

Design and Simulation of Lead-Acid Battery

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Articles Information	Abstract
Received: 14.01.2020 Accepted: 27.06.2020 Published: 26.09.2020	This research intends to design and simulation a model of "Lead-acid battery" using OrCAD PSPICE. It can be used for most renewable energy systems applications. The circuit simulator PSPICE is used to compose battery model at Voc 12V, Isc 4.8A, and six cells at 25 °C. This model has treated the battery parameters as the SOC, battery voltage and temperature of the battery at a charge and discharge state. The simulation results were compared with the battery datasheet, and it showed good agreement. The battery model of lead-acid is defined in the PSPICE library, so it could be used for most renewable energy systems applications.
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1. Introduction

All the modern renewable energy systems like energy and photovoltaics energy should contain the battery as an integral part. These systems need batteries to store the overflowing energy and delivered it to the load when the solar not obtainable. Lead acid batteries are the best type used in photovoltaic systems [1] due to the low cost compared with other batteries that available in many design and different sizes and having a long life. Many authors have mainly described the battery model, such as:

Shen Guo, in 2010, used (GAS) Algorithms as a tool to identify the parameters related to the battery (SOC, capacity, and internal resistance). He observed that there is a link between the SoH and the internal resistance [2].

Mahmoud et al. in 2012 presented an equivalent circuit for a model using MATLAB program. It was determined the stored energy and Ah capacity of the battery by measuring specific gravity and voltage of the battery at the same time and substituting their values in a developed algorithm. [3].

Ovidiu Pop et al. in 2017 used the simplest model to simulate voltage variation of the battery using Thevenin model and simulated in PSPICE program for the discharge state at constant load and constant current. The equivalent PSPICE model was implemented to depict the battery behavior based on its SOC and capacitor in order to model the battery capacity in open circuit. [4].

In this paper, a third-order battery model was presented and simulated by PSPICE program. The circuit simulator PSPICE is used to compose battery model at Voc (12 V), Isc (4.8 A) and six cells at 25 °C. This model is used to treat all battery parameters in charge and discharge mode.

This work may not be up to date, but it is essential to add this battery model to PSPICE library.

2. Lead-Acid Battery

For the last 150 years, there was a lot of technology development for batteries. Some techniques have been developed to solve the battery problems in an application. However, there are still some issues facing the save used and the efficiency of this kind of battery, for example, the determination of SOC.

SOC is one of the most critical parameters for batteries because it expresses to the remaining run time of the system [5], protects battery, prevents over-charge and charge, and lengthen the lifetime of the battery [6]. In general, a decrease in SOC refers to discharging battery results, whilst an increase in SOC refers to charging battery results [7].

Many methods have been developed to measuring the SOC of the battery over the years, as direct measurement, hybrid methods, adaptive system, and book-keeping estimation [6].

3. Modeling and Simulation of Battery

In the last period, researchers paid attention to develop different battery models of different levels of complexity as a dynamic battery model, Thevenin battery model, Third-order model, Fourth-order dynamic model, and improved battery model.

The third-order model is used in this paper. The model is consisting of two parts: a parasitic branch and the main branch [8] as shown in Figure 1.

All model parameters in Figure 1 are functions of the charging/discharging currents, SOC, and the cell temperature.

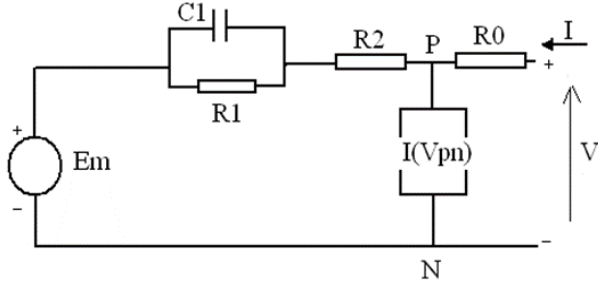


Figure 1. Battery model.

Model of battery was designed to agree with the outputs of the state of charge, cell temperature, battery voltage, inputs of the battery current and ambient temperature, as shown in Figure 2.

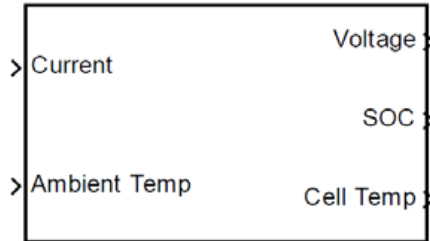


Figure 2. The battery model structure.

Simulation and modeling of the battery need to the know mathematical relationship between battery input and output simulator and parameters. The simulator for battery has been developed using PSPICE. In the next section, the mathematical battery models are explained.

4. Mathematical Model of the Battery

Equation (1) explains the Voc of one cell (E_m). The E_{m0} value is supposed to be constant when the battery was fully charged. The E_m changed with temperature and (SOC) [9].

$$E_m = E_{m0} - K_E (1 - SOC)(273.15 + T_e) \quad (1)$$

The electrolyte temperature (T_e) is varied because of internal resistive losses and ambient temperature, as explained in equation (2) [10].

$$\theta(T) = \theta_{int} + \int_0^t \frac{P_s - \frac{R_\theta}{C_\theta}}{C_\theta} d\tau \quad (2)$$

where P_s : The “ I^2R ” power loss of R_0 and R_2 in Watts.

$$P_s = I^2 * R_{total} \quad (3)$$

$$R_{total} = R_0 + R_2 \quad (4)$$

Equations (5) and (6) used to calculate the resistances of a battery

$$R_o = R_{00} [1 + A_o (1 - SOC)] \quad (5)$$

$$R2 = R20 \frac{\exp[A21(1-SOC)]}{1 + \exp(A22 \frac{Im}{I^*})} \quad (6)$$

The expression of the state of charge is given by equation (7) [11]:

$$SOCn(t) = SOC1 + \frac{1}{SOCm} \int \left(\frac{KVI}{3600} - \frac{D SOCn(t-\tau)SOCm}{3600} \right) d\tau \quad (7)$$

The values of parameters and constants that used for simulations for the “lead acid battery” are appeared in Table 1.

Table 1. Parameters and constants values of the battery model [2,9]

Parameter	Value	Parameter	Value
E_{m0}	2.18 V	R_{00}	2.0 m Ω
K_E	$0.84e^{-3}$ V/C ⁰	R_{20}	15 m Ω
A_{22}	-8.45	R_θ	0.2 C ⁰ /w
A_{21}	-8.0	C_θ	15 Wh/C ⁰
A_0	-0.3	I^*	49 A

In charging mode, the resistor R_{ch} and the battery voltage can be written as follows equation (6) [11]:

$$V_{batt} = V_{ch} + I_{bat} R_{ch} \quad (6)$$

$$R_{ch} = \frac{0.758 + \frac{0.1309}{(1.06 - \beta)}}{SOCm} \quad (7)$$

In discharge mode, the battery voltage and the resistance R_{dch} are then written in the following manner equations (8), and (9) [11]:

$$V_{batt} = V_{ch} + I_{bat} R_{dch} \quad (8)$$

$$R_{dch} = \frac{0.19 + \frac{0.1017}{(\beta - 0.14)}}{SOCm} \quad (9)$$

$$\beta = \frac{SOC}{SOCm} \quad (10)$$

5. Implemented Model

The implemented model of lead-acid battery is presented in the figures below. Figure 3 shows the power dissipated inside the cell according to equation (3) and shows the electrolyte temperature as described in equation (2).

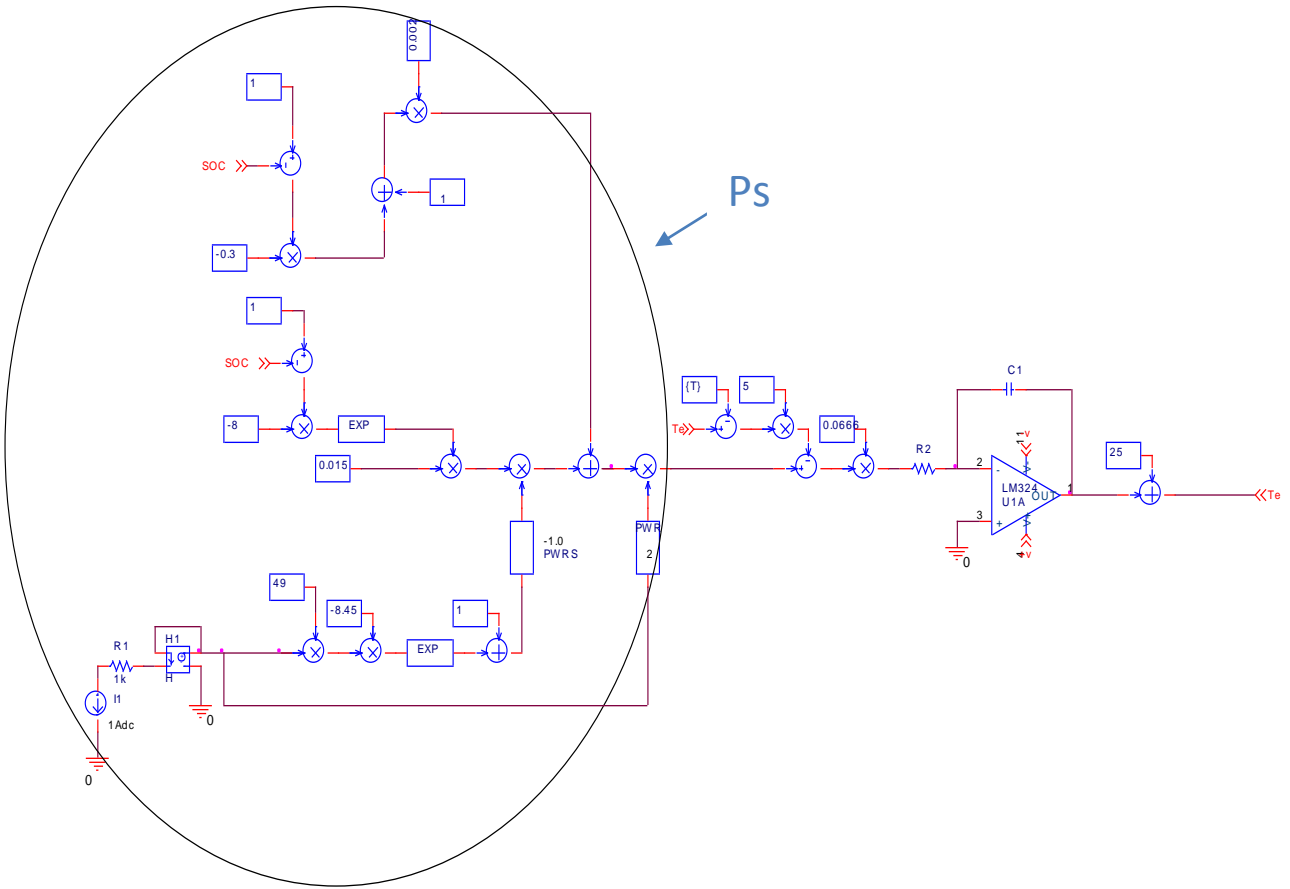


Figure 3. Electrolyte temperature (T_e) circuit in Pspice.

The PV battery has two states one when charging (SOC 0→1), and the other when discharging (SOC 1→0). So, two circuits are built in PSPICE as shown in Figures 4 and 5.

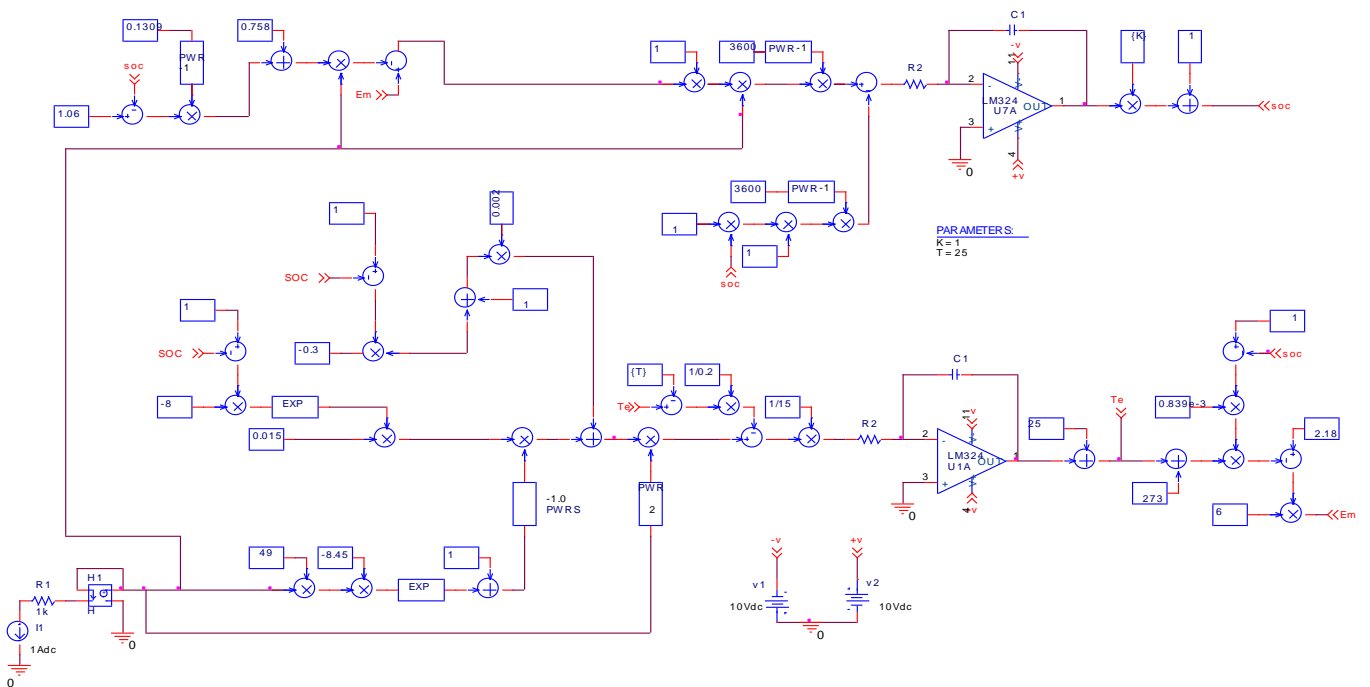


Figure 4. The complete circuit of the battery model with SOC circuit- charge state in PSPICE.

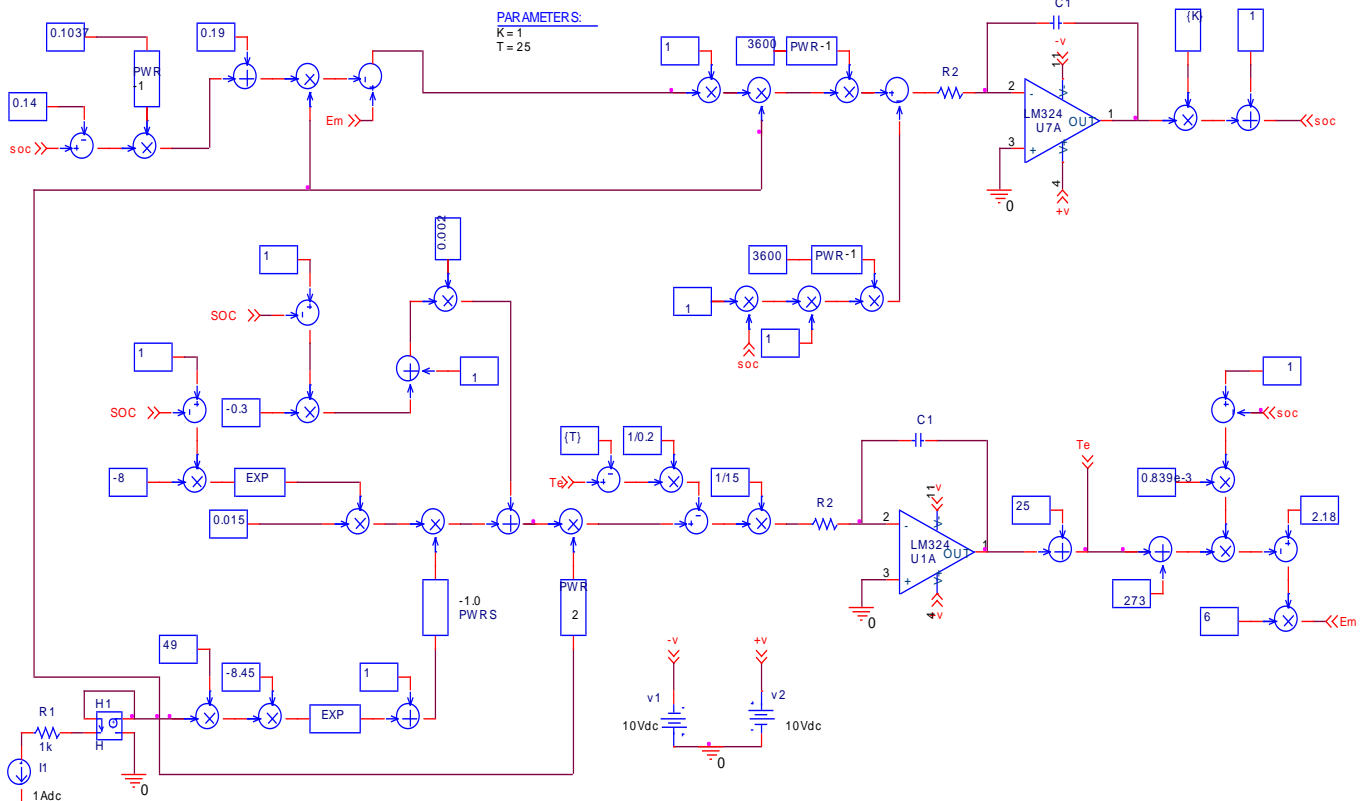


Figure 5. The complete circuit of the battery model with SOC circuit- discharge state in PSPICE.

6. Results

Both Figures 4 and 5 described the complete circuit as the battery model at a charge and discharge state, respectively.

The two circuits are simulated in PSPICE to draw the relations between SOC versus battery current and voltage obtained from DC sweep simulation for the battery model, as shown in Figures 6-10. The five figures give comparable results with battery datasheet [12] graphs.

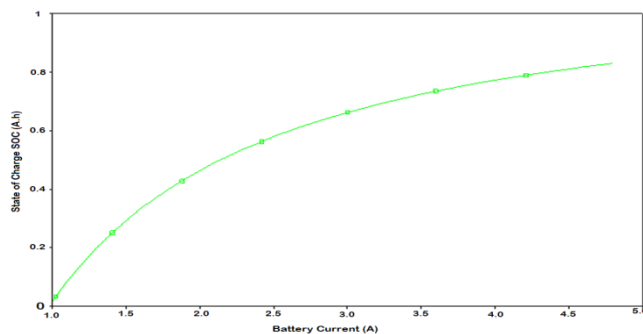


Figure 6. SOC vs. battery current.

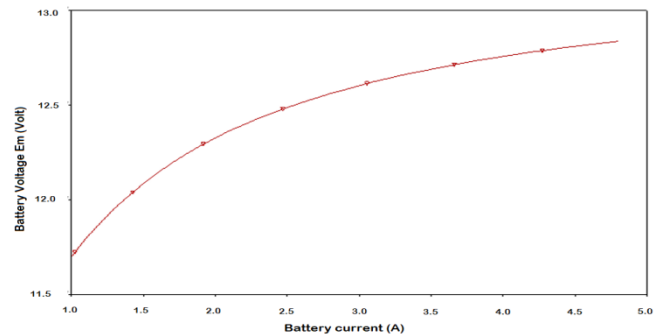


Figure 7. Battery voltage (Em) vs. battery current.

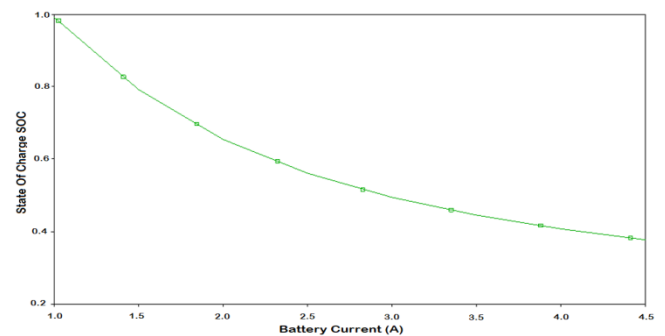


Figure 8. SOC vs. battery current.

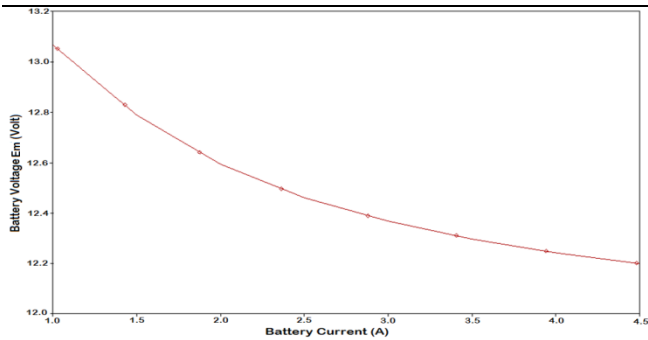


Figure 9. Battery Voltage vs. battery current.

Figure 10 shows SOC as a function of battery voltage, and it reveals that the battery voltage increased as the SOC increased.

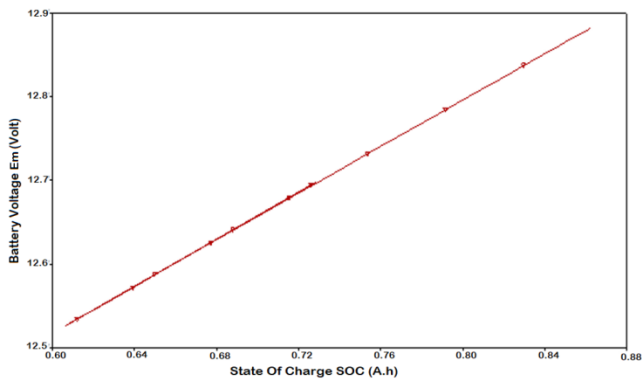


Figure 10. Battery voltage vs. state of charge.

The variation in SOC and battery voltage with time is shown in Figures 11 and 12 at discharge mode and in Figures 13 and 14 at charge mode.

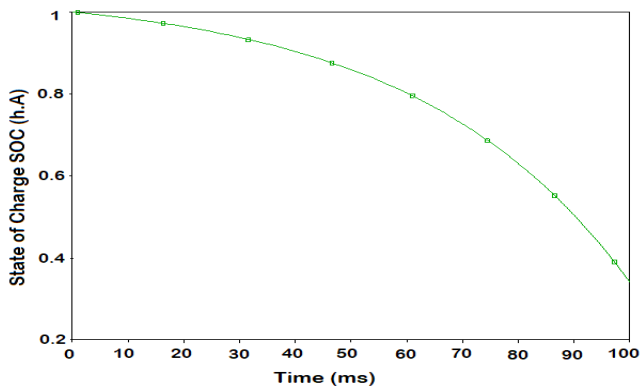


Figure 11. SOC vs. time for discharge state.

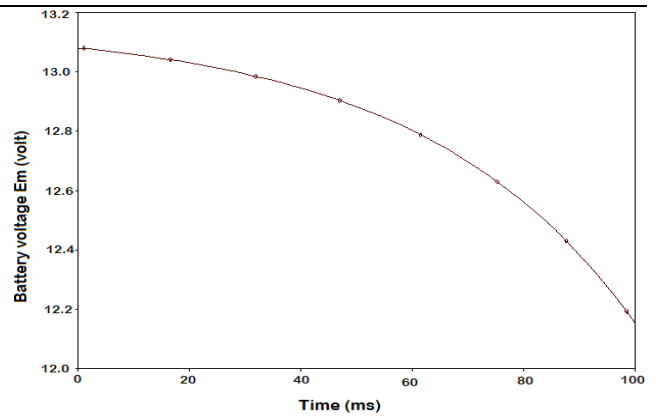


Figure 12. Battery voltage vs. time for discharge state.

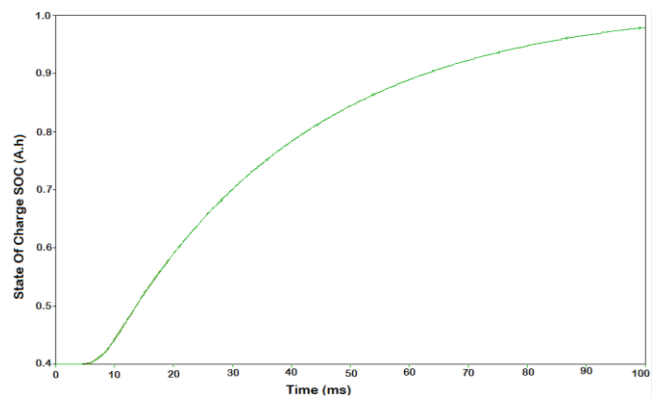


Figure 13. SOC vs. time for charge state.

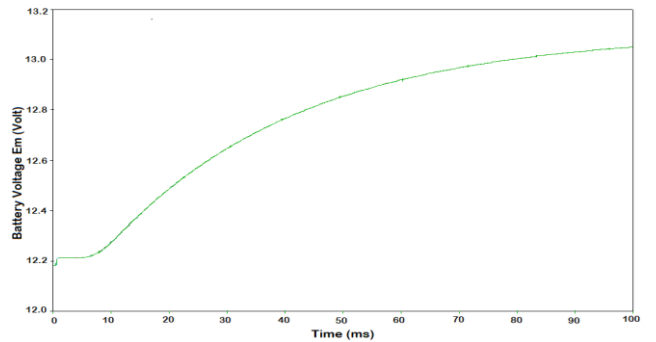


Figure 14. Battery voltage vs. for charge state.

Next, the following Figures 15 and 16 reveal the results of the simulation of SOC and battery voltage vs. time at different (K) values (0.3, 0.5, 0.7, 0.9), respectively.

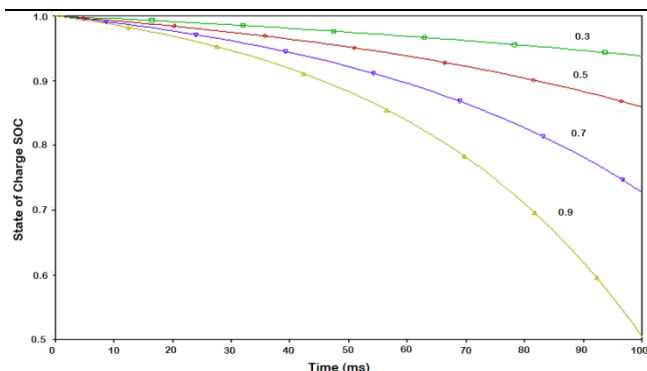


Figure 15. State of charge vs. Time for K (0.3, 0.5, 0.7, 0.9).

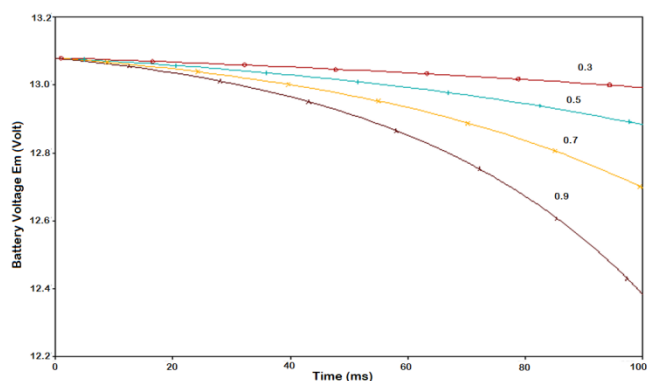


Figure 16. Battery voltage vs. Time for k (0.3, 0.5, 0.7, 0.9).

The curve in Figure 17 appears a small variation of the battery temperature during charge and discharge state.

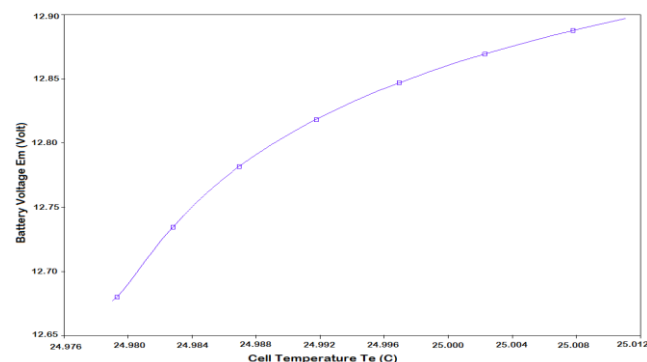


Figure 17. Battery temperature vs. battery voltage.

7. Conclusions

The following points could be concluded:

- The model was simulated for charge and discharge state by using PSPICE program, and the results of simulation are in good agreement with datasheet.
- The main benefit of this model can be easily varying the battery characteristics like (ambient temperature, battery current, and number of cells).

- Battery model of lead-acid is defined in PSPICE library so, it could be used for most renewable energy systems applications.

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