Determine the Performance Characteristics of Battery by Pulse charging Scheme

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***Abstract*—** With technological developments and instantaneous nature of widely variable Renewable energy necessitates efficient storage systems to be employed. One of the storage systems 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. In situation wherein the generation will be high and demand low we need to charge the batteries in minimum time in order to prevent wastage of energy. Thus batteries require an accurate determination of its parameters during charging cycle to extend their operational lifetime. There are different methods to charge the batteries but to regulate the process of healthy pumping in operation in minimum time we require an accurate charge model to be developed. Hence we present here an equivalent charge model to determine the performance characteristics of battery by using Pulse charging scheme.The proposed study aims in charging the battery in minimum time. Simulation results are presented and verified by data sheets.

***Keywords*—** *Equivalent charge model, Capacity, SOC, DOC.*

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I.INTRODUCTION

Energy and the environment are current key issues due to limited fossil fuels sources and concerns over greenhouse emissions on the other hand Renewable energies are sources of clean, inexhaustible and progressively competitive energy. They differ from fossil fuels in their diversity, abundance and potential for use anywhere on the planet, but the vital advantage is they do not produce greenhouse gases nor polluting emissions which harm the environment.

Rechargeable batteries have been persistently used as the energy storage and power source for various electrical systems and devices, such as communication systems, electronic devices,Renewable power systems, electric vehicles,etc. The proper design and operation of these battery-powered systems and devices requires an suitable battery model.For example, modern battery power management systems rely on a high-fidelity battery model to track the State of Charge (SOC) and predict runtime of each battery cell and the whole battery system to optimize its performance.Moreover, the proper design of a battery-powered electrical system or device requires the battery model to be capable of accurately capturing the dynamic electrical circuit characteristics of the battery to facilitate the system-level circuit design and simulation.

Deep-cycle lead acid 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.

II.RELATIONSHIP BETWEEN CAPACITY AND CHARGE CURRENT

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

- average charge current and charge 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 short-period, 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.

From the experiments conducted by [2], the capacity which gives approximate results is given by

$$C_o(I) = \frac{K_c\, C_{o*}}{1+(K_c-1)\left(\left(\frac{I}{I*}\right)\right)^{\wedge} m} \qquad (1)$$

Where

C_0* which stands for no load Capacity

K_c is empirical coefficient and is 1.18 for lead-acid batteries

m is empirical coefficient of 1.20

Variations of the cell temperature also affect the battery capacity. The effect of temperature on the battery capacity is described by the following equation :

$$C(I,\theta) = C_0(I)\left[1+\frac{\theta}{-\theta_f}\right]^{\wedge} \in \qquad (2)$$

Where

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

θ is the cell temperature

C_0 (I) is the capacity of battery under the charge current I at 0°C

$\in$ *is* a constant that equals to 1.29

Therefore

$$C(I,\theta) = \frac{K_c\, C_{o*}\left(1+\frac{\theta}{-\theta f}\right)^{\wedge}\epsilon}{1+(K_c-1)\left(\left(\frac{I}{I*}\right)\right)^{\wedge} m} \qquad (3)$$

III. MATHEMATICAL MODEL OF LEAD ACID BATTERY

The equivalent circuit as shown in the figure 1 has elements E_m and R_0,R_1 dependent on battery state of charge θ represents a measure of the electrolyte temperature, SOC is a measure of the battery state-of-charge, where R_1,C_1 depend on DOC and Rp is parasitic resistor.

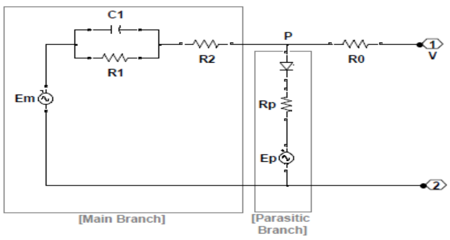

Figure 1 : Equivalent Circuit

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

The emf varied with temperature and state of charge (SOC) which is as shown in equation 4.

$$E_m = E_{mfd} - K_e * (273+\theta) * (SOC) \qquad (4)$$

Where,
E_m is cell voltage (EMF) in volts
E_{mfd} is the open circuit voltage at full discharge in volts
SOC was the battery state of charge
K_e is constant in volts/℃
θ is electrolyte temperature in ℃

B. Internal Resistance

Equation 5 gives internal resistance seen at battery terminals. The resistance is assumed constant at all temperatures, and varied with SOC.

$$R_0 = R_{00}\,[1+A_0(SOC)] \qquad (5)$$

Where:
R_0 is a resistance in Ohms
R_{00} is a constant in Ohms
A_0 is a battery constant
SOC is battery state of charge

C. Main Branch Resistance 1 and Resistance 2

Equation 6 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.

$$R_1 = -R_{10}\ln(DOC) \qquad (6)$$

Where:
R_1 is a main branch resistance in Ohms
R_{10} is a constant in Ohms
DOC is battery depth of charge

$$R_2 = R_{20} * \frac{\exp[A21(1-SOC)]}{1+\exp\left(\frac{A22\,Im}{I*}\right)} \qquad (6\ a)$$

Where
A_{21}, A_{22}, R_{20} are battery constants
I_m Main branch current (Amps)
I* is battery nominal current (Amps)

D. Main Branch Capacitance 1

Equation7 gives a capacitance (or time delay) of main branch. The time constant modeled a voltage delay when battery current changed.

$$C_1 = \frac{\tau}{R1} \qquad (7)$$

Where:

C_1 is a main branch capacitance in Farads
τ is a main branch time constant in seconds
R_1 is 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. The equations that tracked capacity, SOC and DOC were as follows:

F. Charge Consumed

Equation 8 provides the amount of charge consumed from the battery.

$$Q_e(t) = \int_0^t Im\ (\tau)d\tau \qquad (8)$$

Where :
Q_e is the consumed charge in AH
I_m is the main branch current in Amps
τ is integration time variable
t is the simulation time in hours

Equation 9 & 10 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 charge current. Larger charge currents lesser is the time taken for battery to charge.

$$SOC = \frac{Qe}{Cn} \qquad (9)$$

$$DOC = \frac{Qe}{C(I)} \qquad (10)$$

Where:
SOC is battery state of charge
DOC is battery depth of charge
Q_e is battery charge on AH
C_n is nominal battery capacity in AH
C(I) is actual capacity in AH

G. Estimate of Average Current

The average battery current was estimated as follows.

$$I_{avg} = (I_{m*} T_{on})/T$$

Where:
I_{avg} was the mean charge current in Amps
I_m was the main branch current in Amps
T_{on} is the ON time period of one pulse
T is the total time to charge the battery at nominal rate

H. Parasitic Branch

When the battery is being charged, there are some losses, as represented by the parasitic current. This current depends on the electrolyte temperature and the voltage at the parasitic branch The behavior of the parasitic branch is strongly nonlinear. Therefore it is better to use, instead of Rp, an expression of Ip as a function of Vp. The following equation can be used, that matches the Tafel gassing–current relationship [7]

$$I_p = V_{PN} G_{p0} \exp(V_{PN}/V_{p0} + A_p(1 - \theta/\theta_f)) \qquad (11)$$

or, equivalently

$$I_p = G_p V_{PN} \quad G_p = G_{p0} \exp(V_{PN}/V_{p0} + A_p(1 - \theta/\theta_f)) \qquad (12)$$

Where
Gpo, Vpo, Ap are battery constants
θ is temperature in degree Celsius
θf is freezing temperature = -40 degree Celsius

IV. SIMULATION

For Lead Acid battery of C_{10}=500AH, For K_C=1.11 : Co*= 317.9AH : I*= 51.5A, $\theta f = -40\ degree$, $\theta = 25\ degree$

1. I_{avg}=25A.

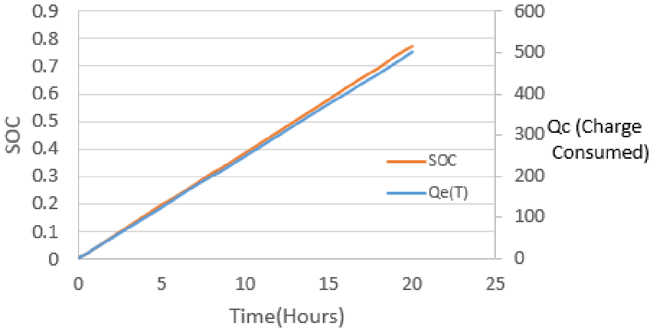

Figure 2a : SOC V/S Q_C V/S Time

Figure 2a represent a graph of SOC V/S Q_C V/S Time it shows that when a current of 25A is given to battery cell charge consumed by battery cell increases with time thereby increasing SOC. Thus as SOC increases from 0-1(Full charge) the cell voltage of battery increases, and implies that the cell will take 20 hours to charge.

2. I_{avg}=75A

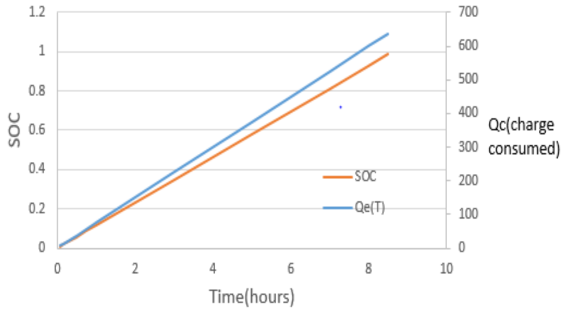

Figure 2b: SOC V/S Q_C V/S Time

Figure 2b represent a graph of SOC V/S Q_C V/S Time it shows that when a current of 75A is given to battery cell charge consumed by battery cell increases with time thereby increasing SOC. Thus as SOC increases from 0-1(Full charge) the cell voltage of battery increases, and implies that the cell will take 8.5hours to charge.

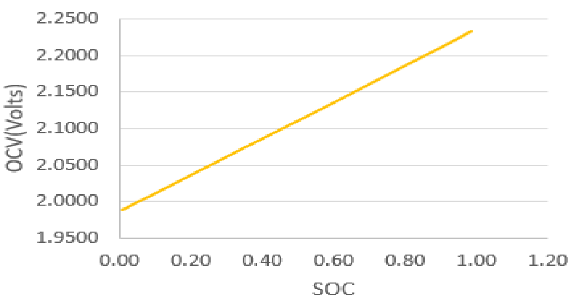

Figure 2c : OCV V/S SOC

Figure 2c represent a graph of OCV V/S SOC it shows that as SOC increases from 0-1(Full charge) the cell voltage of cell /battery increases, and the cell is receiving charge.

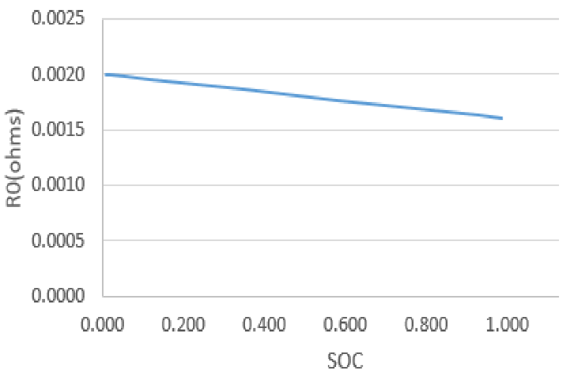

Figure 3: Ro V/S SOC

Fig 3 Represent the internal resistance of the cell as SOC increases from 0-1, R0 Decreases.

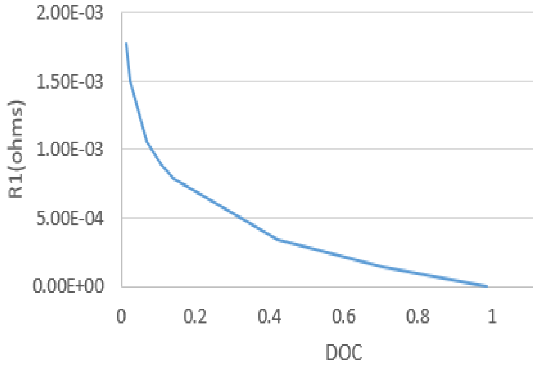

Figure 4: R_1 V/S DOC

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

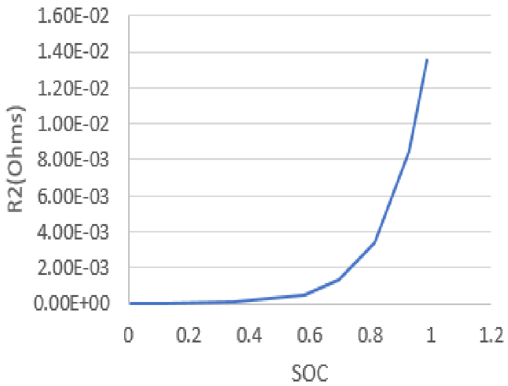

Figure 5: R_2 V/S SOC

Figure 5 represents variation of diffusion resistance with SOC. It increases with increase in SOC.

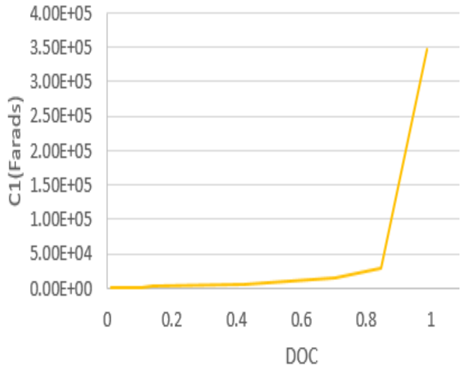

Figure 6: C V/S DOC

Figure 6 represents Capacitance V/S DOC. Capacitor is inversely proportional to Resistor R_1, As a result of which the Capacitance increases with increase in DOC.

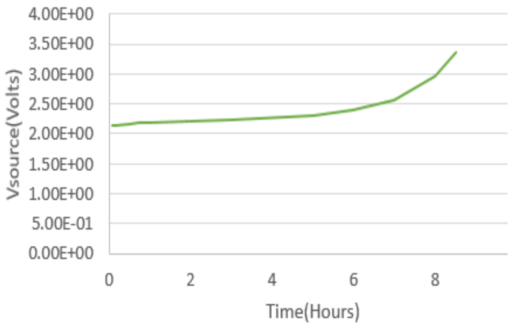

Figure 7 : Vsource V/S Time

Figure 7 represents source Cell voltage V/S charge time

V. CONCLUSION

The complex, nonlinear behavior of electrochemical battery Lead Acid has been conveniently modeled using equivalent electric networks. The Equivalent charge Model of Cell is presented and calculations are carried out in Excel Sheets. The capacity of the battery system is estimated using the ceralo's capacity correction. The Performance characteristics of battery for a charge current is obtained, simulated and verified with data sheets. And it is found that for Pulse Charging with minimum current takes more time to charge whereas higher current takes minimum to replenish charges.

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