IAES International Journal of Artificial Intelligence (IJ-AI)
Vol. 2, No. 2, June 2013, pp. 81~89
ISSN: 2252-8938

A Fuzzy Model for Ni-Cd Batteries

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Article Info

Article history:

Received Nov 11,2012
Revised Jan 27, 2013
Accepted March 02,2013

Keyword:

Battery modeling
Fuzzy logic
Ni-Cd Battery
Charging current

ABSTRACT

The batteries models found in the literature are based mainly on mathematical descriptions of physical, chemical, and electrochemical properties which are difficult to determine. This paper presents new fuzzy based model for Nickel Cadmium (Ni-Cd) batteries. The main advantage of the proposed models is that, the proposed model is able to predict battery output voltage without knowledge of numerous factors. Inputs of the proposed model are battery current and state of charge while battery voltage is selected as the output. To check the accuracy of the proposed models, simulations results are compared with the measured battery data at different charge current as well as many other battery models for a 7Ah, size F, Ni-Cd battery. Simulated shows good agreements with measured data. The advantage of fuzzy model is that for modeling by fuzzy method experimental data isn't needed. The proposed models can apply for modeling of other batteries types.

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1. INTRODUCTION

With increasing of oil price and mounting environment concerns, cleaner and sustainable energy solutions have been demanded [1]. Nowadays electric vehicles are being more and more placed in the center of attraction because of the importance of shortage in fossil fuels [2]. Battery is one of the most important parts in an electric vehicle or hybrid electric vehicle. Although batteries seem to act like simple electrical energy storage devices, when they deliver and accept energy; they undergo thermally dependent electrochemical processes that make them difficult to model. Thus, the electrical behavior of a battery is a nonlinear function of a variety of changing parameters. There are many types of batteries and many factors that affect battery performance. The ultra-fast charging capability, fine performance and high capacity of Nickel Cadmium (Ni-Cd) batteries along with their limited weight and size are attractive and distinct properties for light and compact equipment. Ni-Cd batteries have found many applications including cordless and portable equipment, photovoltaic systems, electric vehicle, satellites, and power plant supporting equipment [3]. Since nonlinear electrochemical behavior of the battery, it is difficult to model battery mathematically. There are various linear models for Nickel-Cadmium [4-7]. These models are not completely accurate. This paper presents a new fuzzy based model for Nickel Cadmium (Ni-Cd) batteries.

Fuzzy modeling is a method to describe nonlinear input-output relationships using fuzzy rules. The main goal of fuzzy modeling is to be characterizing with two main purposes. One is to make an accurate and quick procedure to approach the desired result. The other is to build a general and flexible mechanism which is applicable to solve various fields of modeling problems [8]. The basic description of the fuzzy method presented in [9-12]. Fuzzy systems are very suitable for battery modeling. The main contribution of this paper is nonlinear nature of model parameters and their dependency on battery charging current.

This paper is organized as follows: In section II, the electrical models of Ni-Cd batteries are presented. The proposed model is outlined in section III. Section IV presents simulation of Ni-Cd battery. The simulated and measured data are presented, compared and discussed in section V. Conclusion is presented in section VI.

2. ELECTRICAL MODELS OF NI-CD BATTERIES

In the following section, first, three battery models will be described briefly and then a new fuzzy model for Ni-Cd batteries will be proposed in the next section.

a. Ideal Model

Figure 1(a) shows the ideal equivalent model of the Ni-Cd battery with a simple voltage source [13].

$$V_{bat}(t) = V_o \tag{1}$$

This model is very simple an in this model nonlinear behavior and internal parameters.

b. Linear Model

Figure 1 (b) shows the linear model of the Ni-Cd battery with open-circuit voltage V_o and its internal resistance [13]. Moreover, voltage source V_o and internal series resistanceR are fixed and don't change with charge/discharge rates:

$$V_{bat}(t) = R\,I_{bat} + V_o \tag{2}$$

This model is inappropriate for electric vehicle applications.

c. Thevenin Model

Figure 1(c) display the Thevenin model of Ni-Cd battery contains of an ideal no-load voltage V_o, internal resistance R_2 and a parallel R_1C circuit that incorporates the impact of over voltage conditions [13]. The battery voltage can be computed as:

$$V_{bat}(t) = R_2 I_{bat} + R_1 I_{bat}(1 - e^{\frac{-t}{R_1 C}}) + V_o \tag{3}$$

The main disadvantage of the Thevenin battery model is that all the elements are assumed to be constant, but in reality all the elements are functions of the operation conditions.

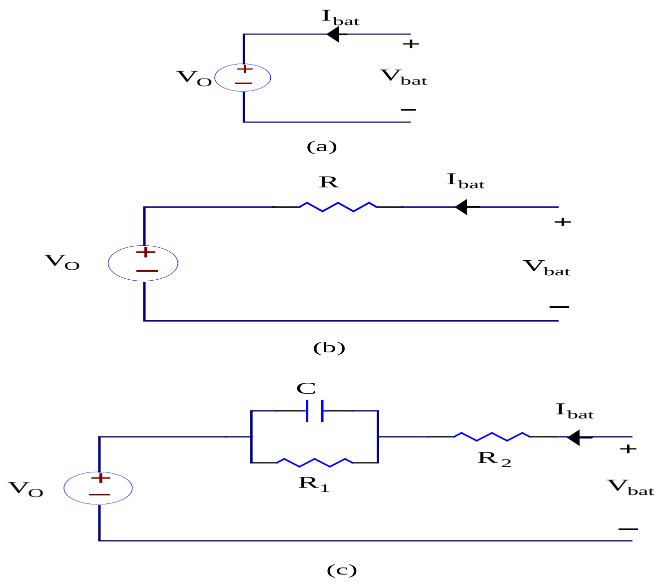


Figure 1. Electrical models of Ni-Cd batteries; (a) Ideal model, (b) Linear model, (c) Thevenin model

3. THE PROPOSED FUZZY MODEL FOR NI-CD BATTERIES

In the above mentioned models nonlinear electrochemical behavior of battery was neglected. In this section, a new fuzzy model for Ni-Cd batteries has been presented. Fuzzy logic can model nonlinear functions of arbitrary complexity [9, 14]. The theory of fuzzy sets was pioneered in 1965 by Lotfi A.Zadeh [9]. Nowadays, fuzzy systems are applied to many different application areas. Defining the input and output variables is one of the important steps in the fuzzy modeling. Inputs of the proposed fuzzy model are battery current (I_{bat}) and state of charge (SOC) while battery voltage (V_{bat}) is selected as the output. The fuzzy system includes three blocks: fuzzification, fuzzy rule algorithm, and defuzzification.

Fuzzification: A membership function associated with a given fuzzy set maps an input value to its appropriate membership value. The membership functions of SOC have seven fuzzy subsets and the membership functions of I_{bat} have five fuzzy subsets. The fuzzy sets of membership functions for the input variables are as shown in the Figures. 2 and 3 Also five triangle membership functions considered for output variable. The fuzzy variables are expressed by linguistic variables “positive big” or (PB), “positive medium” or (PM), “positive small” or (PS), “zero” or (ZZ), “negative small” or (NS), “negative medium” or (NM), “negative big” or (NB).

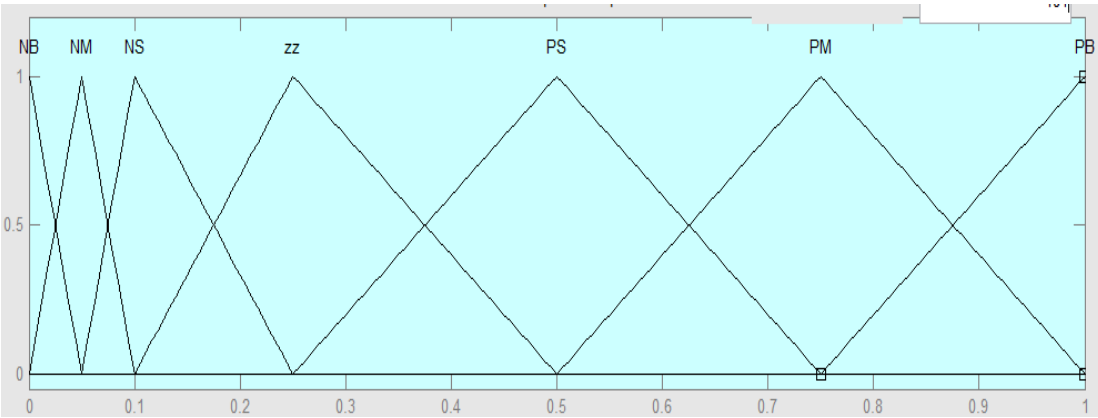


Figure 2. Membership functions of SOC

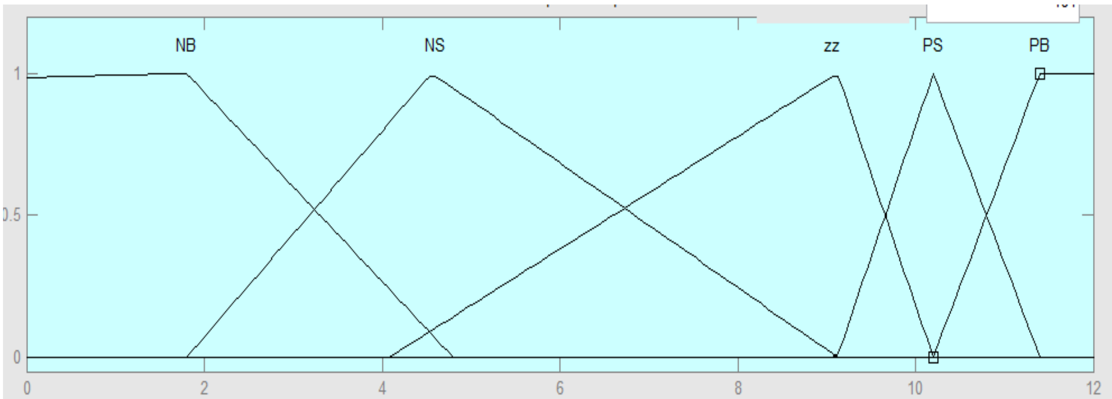


Figure 3. Membership functions of I_{bat}

The fuzzy rule algorithm: A fuzzy system consists of several fuzzy IF-THEN rules, which map an input space to an output space. In this paper, the fuzzy rule algorithm includes 35 rules, which are based on the five membership functions of the first input variable and seven membership function of the second input variable. Table 1 shows the rules for the proposed fuzzy model.

Defuzzification: The output of fuzzy system is a fuzzy subset but the actual system requires a crisp value. For convert the fuzzy output into a crisp value, defuzzification is done using center of area (COA) algorithm as following:

$$\Delta U(K) = \sum_{i=1}^{n} \mu(D_i) D_i \Big/ \sum_{i=1}^{n} \mu(D_i) \quad (4)$$

Where $\Delta U(k)$ is the output of the fuzzy system and D_i are the centers of Max-Min composition output membership function.

Table 1. Fuzzy logic rules

SOC / ***Ibat***	**NB**	**NM**	**NS**	**ZZ**	**PS**	**PM**	**PB**
NB	PB	PB	PM	PM	PM	PM	PB
NS	PB	PM	PM	PS	PS	PS	PS
ZZ	PB	PM	PS	ZZ	ZZ	ZZ	ZZ
PS	PB	PS	NS	NS	NM	NM	NM
PM	PB	PS	NM	NM	NM	NM	NB

Figure 4 shows the basic structure of a fuzzy system consist of four main components, fuzzifier, inference engine, knowledge base and defuzzifier.

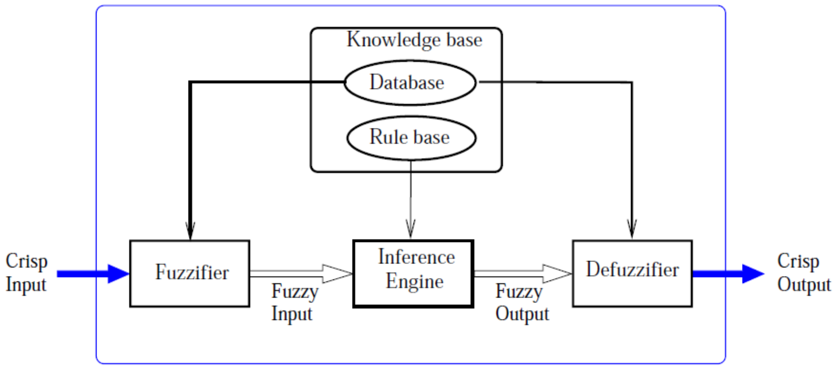


Figure 4. Basic structure of a fuzzy inference system

4. SIMULATION OF BATTERY

To compare battery models, all of the mentioned models of Ni-Cd battery are simulated in Matlab/Simulink environment. Figure 5 shows the proposed fuzzy model in MATLAB/SIMULINK environment. In this section of simulation SOC and Current are respectively its inputs. The SOC is a function of I_c and time, the value of I_c is changed when effect of the ambient temperature are neglected.

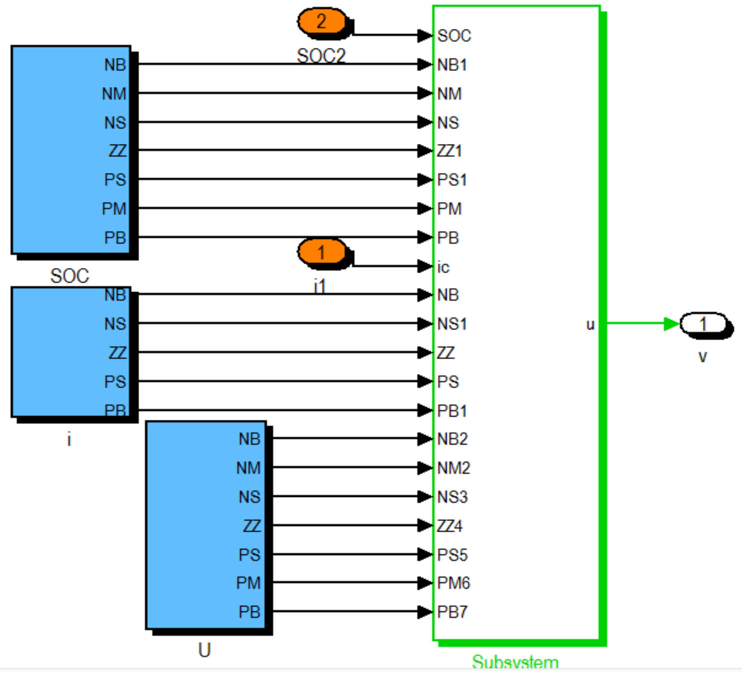


Figure 5. The proposed fuzzy model of battery in MATLAB/SIMULINK

The general block diagram of battery model in MATLAB/SIMULINK environment is shown in Figure 6 Inputs of the new fuzzy model are battery current (I_{bat}) and state of charge (SOC) while battery voltage (V_{bat}) is selected as the output. When the current is changed, first the SOC is computed and then both of current and SOC considered as new battery fuzzy model. The initial value of SOC was 0.1.

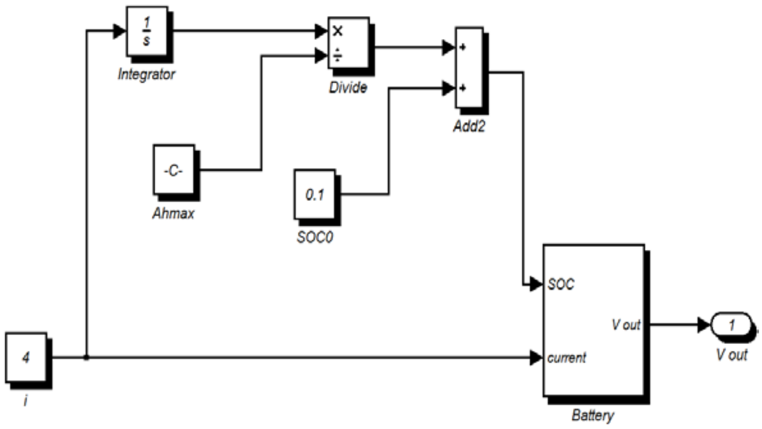


Figure 6. Battery model in MATLAB/SIMULINK environment

5. COMPARSION OF SIMULATED AND MESURED RESULTS

In order to investigate the accuracy and validity of the proposed model, the simulated results of the proposed model are compared with results of conventional models (e,g., ideal, linear, thevenin) for the Ni-Cd battery at different charge current (e.g., 3.5A, 5A, 6A and 7A). Also these results are compared with measured results. The experimental setup consisted of a SANYO, 7Ah, size F, Ni-Cd battery, an adjustable current source, a personal computer and an interface board (Figure 7). The adjustable current source generates the desired current level for battery charging. The interface circuit sample battery voltage during charging time (about 40 minutes) and stores data in the personal computer.

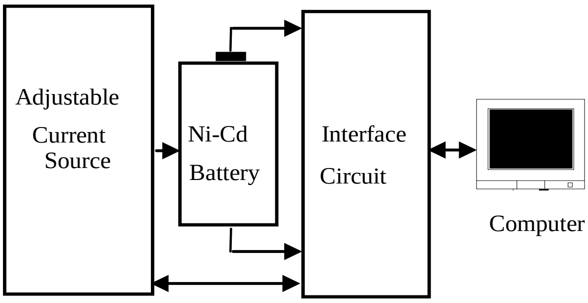


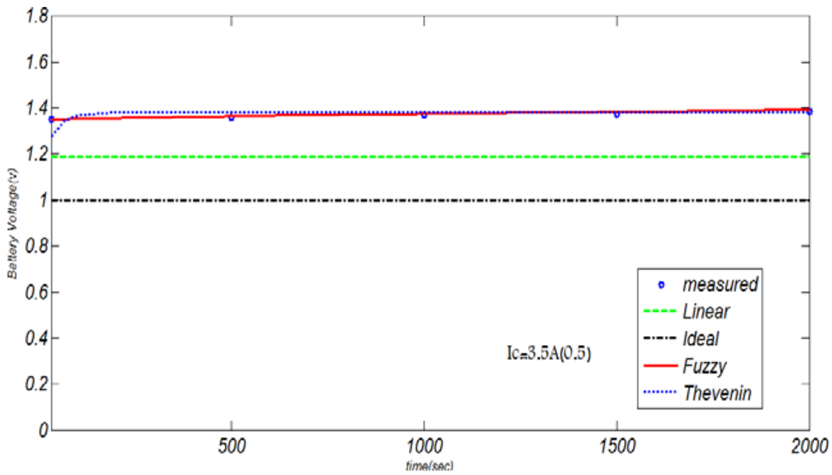
Figure 7. The experimental setup used to measure battery character

Comparison of simulated results and measured data are presented for three following main reasons:

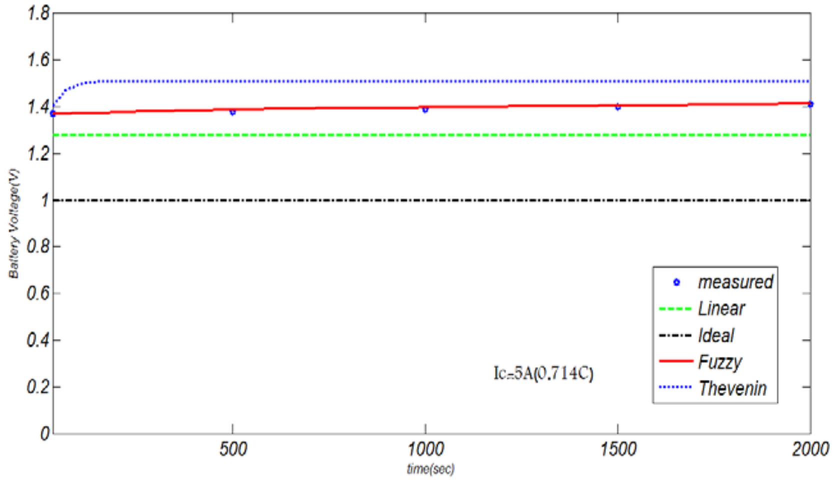
- To validate the proposed fuzzy model at charge currents (Figure 8 and Tables 2-5)

Figure 8 shows these results. The error between measured and simulated results at mentioned charge current is shown in Tables 2-5 where error is computed as following:

$$Error = |Measured - Simulated|$$

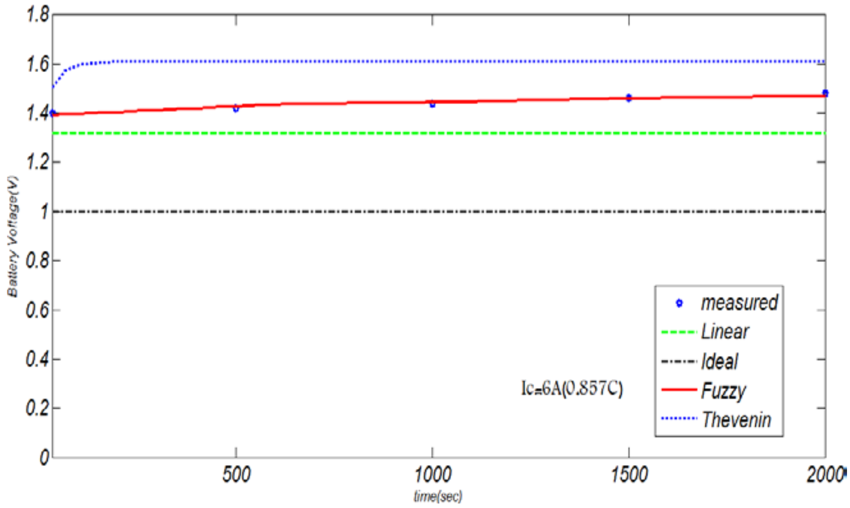


(a)

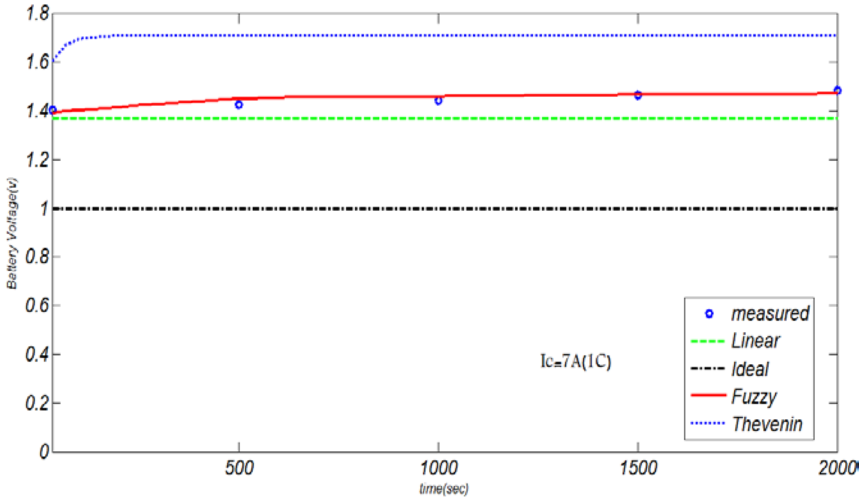


(b)

Figure 8. Comparison of simulated and measured battery voltages at different charge rates; (a) I_c=3.5A, (b) I_c =5 A.



(c)



(d)

Figure 8. (continued). Comparison of simulated and measured battery voltages at different charge rates; (c) I_c =6 A, (d) I_c =7 A.

Table 2. Errors between measured and simulated data at I=3.5(A) in different time

Time(sec)	Ideal	Linear	Thevenin	Fuzzy
500	0.37	0.18	0.01	0.002
1000	0.378	0.188	0.018	0.001
1500	0.385	0.195	0.025	0.005
2000	0.39	0.20	0.03	0.008

Table 3. Errors between measured and simulated data at I= 5(A) in different time

Time(sec)	Ideal	Linear	Thevenin	Fuzzy
500	0.39	0.13	0.1	0.004
1000	0.398	0.138	0.092	0.004
1500	0.406	0.146	0.084	0.001
2000	0.41	0.15	0.08	0.002

Table 4. Errors between measured and simulated data at I= 6(A) in different time

Time(sec)	Ideal	Linear	Thevenin	Fuzzy
500	0.42	0.1	0.17	0.009
1000	0.44	0.12	0.15	0.002
1500	0.46	0.14	0.13	0.003
2000	0.47	0.15	0.12	0.005

Table 5. Errors between measured and simulated data at I= 7(A) with different time

Time(sec)	Ideal	Linear	Thevenin	Fuzzy
500	0.43	0.06	0.16	0.013
1000	0.45	0.08	0.14	0.008
1500	0.47	0.1	0.12	0.002
2000	0.48	0.11	0.11	0.003

Battery voltage at different charge currents for battery initial State of Charge (SOC) about 10% is shown in Figure 9, to show the effect of change at battery current by increasing of this current in the proposed fuzzy model.

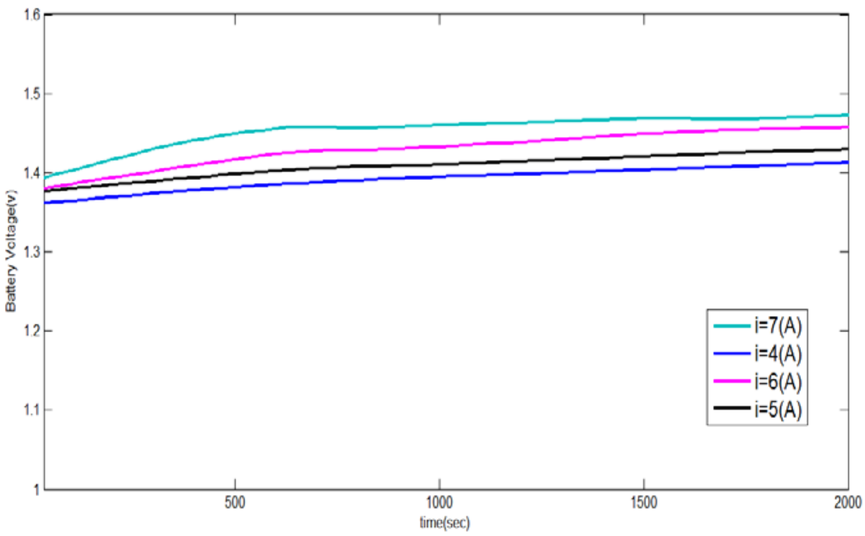


Figure 9. The battery voltage at different charge current

6. CONCLUSION

In this paper, a new fuzzy model for Ni-Cd batteries is proposed, and its characteristics is compared with several conventional battery models (ideal, linear, Thevenin) as well as measured results. The proposed fuzzy model can model nonlinear electrochemical behavior of Ni-Cd batteries. As conclusion the use of the proposed model of the battery allows a better understanding and prediction of the battery behavior.

The comparisons of simulated and measured results show that the proposed fuzzy model accurately predicts the behavior of Ni-Cd batteries. The contribution of the proposed model as compared with other battery models is the inclusion of the nonlinear electrochemical characteristics and their dependency on charging current which makes the simulation results more accurate. Also the proposed model can be used to model other battery types.

REFERENCES

[1] YL Zhou. *Electrical Power Engineering*. MSC Thesis, Dept. Elect, Science and Technology Univ, Beijing. 2005.

[2] S Zoroofi. *Electrical Power Engineering*. MSC Thesis Dept. Elect, Chalmers Univ, Gothenburg, Sweden. 2008.
[3] BY Liaw, M Dubarry. "A roadmap to understand battery performance in electric and hybrid vehicle operation, in Electric and Hybrid Vehicles. Power Sources, Models, Sustainability, Infrastructure and the Market". *G. Pistoia, (Ed). Amsterdam, Netherlands, Chapter 15*. 2011: 375-403.
[4] JR Lee, BH Cho, FC Lee. *IEEE Trans. on Aerospace and Electronic Systems*. 1988; 24: 295.
[5] J Robbins, J Hawkins. "Battery model for over current protection simulation of DC distribution systems". *The 16th International Telecommunication Energy Conference, Vancouver, BC*. 1994: 307-314.
[6] R Nailen. "Battery protection-where do we stand". *IEEE Trans. on Industry Applications*. 1991; 27: 658.
[7] D Temkin, M Mcvey, V Carlson. "A Spacecraft Electrical Battery Model and Simulator". *Energy Conversion Engineering Conference*, IECEC-90. 1990: 19-26.
[8] HM Feng. "Hybrid Stages Particle Swarm Optimization Learning Fuzzy Modeling Systems Design". *Tamkang Journal of Science and Engineering*. 2006; 9(2): 167-176.
[9] LA Zadeh. *Fuzzy Set, Inform. and Contr.* 1965; 8: 338.
[10] T Takagi and M Sugeno. "Modified recurrent neuro-fuzzy network for modeling ball-screw servomechanism by using Chebyshev polynomial". *IEEE Trans. on Systems, Man, Cybernetic*. 1985; 16: 116.
[11] JM Mendel. *Uncertainty, fuzzy logic, and Signal Processing*. 1999; 80: 913-933.
[12] R Babuska. "Recent Advances in Intelligent Paradigms and Applications". *Springer-Verlag*. 2002: 161.
[13] YH Kim, HD Ha. "Design of interface circuits with electrical battery models". *IEEE Trans. on Industrial Electronics*. 1997; 44: 81.
[14] LA Zadeh. "Outline of a New Approach to the Analysis of Complex Systems and Decision Processes". *IEEE Trans. on Systems, Man, and Cybernetics*. 1973; 3: 28-44.

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