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ESTIMATION OF STATE OF CHARGE FOR LEAD ACID BATTERY BASED ON OPEN-CIRCUIT VOLTAGE AND ENERGY METHOD

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Abstract- *Prediction of the remaining capacity in used batteries is momentous fact to the user. Determining the state of charge (SoC) is thus particularly important for electric vehicles (EVs), hybrid EVs, or portable devices. To provide over-charge protection and optimize charging time, SoC plays an energetic role. But estimating the SoC of a lead acid battery (LAB) is a stiff job because of unpredictable behavior of the batteries. One of the common methods of estimating the SoC of LAB is by means of measuring the open-circuit voltage (OCV) of LAB. However, provided result in this method contain considerable error, but due to its ease of use, it is widely adopted. This paper proposes a methodology to estimate SoC by combination of OCV and Energy method for higher accuracy during rest, charging and discharging condition.*

Keywords: Lead Acid Battery, State of Charge (SOC), Open-circuit voltage method and Energy method.

1. INTRODUCTION

Lead acid battery is widely used in different application at present such as IPS, Solar home system, electric vehicles, telecommunication systems etc. for its higher current capacity. For reliable operation of any of these systems, it is important to know the amount of energy remaining in the battery at any point of time. High depth of discharge (DOD) and overcharge causes irrecoverable damage of battery health and its life cycle [1]. Accurate indication of the SoC of battery is an excellent way to utilize the batteries efficiently [2]. Accurate indication of SoC of battery is a hard job because of unpredictable behavior of the batteries [3]. Hence estimation of SoC of battery remained a topic of active research over the years.

2. STATE OF CHARGE

The SOC is defined as the available capacity expressed as a percentage of the amount of energy left in a battery compared with the energy it had when it was full gives the user an indication of how much longer a battery will continue to perform before it needs recharging[4]. It is a measure of the short term capability of the battery. Hence the state of charge of battery can be defined as the available capacity (AHr) expressed as the percentage of the rated capacity (AHr) [5].

$$\text{SoC} = \frac{\text{Available capacity (AHr)}}{\text{Rated capacity (AHr)}} \times 100\ \% \qquad (1)$$

3. METHOD OF ESTIMATION OF SOC

Usually, SoC cannot be measured directly but it can be estimated from direct measurement variables in two ways: offline and online. In offline techniques, the battery desires to be charged and discharged in constant rate such as Coulomb-counting. This method gives precise estimation of battery SoC, but they are protracted, costly, and interrupt main battery performance. Therefore, researchers are looking for some online techniques. In general there are some methods to determine SoC indirectly that are [6]

- Chemical
- Open circuit Voltage
- Energy Method
- Current integration
- Kalman filtering
- Pressure

For higher accuracy and low cost open circuit voltage and energy method is combinedly used to estimate SoC of Lead Acid Battery.

3.1 Open Circuit Voltage Method

The term "voltage" in a battery refers to the difference in electric potential between the positive and negative terminals of a battery. A greater difference in potential results in a greater voltage. The theoretical standard cell voltage can be determined from the difference between cathode and anode voltage. The actual voltage produce will always be lower than the theoretical voltage due to polarization and the resistance losses (IR drop) of the battery and is dependent upon the load current and the internal Impedance of the cell. State of Charge can be estimated by measuring terminal voltage of the battery [7]. The relation among this is shown in the figure below.

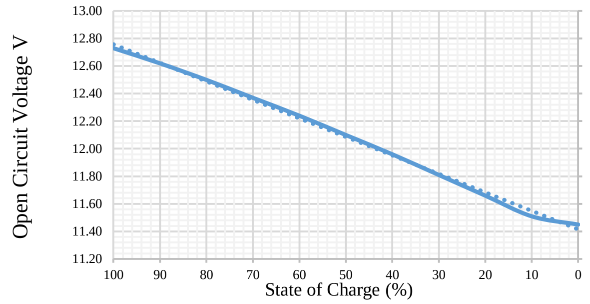

Fig.1: State of charge VS. Terminal voltage of the battery (12V Lead-acid).

3.2 Energy Method

Since traditional estimation methods have their own limitations, new kinds of estimation methods are still under exploration. Energy method is one of the new kind of estimation technique of the remaining energy in the battery [8]. Based on the law of energy conservation, SoC is defined as

$$SoC = \frac{V_{Rated} \times Rated\ Ah - V_t \times \int I dt}{V_{Rated} \times Rated\ Ah} \qquad (2)$$

Where, V_{Rated} is the rated voltage of the battery, Rated Ah is the current rating of the battery, Vt is the instantaneous terminal voltage of the battery, I is the load current supplied by battery, t is the operating time of the battery. In this method battery should be fully charged initially.

4. HYBRID METHOD FOR SOC ESTIMATION

Each method have its own advantages and dis advantages. SoC estimation using any single method provides significantly poor accuracy and reliability. In this paper, more than one method is taken into account to achieve higher accuracy and reliable operation. Block diagram of hybrid method of SoC estimation is given in below.

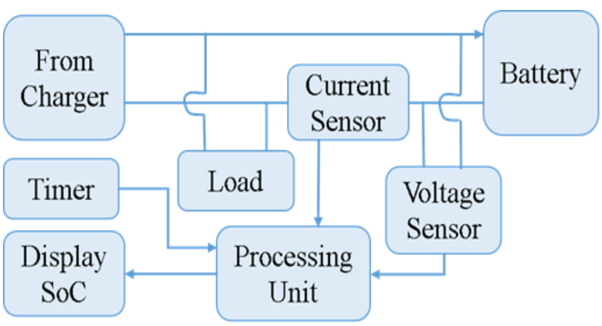

Fig.2: Block diagram of Hybrid Method of SoC Estimation.

In this method voltage sensor sense the open circuit voltage of the battery and provide sense voltage to the processing unit. Processing unit estimate the remaining energy in the battery form the State of charge vs. open circuit voltage table which is shown in fig1. In time of charging or discharging current flow towards or from the battery and this current sensed by the current sensor. Current sensor provide measured current magnitude as well as direction information to the processing unit. Timer is automatically started when current flow through the current sensor. Timer count time of current flow in every specified time interval. This information is send to processing unit within same time interval. Processing unit analyze all data received from different sensors and timer, then calculate present state of charge of the battery. This information is transfer to the display unit for user interface. State of charge is shown as percentage in display.

5. THEORY OF CALCULATION

Voltage sensor measure open circuit voltage of the battery as Vo, according to fig1 corresponding battery state of charge SoCo. Now it need to determine remaining energy Eo in the battery for measured SoCo.

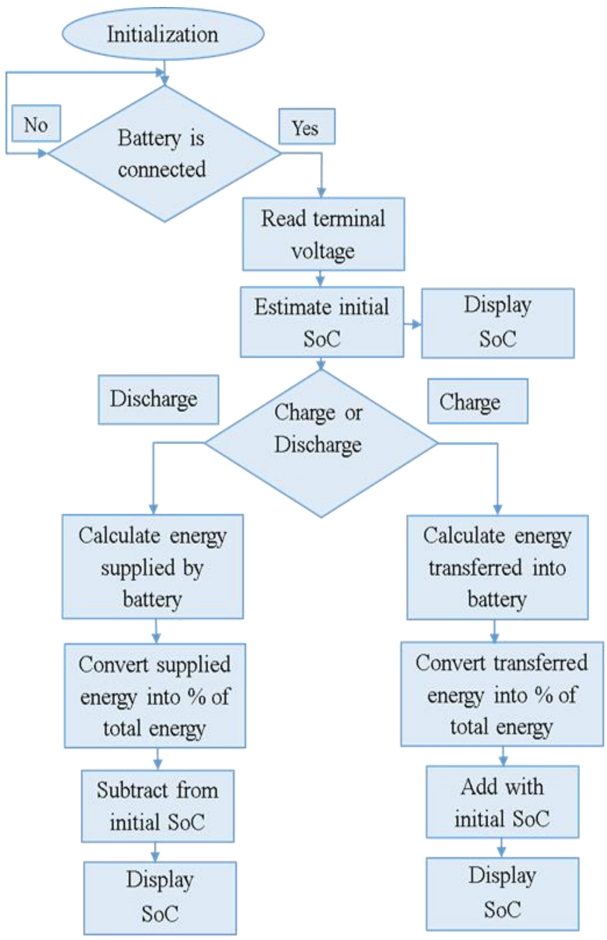

Fig.3: Flow chart of SoC Estimation.

Where ET is total energy that battery can store.

Case-1: Charging

Charging voltage provided by charge controller V_{ch} , Charging current I_{ch} and charging time measured by timer T_{ch}. If energy transferred into the battery is E_{in} then,

$$E_{in} = V_{ch} \times I_{ch} \times T_{ch} \quad (4)$$

So present energy contain in the battery E_p,

$$E_p = E_o + E_{in} \quad (5)$$

Present state of charge, $SoC_p = \frac{100 \times E_p}{E_T}$ (6)

Case-2: Discharging

Drawn current from battery I_{out}, at the time of discharge battery voltage is V_{Bat} and total discharge time measured by timer T_{dch}. If energy delivered by the battery is E_{out} then,

$$E_{out} = V_{dch} \times I_{dch} \times T_{dch} \quad (7)$$

So present energy contain in the battery E_p,

$$E_p = E_o - E_{out} \quad (8)$$

Present state of charge, $SoC_p = \frac{100 \times E_p}{E_T}$ (9)

6. RESULT

Implemented state of charge estimation circuit based on combination of open circuit voltage method and energy method provides excellent performance. Using 100W solar panel, a 12V 8.2Ah battery is charged in a sunny day. For efficiently utilize a battery should have maximum Depth of discharge 20%. In this experiment, battery have open circuit voltage is 11.65V, according to Fig1 initial charge of the battery is 21.30%. Total energy of the battery = 12*8.2 Whr= 98.4 Whr. 21.30% energy = 20.96Whr. After one hour, energy transferred into the battery is 17.25 Whr. Now Energy in Battery = 20.96+17.25 = 38.21Whr. Present SoC= (38.21/98.4)*100 = 38.80%. So practically and theoretically same result is obtained with slight error. Error in SoC = (38.80-38.55) = 0.25% which is negligible. So high accuracy is achieved by combine two method. Reading is taken in every one hour interval until battery is fully charged. Obtaining results is provided in a table below.

Table 1: Experimental result showing SoC, Energy transferred to battery and required time.

No. of Obs.	Solar Panel Voltage (V)	Charging Voltage (V)	State of Charge (SoC) (%)	Energy Transferred to the EV (Whr)	Required Time (hours)
1	18.5	14.72	21.30	0	0
2	18.8	14.76	38.55	17.25	1
3	17.9	14.78	54.82	33.52	2
4	19.1	14.81	69.73	48.43	3
5	18.9	14.80	84.69	63.39	4
6	17.7	14.82	96.11	74.81	5
7	18.2	14.81	100	78.70	5.78

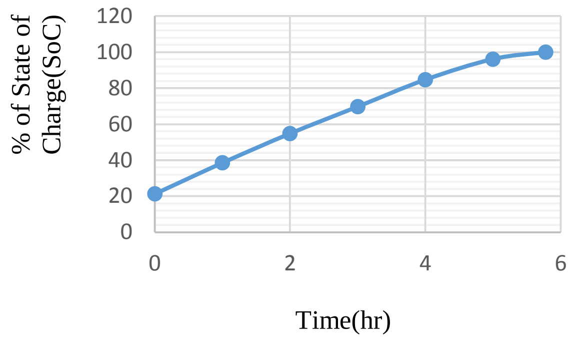

Fig.4: State of charge VS. Charging time of the battery (12V Lead-acid).

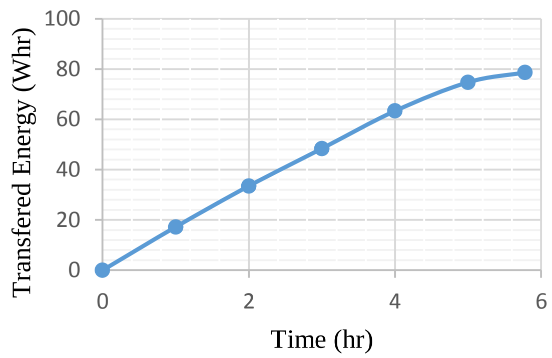

Fig.5: Charging time VS. Transferred energy into the battery (12V Lead-acid).

7. CONCLUSION

Accurate SOC estimation of power Lead Acid battery is an important issue to the development of electric vehicles. The existing SOC estimation methods have their advantages and disadvantages respectively. In this paper, combination of two method Open circuit voltage and Energy method is presented. In this method, SOC is defined from open circuit voltage and the view of energy charge and discharge. As a result, it is of high practical value. Simulation and experimental results indicate that this combined method can provide a more accurate SOC estimation than the other method. Under high current and variable current discharging conditions, the Ah method has more of a reaction which leads to a much quicker drop than the energy method. All parameters are imported at the real time and the changing conditions have no effect on accuracy. Therefore, this method is suitable for practical implementation especially under complex working conditions.

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