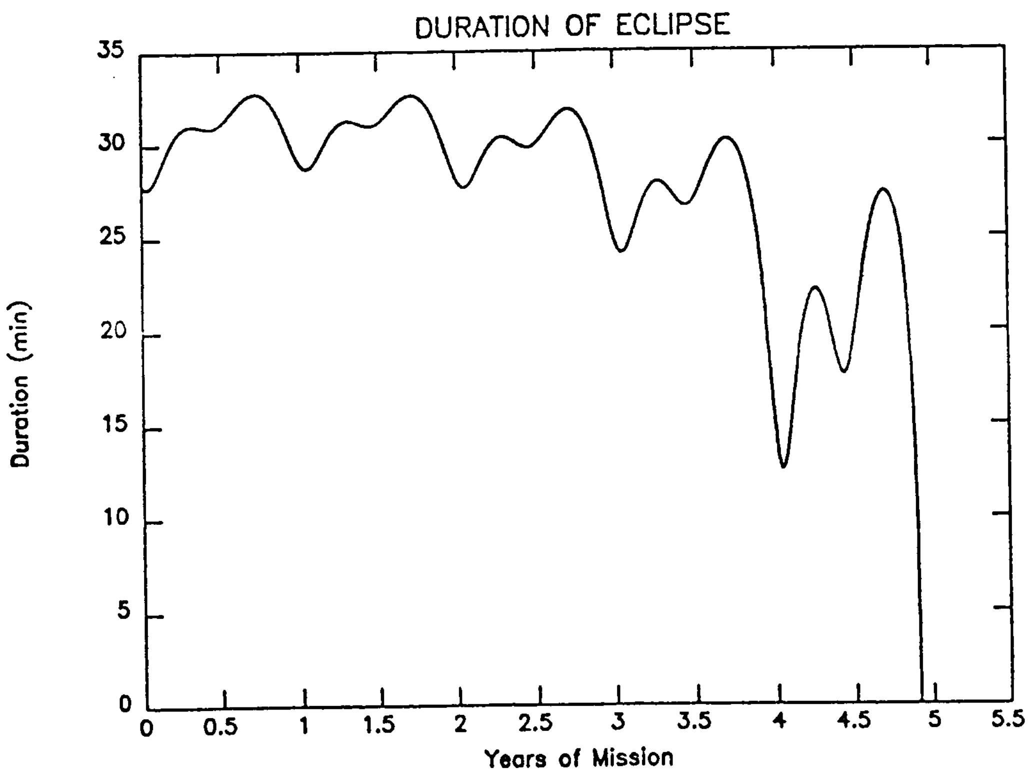

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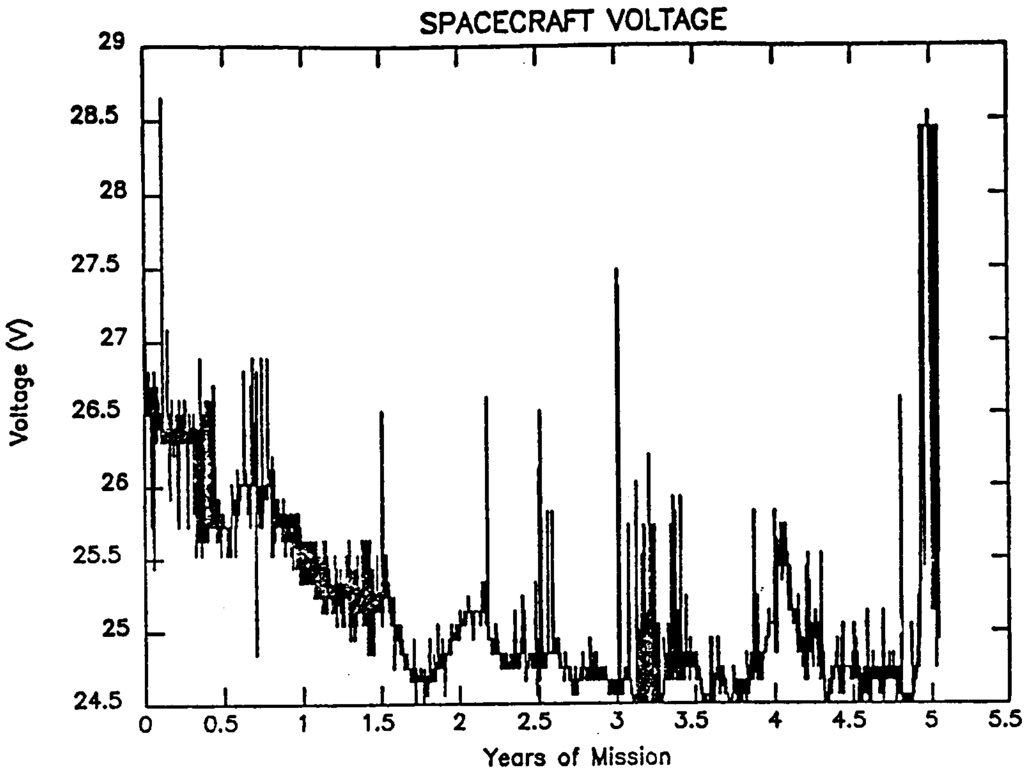

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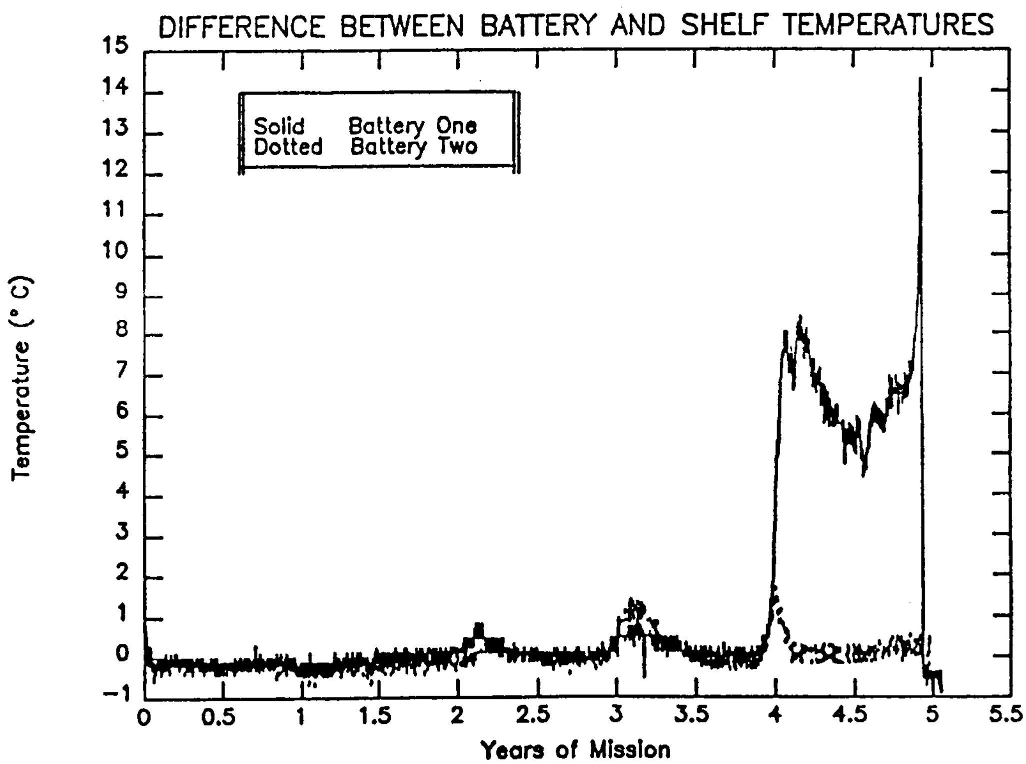

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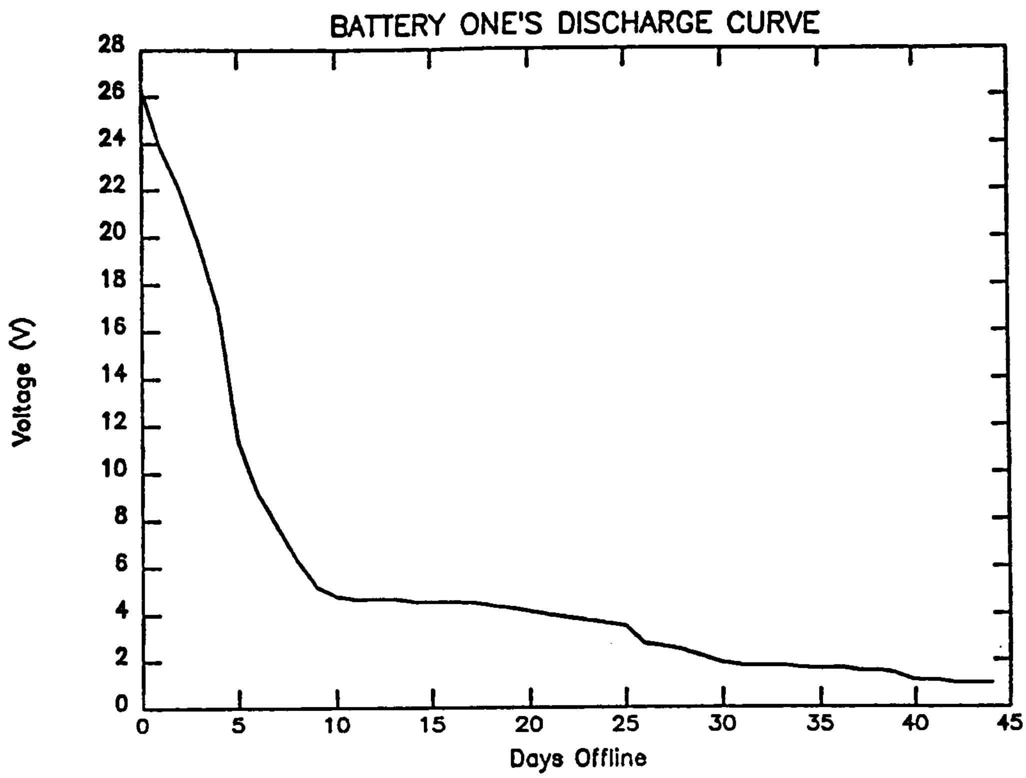

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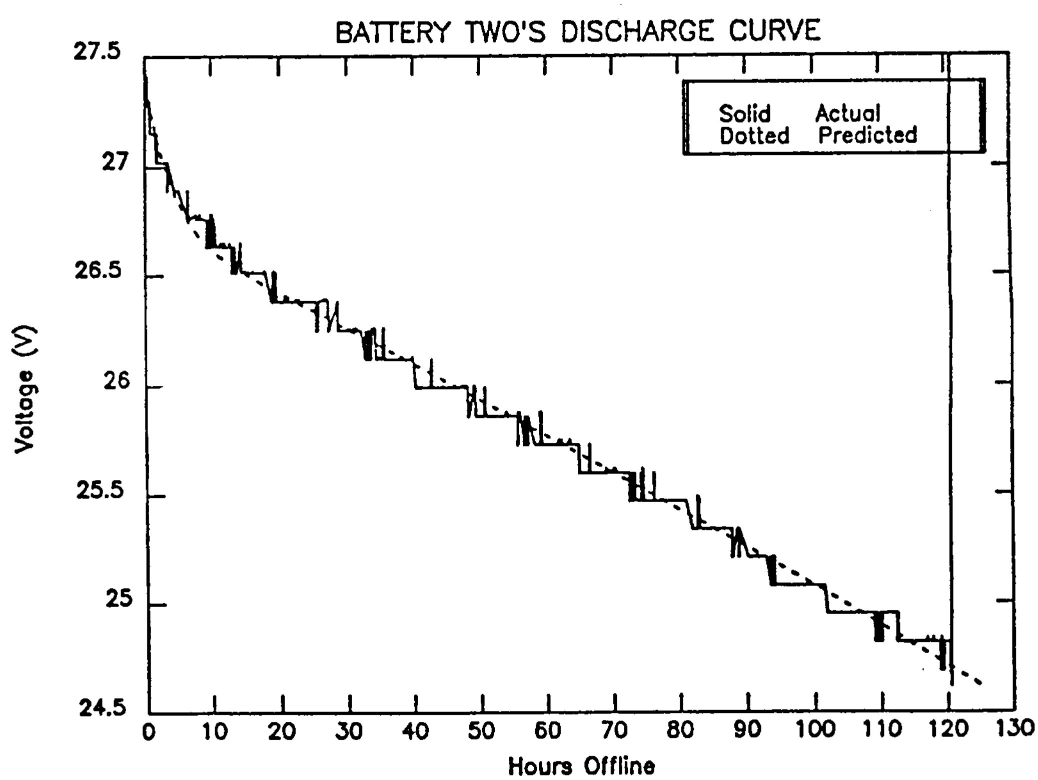

Figure 7.