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FUZZY MODELING OF BATTERY AVAILABLE CAPACITY ESTIMATION FOR ELECTRIC VEHICLES APPLICATIONS

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Abstract

Different types of electric vehicles (EV) have been recently developed with the aim of solving pollution problems caused by the emissions of gasoline powered engine. One of the weakest points of EV is the battery system due to its highly complex nonlinear characteristics so the distance of travel is not defined accurately. One of challenges of EV is the battery modeling to know the battery available capacity and state of charge to charge the EV at the suitable distance of travel. If the battery available capacity (BAC) and state of charge (SOC) are estimated accurately, the user will know exactly the amount of the power that the battery capable of providing. Knowing the BAC and SOC prevents EVs from being stopped on the road and also optimize the utilization of the battery energy storage system in EVs. In this paper a proposed fuzzy model for BAC estimation based on battery temperature and discharge current is presented, then the SOC is estimated based on the BAC and discharging current. Experimental data are collected for model building and model training. Comparison between the calculated BAC from the fuzzy model and the measured BAC from the measured experiments shows a good agreement. Also the proposed technique can be applied for modeling of different types of batteries for EV applications.

Keywords: Electric vehicles, Batteries, Battery available capacity, fuzzy model.

1 INTRODUCTION

Different types of electric vehicles (EV) have been recently developed with the aim of solving pollution problems caused by the emissions caused by gasoline powered engine. One of the weakest points of EV is the battery system due to its highly complex nonlinear characteristics. The Battery Available Capacity (BAC) refers to the quantity of electricity that can be delivered by a fully charged battery at certain discharge current and temperature before reaching a specified cut-off voltage. The BAC depends on the discharge current and the temperature. A rapid increase in battery temperature or lowering the discharge current will increase the BAC. The BAC indicator is similar to oil gauge in the internal combustion engine vehicles. If the BAC can be estimated accurately, the driver of the vehicle will know exactly the amount of the power that the battery capable of providing and also the distance travelled by the vehicle. Knowing the BAC, and, thus the driving range not only prevent EVs from being stopped on the road but also optimize the utilization of the battery energy storage in EVs. Many literatures handled the problem of estimation of BAC using neural network and neuro-fuzzy such as [1-3]. The other phase of estimation of available power in the battery or the state of the battery is the state-of-charge. State of charge (SOC) is the ratio between the remaining capacity in the battery to its original capacity. This concept is a very important component of battery management system (BMS). According to SOC, BMS can not only determine the working time, but also try to avoid battery over discharge/over charge and diagnoses battery state of health (SOH). Many literatures handled SOC estimation using different techniques such as [4-6].

$$SOC = \frac{(C_a - \int idt)}{C_a} 100\,\% \qquad (1)$$

Ca: The available discharging capacity of battery is a function of discharging current and temperature, i is the discharging current, and t is the time. Many literatures handled SOC estimation using different techniques such as [4-6].

Mathematically, the battery available discharge capacity can be expressed as:

$$BAC = C_a = \left(f(I_d(t), T(t), V(t)\right)_{V(t)=V_{off}} \qquad (2)$$

Where *V (t)* is the battery terminal voltage, *T (t)* is the temperature, I_d *(t)* is the discharging current, and V_{off} is the cut-off voltage. From the previous definition, the BAC is depends on both temperature and discharge current. Increasing the battery temperature or lowering discharge current will cause an increase of the BAC as shown in Fig.1. This paper proposes a mamdani fuzzy modeling for BAC estimation based on battery temperature and discharge current. Data is collected using experimental measurements of BACs at different discharging currents and temperatures. The calculated BAC and discharging current are used to calculate the SOC of the battery. Comparisons between actual measured BACs and the modeled BACs are presented which show good agreement between them and show the effectiveness of the proposed modeling method. The next section describes fuzzy modeling techniques, section (3) describes experimental system setup, and section (4) describes the results of the measured BACs compared with modeled BACs using proposed method, and section (5) conclusions.

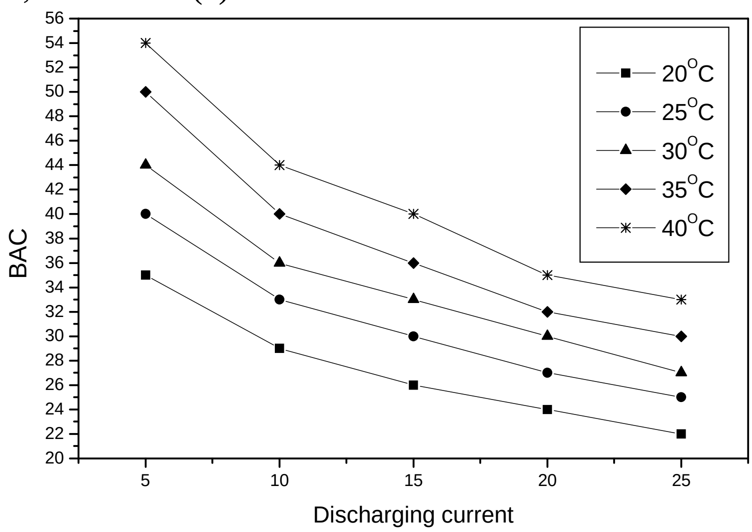

Figure 1: BAC versus discharging current at different temperatures.

2 FUZZY MODELING TECHNIQUES

Fuzzy modeling techniques are increasingly popular for modeling complex systems to which standard linear methods cannot be applied due to insufficient knowledge about the underlying physical mechanisms, process, nonlinearity, and parameter uncertainty. Fuzzy models are based on a fuzzy mapping between input and output using fuzzy sets. The modeling is based on the fuzzy sets theory which mapping the input-output relations using linguistic membership functions. Each rule is valid for a specific region in the antecedent space [7]. Design of a fuzzy model based on the available data, the following steps summaries the design process:

1. Select the input and output variables, the structure of the rules, and the inference and defuzzification methods.

2. Decide on the number of linguistic terms for each variable and define the corresponding membership functions.

3. Formulate the available knowledge in terms of fuzzy if-then rules.

4. Validate the model. If the model does not meet the expected performance, iterate on the above design steps.

The collected data and modeled data of the BAC and the discharging current at different temperatures are shown in Tab. I.

Table I: Experimentally measured BAC at different temperatures and discharging currents.

Temp / I_{dis}	20	25	30	35	40
5	35	40	44	50	54
10	29	33	37	40	44
15	27	30	33	36	40
20	24	27	30	32	35
25	22	25	27	30	33
	BAC				

Membership functions for the first input (discharging current) is shown in Fig.2, membership functions for the second input (temperature) is shown in Fig.3 and the output membership functions are shown in Fig.4.

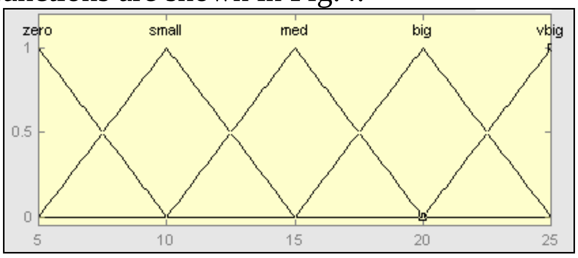

Figure 2: Discharging current membership functions.

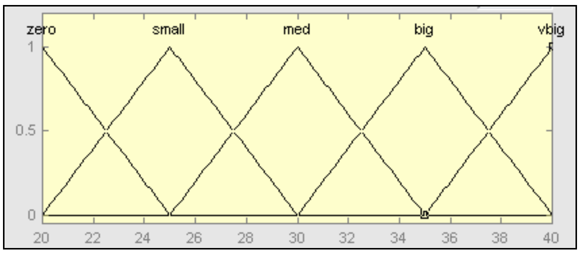

Figure 3: Temperature membership functions.

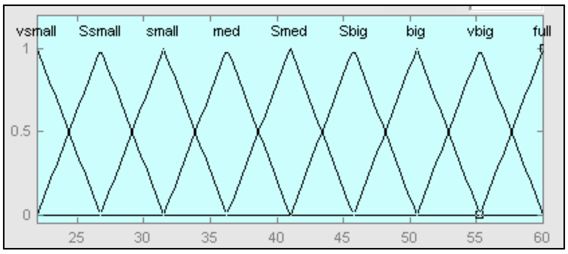

Figure 4: BAC membership function.

Knowing the BAC from the fuzzy model and the discharging current, the battery SOC can be calculated by equation (1). The simulink block diagram explains SOC calculation is shown in Fig.5.

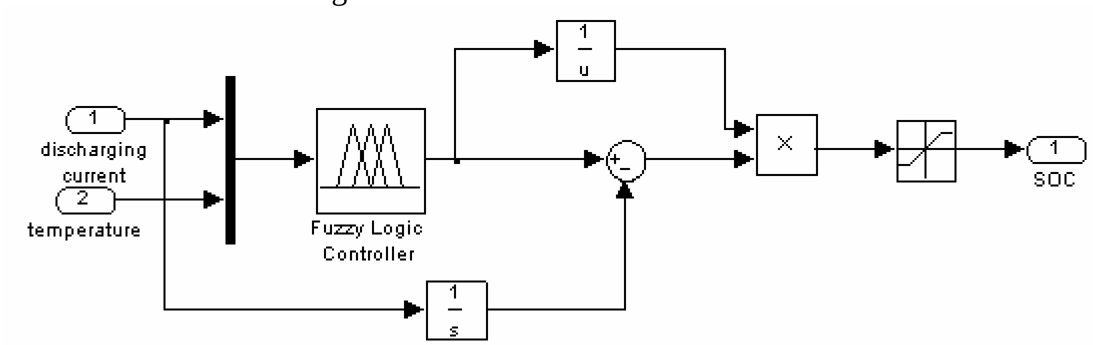

Figure 5: simulink block diagram of SOC estimation.

SOC at different discharging currents are shown in Fig.6.

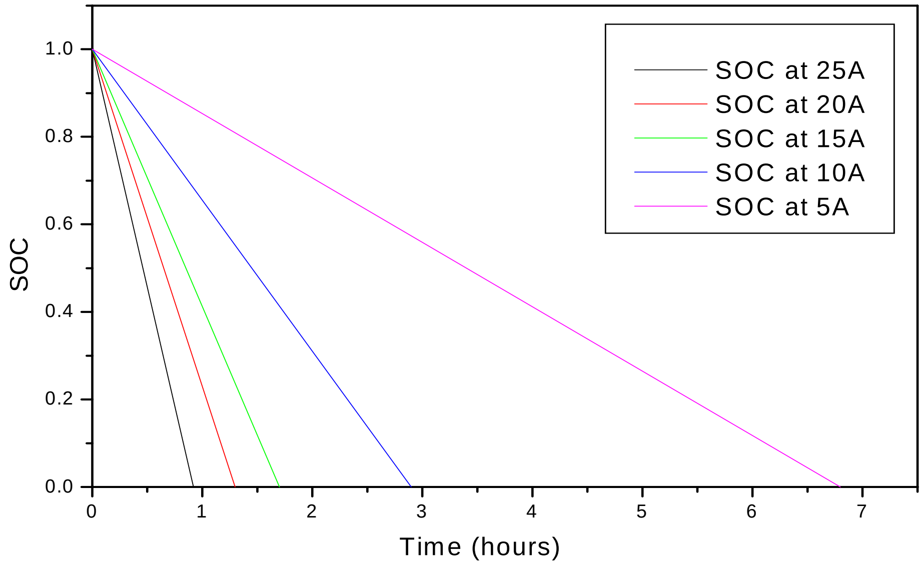

Figure 6: SOC at different discharging currents.

3 EXPERIMENTAL SYSTEM SETUP

Fig.7 shows the block diagram of the experimental system setup. It consists of the following parts:

1- Rechargeable lead acid battery 12V, C_n = 60AH contained in temperature controlled room.
2- Electronic load (300W), which serves as a load for the battery and introduce constant current mode, constant voltage mode, constant power mode and constant resistance discharge. In this work, the electronic load operates at

constant current discharge mode at currents (C_n/12=5A), (C_n/6=10A), (C_n/4=15A), (C_n/3=20A), (C_n/2.4=25A).

3- Current and voltage sensors in order to sense the current and voltage during discharging process.

4- Data acquisition and data logging system, which calculates the battery available capacity and records data.

The following tests are performed until a complete set of data is collected as follows:

- Charge the battery to fully charging state.
- Discharge the battery at different currents as mentioned in the previous step number 2.
- Using the temperature controlled room, setting the temp at the required degree using thermostat and heater, and by setting the mode of the electronic load to operate in constant current mode (cc), the terminal battery voltage can be monitored and measured by the voltage sensor and logged using data acquisition system. By knowing the cut off voltage of the battery, we can calculate the battery available capacity for each discharging rate.
- Repeat the previous steps at different temperatures: 20^{o}C ,25^{o}C, 30^{o}C, 35^{o}C, 40^{o}C

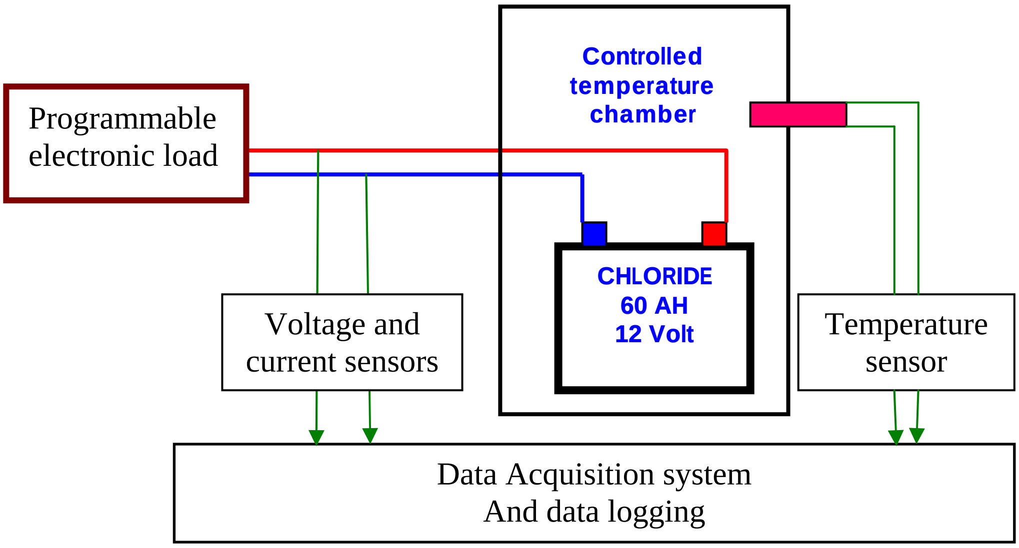

Figure 7: Block diagram of the experimental system.

Figure 8: Experimental system devices.

4 RESULTS AND DISCUSSION

Table (II) compares between the actual measured BAC and the modeled one using mamdani fuzzy modeling at different rates of discharge and different temperatures. Fig.9 shows the actual measured and modeled BAC. The results show a good agreement between them with a maximum error 5%, and that shows the effectiveness of the proposed model.

Table II: Actual measured BAC versus modeled BAC at different discharging current and temperatures.

	BAC									
Temperature	20		25		30		35		40	
Discharging current (A)	actual	model	actual	model	actual	model	actual	model	actual	model
5	35	34	40	38	44	42	50	50	54	53
10	29	30	33	34	37	38	40	42	44	46
15	27	26	30	30	33	34	36	38	40	42
20	24	26	27	26	30	30	32	34	35	34
25	22	23	25	26	27	26	30	30	33	34

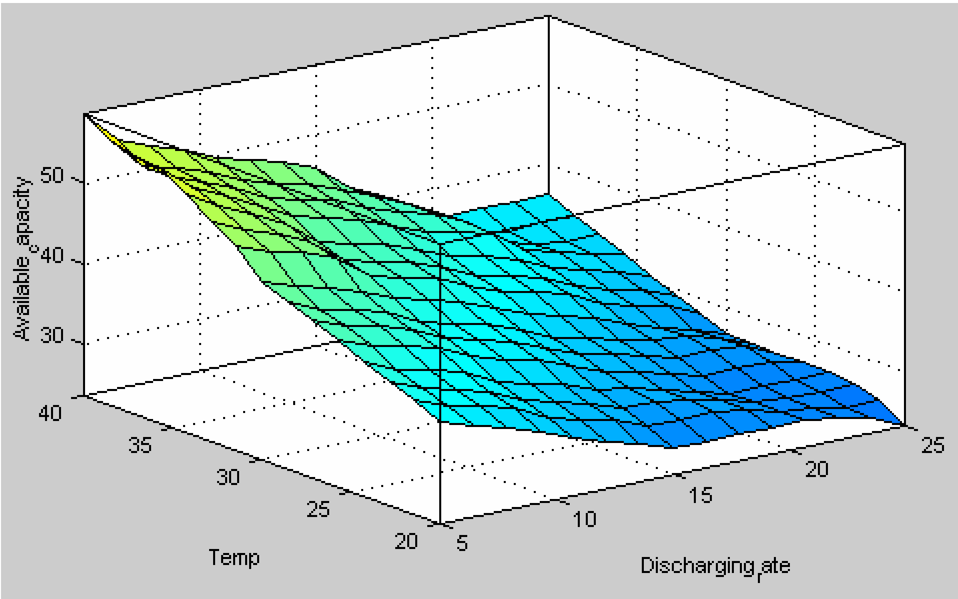

Figure 9: Comparison between modeled BAC and actual BAC.

5 CONCLUSIONS

A fuzzy modeling for BAC estimation based on discharging current and temperature is proposed. Experimental results are obtained for discharging the battery at different currents and temperatures using temperature controlled room, some of these data are used in training the fuzzy model and the other are used for testing. Battery SOC is calculated from the modeled BAC. The proposed model can be applied for any battery type when the battery conditions are fed into the model. The comparison between the measured BAC and modeled one shows a good agreement between them, that proves the effectiveness of the proposed fuzzy model. From the proposed model, the BAC can be estimated accurately, the driver of the vehicle will know exactly the amount of the power that the battery capable of providing and also the distance travelled by the vehicle.

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