EQUIVALENT BATTERY DISCHARGE MODEL

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Abstract

With technological advances and instantaneous nature of widely variable Renewable energy necessitates efficient storage systems to be employed. One of the storage system is rechargeable batteries. Indeed there are different rechargeable batteries, which differ from each other by several characteristics, such as the chemical compositions, energy density and their charge and discharge characteristics. Batteries require an accurate determination of its parameters during discharging cycle to extend their operational lifetime. To regulate the process of healthy pumping out operation we require an accurate Discharge model to be developed. Hence we present here an equivalent discharge model which gives insight into the performance status parameters during the pump out scheme, which will help in determining the available energy within battery and how much it can be utilized. Hence the proposed study aims in determining optimal energy pump out and behavior of the battery system under higher discharge current rates. The derating factor is calculated and compared with data sheet results. The capacity of the battery system is estimated by Peukerts methodology and more accurate assessment of capacity by using the ceralos capacity correction.

The Performance characteristics of battery for various Discharge current conditions is studied using the developed model including temperature effects on capacity of the battery storage system. Simulation results are presented.

Keywords: Equivalent battery model, Capacity, SOC, DOC.

I . Introduction

Renewable energies are sources of clean, inexhaustible and increasingly competitive energy. They differ from fossil fuels principally in their diversity, abundance and potential for use anywhere on the planet, but above all they produce neither greenhouse gases–which cause climate change – nor polluting emissions which harm the environment. Their costs are also falling and at sustainable rate.

Rising crude oil prices and worldwide awareness of environmental issues have resulted in increased development of energy storage systems. The battery is one of the most attractive energy storage systems because of its high efficiency and low pollution[1]. Because the sun doesn't always shine, solar utilities need a way to store extra charge for a rainy day. The same goes for wind power facilities, since the wind doesn't always blow. To take full advantage of renewable energy, electrical grids need large batteries that can store the power coming from wind and solar installations until it is needed. For a typical residential solar panel customer, electricity must be either used as it's generated, sold back to the electrical grid, or stored in batteries. Deep-cycle lead batteries or lithium ion batteries are already on the market, but each type presents challenges for use on the grid.

The electrical engineer would take advantage of a sufficiently simple although accurate battery model in several ways,such as:

- simulation of the battery behavior in different conditions, instead of setting-up lab experiments which may be costly at times;
- computation of useful parameters, often not available from the battery such as short circuit currents, constant power outputs at different time ranges, etc.

II Relationship between Capacity and Discharge current

The capacity of a cell/battery is the amount of charge available in it for discharge**.** The cell capacity (extractable charge) depends upon a number of factors, including:

- average discharge current and discharge time
- inner cell temperature
- value of end-of-discharge voltage
- storage time (self-discharge)
- number of charge-discharge cycles that the cell has undergone (aging)

Over the short-term, the list can be limited to just three factors — inner cell temperature (T), average cell discharge current (I), discharge time, and end-of-discharge voltage is usually provided by the manufacturer. Hence, cell capacity

$$CQ = CQ(I,T) \qquad (1)$$

In addition, the capacity of a battery is not a fixed quantity but varies according to how quickly it is discharged. This is known as Peukert's law [5]:

$$Cp = I^{k} t \qquad (2)$$

where

Cp is the capacity on one-ampere discharge rate, which is a constant

I is the discharge current (A)

t is the time of discharge (h)

k is the Peukert constant and for a lead-acid battery with the value between 1.1 and 1.3 (varies for each individual battery),

The inadequacies of Peukert's equation (i.e lack of consideration of temperature,and predicts capacities larger at low currents than those experimentally obtainable(up to infinite capacity at zero current).From the experiments conducted by [2], the capacity which gives approximate results is given by

$$Co(I) = \frac{Kc\,Co*}{1+(Kc-1)\left(\left(\frac{I}{I*}\right)\right)^{m}} \qquad (3)$$

where

CO* which stands for the capacity when discharging at the rated discharge rate, usually the nominal capacity C10

Kc is empirical coefficient and is 1.18 for lead-acid batteries,

m is empirical coefficient of 1.75

III Mathematical Model of Lead Acid Battery

For Automotive real time applications Equivalent Circuit based modelling is suitable, since it does not require deep understanding of the electrochemistry of the cell and at the same time is well proficient of simulating battery dynamics. ECMs simulate the battery model as circuit composed of resistors and capacitors and other elements. There is a wide collection of models depending on accuracy and time required.Voltage source is selected to denote open-circuit voltage (OCV), with rest of the circuit representing battery internal resistance and dynamic effects.

It is not new in literature the idea of simulation of batteries by means of electric networks (cf. [4], [11]); A Simple non linear equivalent circuit is modeled which is as shown in Figure1,consist of two parts:a main branch which estimated the battery dynamics under most of the condition,a parasitic branch which accounted for the battery behavior at the end of charge.For analyzing discharge model parasitic branch is not needed,so it can be ohmitted.

The equivalent circuit as shown in the figure 1 has elements E and Ro dependent on battery state of charge and electrolyte temperature θ represents a measure of the electrolyte temperature, SOC is a measure of the battery state-of-charge (later on details will be given on this quantity),where as R1,C1 depend on DOC.

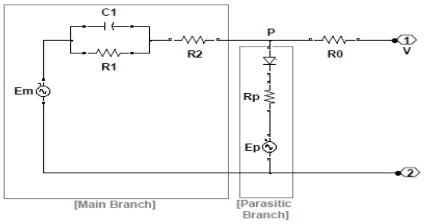


Figure 1 : Equivalent Circuit

The battery equivalent circuit represented one cell of the battery. Each equivalent circuit element was based on nonlinear equations. The equations were as follows:

A.Main Branch Voltage

Equation 4 provides the internal electro-motive force (emf), or open-circuit voltage of one cell. The emf value was assumed to be constant when the battery was fully charged.

The emf varied with temperature and state of charge (SOC) which is as shown in equation 2. The emf equation without considering the temperature is given by [4]

$$E_m = E_{mf} - (E_{mf} - E_{md}) * (1 - SOC) \quad (4)$$

Where

E_m is open circuit voltage (EMF) in volts

E_{mf} is the open circuit voltage at full charge in volts

E_{md} is the open circuit voltage at full discharge in volts

SOC was the battery state of charge

$$E_m = E_{mf} - K_e * (273 + \theta) * (1 - SOC) \quad (5)$$

Where,

Ke is constant in volts/°C

θ is electrolyte temperature in °C

B.Internal Resistance

Equation 6 gives internal resistance seen at battery terminals.The resistance is assumed constant at all temperatures, and varied with SOC.

$$R_o = R_{oo}[1 \pm A_o(1 - SOC)] \quad (6)$$

where:

R_o was a resistance in Ohms

R_{oo} was the value of R0 at SOC=1 in Ohms

A_o was a constant

SOC was battery state of charge

C.Main Branch Resistance 1

Equation 7 gives a resistance in the main branch of the battery. The resistance varied with depth of charge, a measure of the battery's charge adjusted for the discharge current.

$$R_1 = -R_{10} \ln(DOC) \quad (7)$$

where:

R_1 was a main branch resistance in Ohms

R_{10} was a constant in Ohms

DOC was battery depth of charge

D.Main Branch Capacitance 1

Equation 8 gives a capacitance (or time delay) of main branch. The time constant modeled a voltage delay when battery current changed.

$$C1 = \frac{\tau}{R1} \quad (8)$$

where:

C1 was a main branch capacitance in Farads

τ1 was a main branch time constant in seconds

R1 was a main branch resistance in Ohms

E.Charge and Capacity

Capacity measured the maximum amount of charge that the battery could hold. State of charge (SOC) means the ratio of the battery's available charge to its full capacity. Depth-of-charge (DOC) means the fraction of the battery's charge to usable capacity, because usable capacity decreased with increasing discharge current. The equations that tracked capacity, SOC, and DOC were as follows:

F.Extracted Charge

Equation 9 provides the amount of charge extracted from the battery.

$$Qe(t) = -\int_0^t Im(\tau)d\tau \quad (9)$$

Where

Qe is the extracted charge in AH

Im is the main branch current in Amps

τ is integration time variable

t is the simulation time in hours

Equation 10 & 11 calculated the SOC and DOC as a fraction of available charge to the battery's total capacity. State of charge measured the fraction of charge remaining in the battery. Depth of charge measured the fraction of usable charge remaining, given the average discharge current. Larger discharge currents caused the battery's charge to expire more prematurely, thus DOC was always less than or equal to SOC.

$$SOC = 1 - \left(\frac{Qe}{Cn}\right) \quad (10)$$

$$DOC = 1 - \left(\frac{Qe}{C(I)}\right) \quad (11)$$

Where:

SOC is battery state of charge

DOC is battery depth of charge

Qe is battery charge on AH

Cn is nominal battery capacity in AH

C(I) is actual capacity in AH

G. Effect of temperature on capacity

Battery Capacity is also affected by variation of temperature.The effect of temperature on the battery capacity is given by equation :

$$C(I,\theta) = Co(I)\left[1 + \frac{\theta}{-\theta f}\right]^{\wedge}\epsilon \quad (12)$$

where

θf is the electrolyte freezing temperature and is equal to -40°C

θ is the cell temperature

$Co(I)$ is the capacity of battery under the discharge current I at 0°C

ϵ is a constant that equals to 1.25

Therefore

$$C(I,\theta)=\frac{Kc\ Co*(1+\frac{\theta}{-\theta f})^{\wedge}\epsilon}{1+(Kc-1)((\frac{I}{I*}))^{\wedge}m} \tag{13}$$

IV. Simulation

For a Lead Acid battery of C10=500AH , For KC=1.11 : Co*= 317.9AH : I*= 51.5A $\theta f = -40\ degree$, $\theta = 25\ degree$

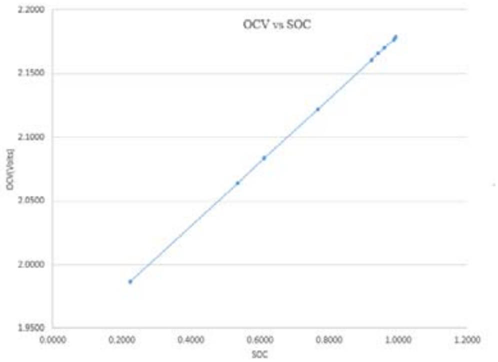


Figure 2 :OCV vs SOC

Figure 2 represent a graph of OCV vs Soc it shows that as SOC increases from 0-1(Full charge) the open circuit voltage of cell /battery increases.

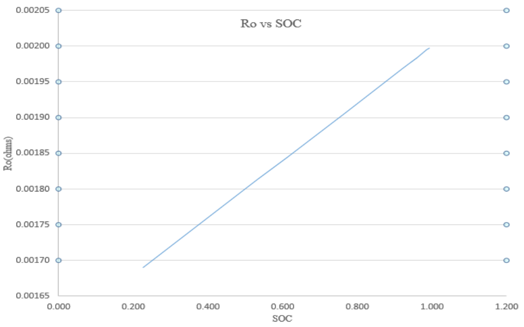


Figure 3 :Ro vs SOC

Fig 3 Represent the internal resistance of the cell as SOC increases from 0-1, Ro also increases.

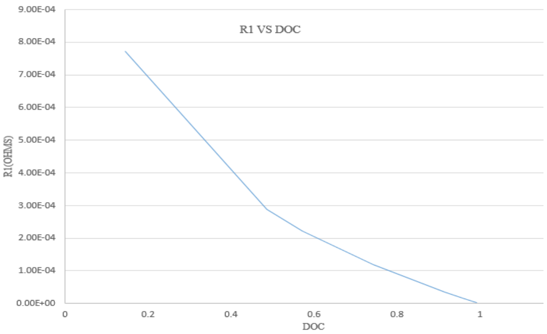
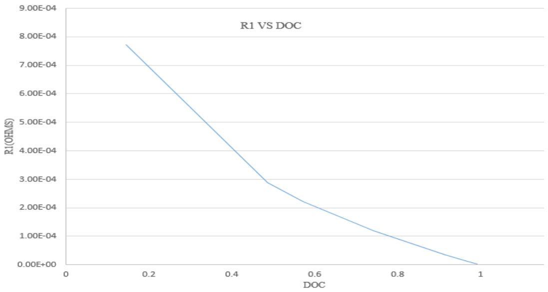


Figure 4 :R1 vs DOC

Figure 4 represents variation of Transfer resistance with DOC.It decreases with increase in DOC.



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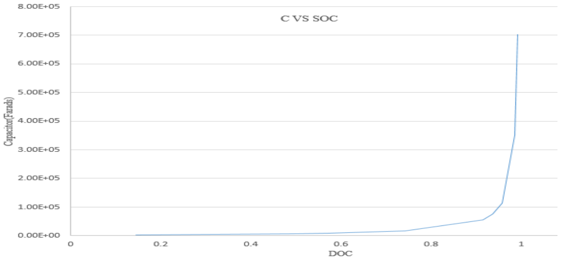

Figure 5 :C vs DOC

Figure 5 represents Capacitance vs DOC.Capacitor is inversely proportional to Resistor R1, As a result of which the Capcitance increases with increase in DOC.

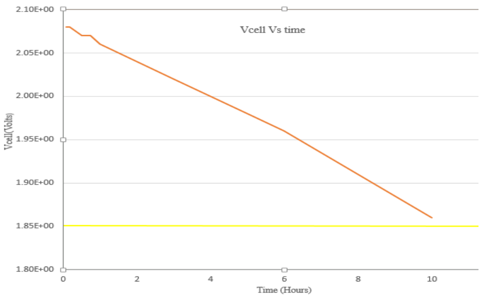

Figure 6 :Vcell vs Time

Fig 6 represents Cell voltage Vs Discharge time

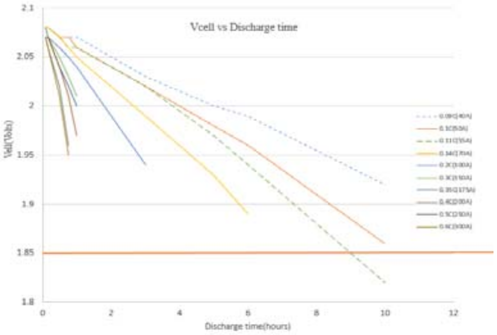

Figure 6a Vcell vs Discharge current

Figure 6a represents the cell voltage vs Discharge time for different C-rating.

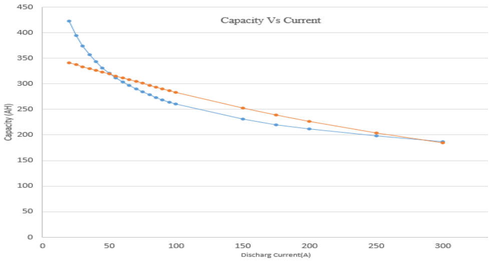

Figure 7 : Capacity vs Discharge current

Figure 7 represents a comparison of Peukert's and Ceralo's Capacity with respect to discharge current and a good assessment is obtained by using Ceralo's Capacity equation.

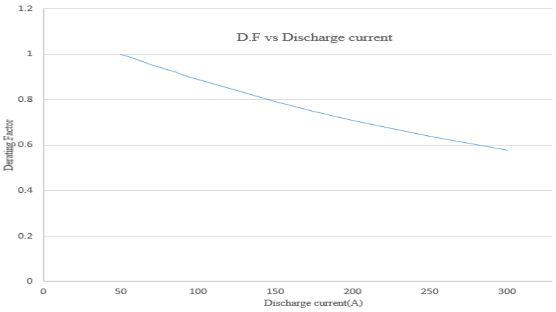

Figure 8:Derating Factor Vs Discharge Current

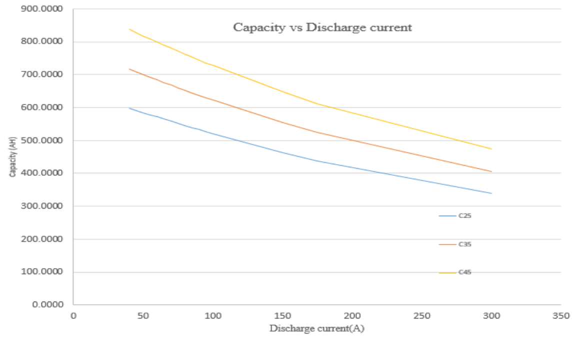

Figure 9 :Capacity vs Discharge Current(with different temperature)

From figure 9 it is clear that as temperature increases the capacity increases for a particular discharge rate.

V.Conclusion

The complex, nonlinear behavior of electrochemical battery Lead Acid has been conveniently modeled using equivalent electric networks. The Equivalent Discharge Model of Cell is presented and calculations are carried out in Excel Sheets. The capacity of the battery system is estimated by Peukerts methodology and more accurate assessment of capacity by using the ceralos capacity correction.The Performance characteristics of battery for various Discharge current is obtained,simulated and verified with data sheets.And it is found that Both Capacity and delivered voltage vary as inverse function of discharge rate.A cut off value of the working voltage is selected around 1.85V as discharge voltage limit .The effect of temperature on Capacity is discussed with reference to discharge model and to take care of higher discharge rates than the manufacture suggested values for the model and derating factor is estimated and presented.

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