Page No.
Date

BATTERIES

- A battery is a self-contained, chemical power pack that can produce a limited amt of electrical energy whenever it's needed.

- Allows energy convertion between chemical & electrical energy.

- The basic power unit inside a battery is called a cell, & it consists of 3 parts: Anode, cathode & Electrolyte.

- ~~A~~ The difference between a battery & a cell is simply that a battery consists of 2 or more cells hooked up in series & parallel so their power adds together.

- 2 types of batteries:- Primary Battery & Secondary Battery.

- The newly-generated Lithium-ion batteries by the 3 scientists who were awarded Nobel Prize:

1. These batteries are used globally to power the portable electronics that we used to communicate, work, & etc. These are lighweight batteries of high enough potential, useful in many applications.

2. The discovery of energy-rich material called titanium disulphide, was used to make ~~cathode~~ +ve terminal anode & battery's -ve terminal from metallic lithium as cathode.

Date

→ BATTERY TYPES:

1. Primary cells

a) Non rechargeable
b) Both Alkaline (High energy density) & Zinc-Carbon (Economical types)
c) Applications: Toys, torches, military communications, remote control, wrist watches.

2. Secondary cells

a) Rechargable batteries.
b) Small capacity secondary batteries are used to power portable electronics like phones, laptops & other gadgets & application.
c) Heavy-duty batteries used in car-ignition, driving EVs, generators, PV energy storage, etc
d) Expensive when compared with primary batteries but are cost effective when used in long term.

i) Lead-Acid Batteries:

a) PB/PBO_2. Heavy batteries. High power density; Wet & dry both
b) Eg:- ~~Self ignition~~ Self lighting ignition (SIL) batteries. Cars, Two / three-wheelers. UPS, Inverters, PV systems, EVs etc

3. ii) Nickel Batteries:

a) Nickel-Cadmium ; Ni-Metal Hydride (NiMH): Dry, High energy batteries, Light-wt & maintenance free used in cameras, calculators & photoflash equipments.

ii) Sodium-Sulphur batteries:

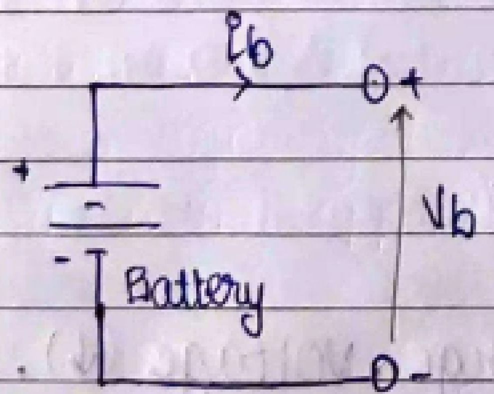
a) Type of molten-salt battery constructed from liquid sodium (Na) & sulphur (S). high energy density, high efficiency of charge/discharge & long cycle life, operating temps of 300°C to 350°C & suitable for stationary energy storage applications. Cell becomes more economical with increasing size.

b) Applications: grid & standalone systems space, transport & heavy machinery etc.

iii) Lithium-ion, Lithium Polymer, Lithium Ferro-Phosphate Batteries ($LiFePO_4$): Compact, durable.
Applications used in Modern EV, Laptops, mobiles, modern electronic gadgets, street lighting, mobile energy storage.

→ BATTERY CAPACITY.

A battery circuit with V_b & I_b as rated battery voltage and currents respectively:



Energy stored is: $\boxed{E = \int_0^t (V_b \cdot I_b) \, dt}$ ... ①

1. The energy E is expressed in Watt-hr & considered as total Energy Capacity of the battery.

2. The capacity of the battery in terms of total charge stored is denoted as ampere-hr & expressed as:

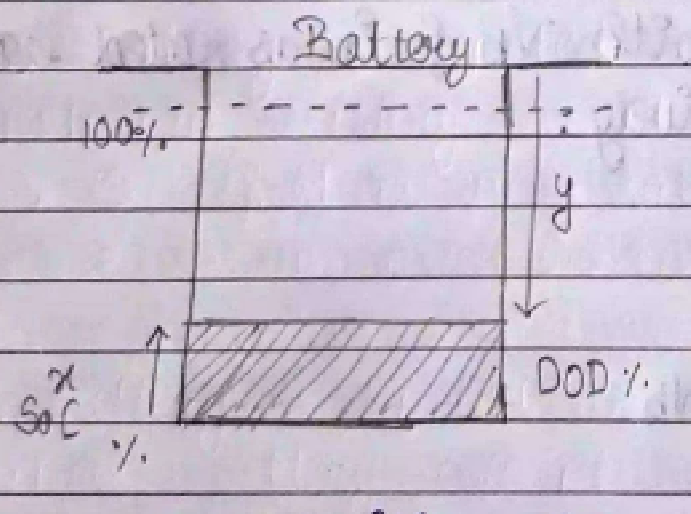
$$\boxed{Q = \int_0^t i_b \, dt} \quad \text{②}$$

3. Commercially, the battery capacity is always represented as charge-capacity in Ampere-hr.

→ DOD & SOC of BATTERY

1. Let the nominal capacity of a battery is expressed in Amp-hr & considered as 100%.

2. The depth of discharge DOD(y) is a % measure of how much battery is empty with ref to its nominal charge capacity.



3. As we go on exciting charge, voltage (↓), Charge is removed, voltage goes on decreasing.

Scanned By ScanIt

Page No.
Date

4. The state of charge SOC (x) is % how much battery is filled with reference to its nominal charge capacity.

5. The SoC (x). is expressed as 100-y & the DoD (y.) is 100-x, & hence both are complementary.

6. Sometimes, it is possible to have the DoD value of a specific case more than 100%.

7. Both SoC & DoD. are dynamic conditions of the battery to express charge-status at a given time.

→ BATTERY ENERGY & POWER DESITIES.

1. There are two types of Battery energy & power densities gravitometric & Volumetric.

2. Gravitometric energy density is expressed in Watt-hr/kg & sometimes referred as specific Energy of a Battery, decides the Range of a Battery powered EVs or HEVs.

3. Volumetric Energy density is expressed in Watt-hr/lit & has a bearing on size or space static application of the battery.

4. Gravitometric Power density is expressed in Watt/kg & sometimes referred as Specific Power of a battery & decides the acceleration or overtaking ability of a battery powered EVs & HEVs on mobile platforms.

Page No.
Date

5. Volumetric Power density is expressed in Watt/lit & has a bearing on size or space requirements.

6. For a specific Battery, Watt-hr/kg & Watt/kg densities are complementary to each other.

→ C-RATE OF A BATTERY

1. C-Rate is defined as the rate at which charge cap of the battery reqd to charge or discharge.

~~Let~~ Consider a battery has a capacity $C = 100$ Amp hr. The dis-charging current I_b at a nominal battery voltage V_b for continuous time $N = 10$ hrs is given as:

$$\boxed{I_b = \frac{C}{N}} = \frac{100\,A\cdot hr}{10} = 10A \quad \cdots ③$$

Using the battery ~~of~~ for 10 hrs with a capacity of a 100 A·hr, will drain a current ~~for~~ upto 10A & give backup of 10 hrs.

This battery is denoted as C_{10} rated, if $I_b = 10A$ is a nominal battery current.

~~$C_1 \rightarrow 10$~~ If it is a C_1 rated ⇒ 100A in 1 hr.
C_{10} rated ⇒ 100A in 10hr.

2. This battery is denoted as C_{10} rated, if $I_b = 10A$ is a nominal battery current. This current could be $I_b = 5A$ for $N = 20$ ~~&~~ (C_{20}), $I_b = 20A$ for $N = 5$ (C_5) & $I_b = 200A$ for $N = 0.5$ $\left(\frac{C}{0.5}\right)$ or 2C rated.

Scanned By ScanIt

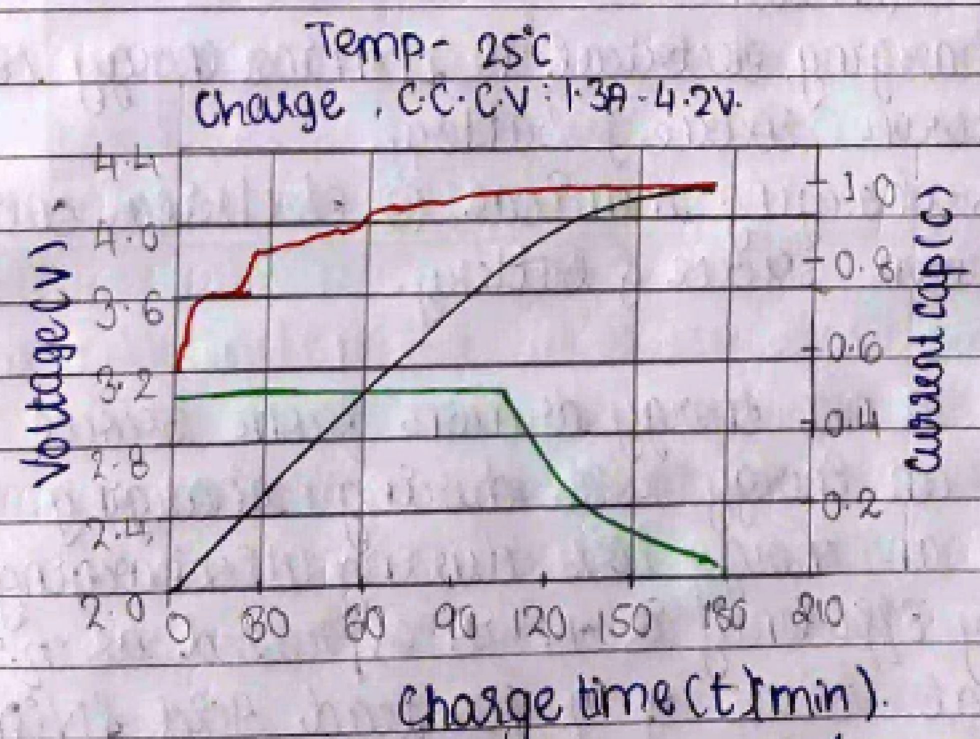
Page No. | Date

→ CHARGING CHARACTERISTICS

1. Batteries can be charged at different rate viz. slow charging at 0.1C rate, Quick charge at 0.3C rate & fast charge at 1.0C rate.
If the prefix is increasing, discharging rate current is increasing. If suffix is increasing & the allowable current o/p is decreasing.

2. Special precautions are needed to maximise the charging rate & to ensure that the battery is fully charged while at the same time avoiding overcharging.

3. Charging method switches to constant voltage before the cell voltage reaches its upper limit.



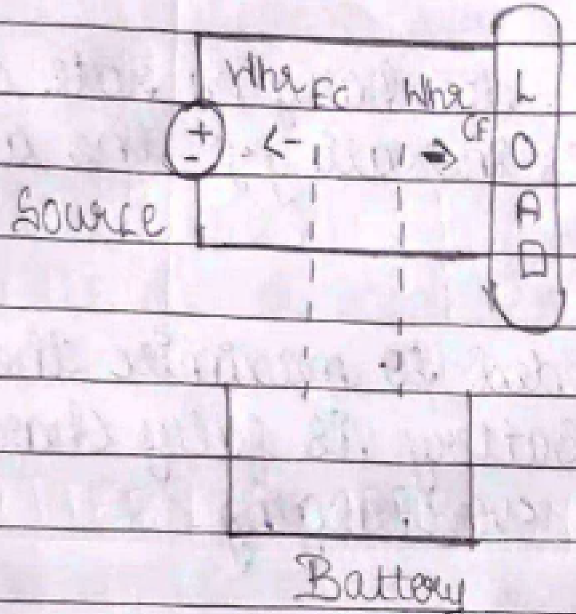
During this const voltage period, the current decreases to a trickle charge & cut off occurs when a predetermined min current pt is reached. Charging (I) should not exceed rated (I) hence this const current has to be maintained during charging.

Scanned By ScanIt

Page No.
Date

→ BATTERY EFFICIENCY

In most applications Battery acts as an interface between power source & load.



If Whrsc is a net power drawn from the source, the Battery Efficiency during a complete charge-discharge cycle is written as:

1. During charging, electrical to chemical energy conversion occurs between source & battery.
2. During dis-charging chemical to electrical energy conversion occurs between source & battery.

3. - Whrsc is a net energy drawn from source
- Whr EC is an Energy loss during charging.
- Whr CE is an Energy loss during discharging.
- The battery Efficiency is % is expressed as η.
- The typical values of η for Lead Acid & NiMH batteries are 70 & for Lithium battery in the range 80%.

Battery efficiency:

$$\boxed{\eta = \frac{Whr_{SC} - (Whr_{EC} + Whr_{CE})}{Whr_{SRC}} \times 100}$$

Scanned By ScanIt

Page No.
Date

→ BATTERY SELECTIONS:

1. Battery chemistry: Selected on app, availability & capital.

2. What is allowable DoD based on app.? Eg. Car ignition select 20%. For EV select 80%.

3. What is the Whr requirement of the load?
4. Find AmpHr rating of the battery

$$Wh_{bat} = \frac{Wh_{load}}{DoD} \quad . \quad Ah_{bat} = \frac{Wh_{bat}}{V_{nom}}.$$

Eg. A battery is required to provide backup of 10hrs for a 800W.

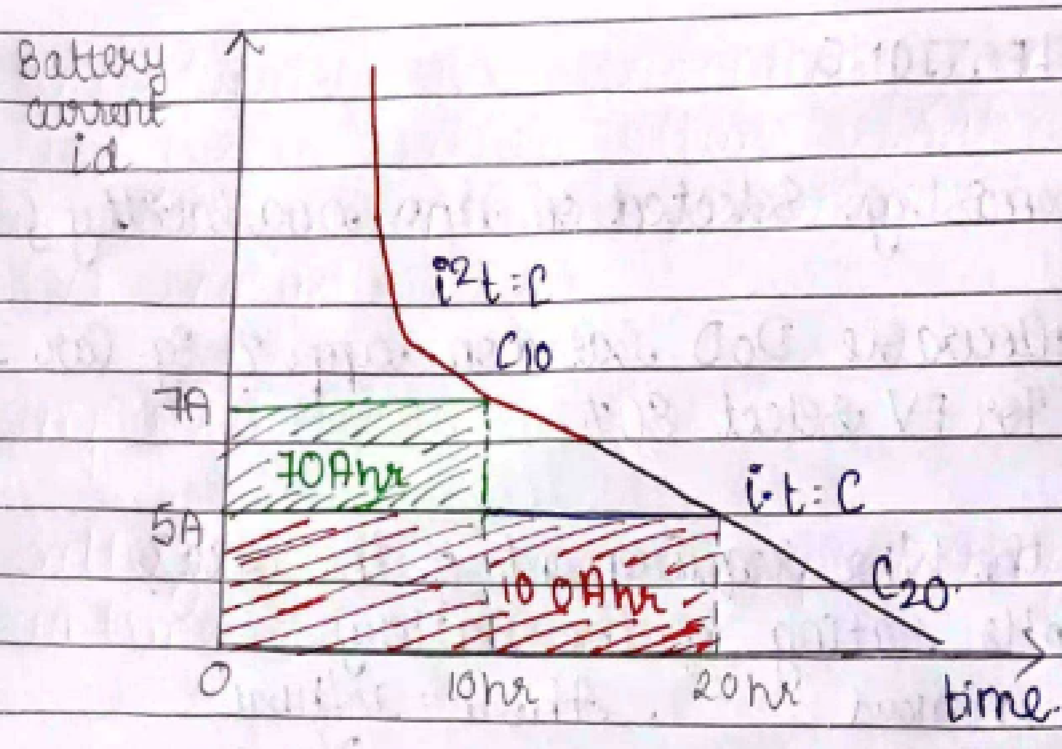
$Wh_{load} = 800 \times 10 = 8KWhr.$

Suppose DoD = 60%. $V_{Nom} = 110V$.

$$Wh_{batt} = \frac{8000\,Whr}{0.6} = 13.33\,KWhr$$

$$Ah_{batt} = \frac{13.33 \times 10^3}{110} = 121.21A.$$

5. Selection of C-rating of the battery:
a) Find average Id from given application & refer the discharge characteristics as shown.
b) At low discharge current, refer st line portion i.e. id.t of the discharge characteristics.
c) For higher discharge current, select $i^2d.t$ portion of the discharge characteristics.



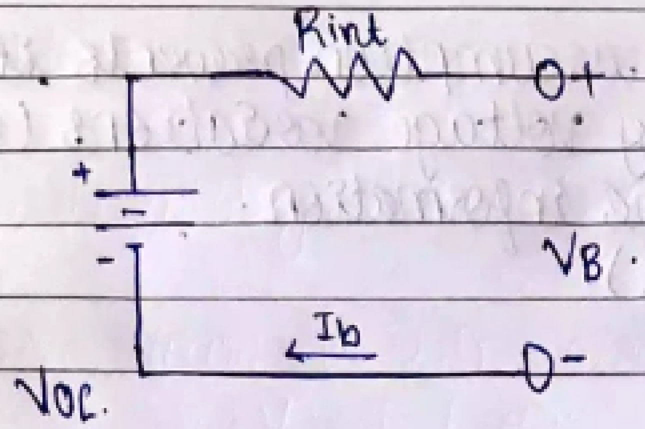
→ BATTERY COMPARISON

Type	Wh/kg	W/kg	Wh/lit	Temp	η	Life (cycles)
Lead acid	35	100	80	Ambient	70	1000
Ni metal hydride	55	100	150	Ambient	70	2000+
Sodium sulphur	100	150	300	350d.	75	1000
Lithium Polymer.	150+	200+	450	Ambient	80	8000-10000

Lead acid batteries are with low initial cost. maintainable & ease of availability.
Lithium polymer are with higher initial cost but higher power & energy densities. compact in size.

→ BATTERY MODELLING:

1) Simple Model:
A simple battery model consists of a series combination of an OC. voltage source is a variable resistance that represent the battery power loss & other non-linearities.

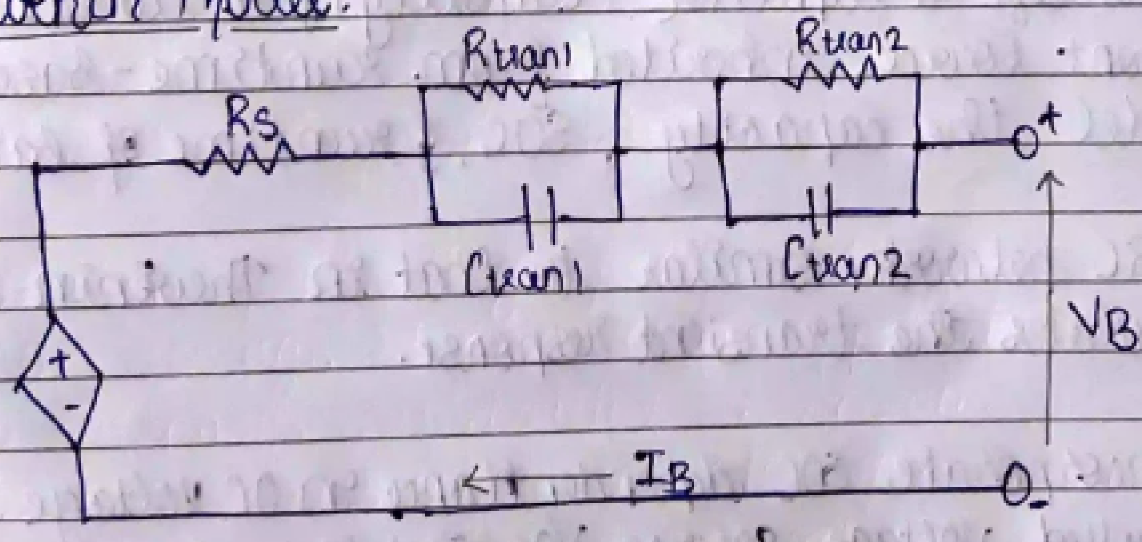


Let Q is a Ampere capacity of a battery.
Let z(t) is a time varying SOC funⁿ of the battery.
z(t0) is an initial SOC at the charge or discharge cycle.
The open circuit voltage is not constant but is a funⁿ. of SOC. i.e. z(t)

$$\frac{dz(t)}{dt} = \frac{-i(t)}{Q}$$

$$z(t) = z(t_0) - \frac{1}{Q}\int_0^t i(\tau)\, d\tau$$

2) Thevenin Model:

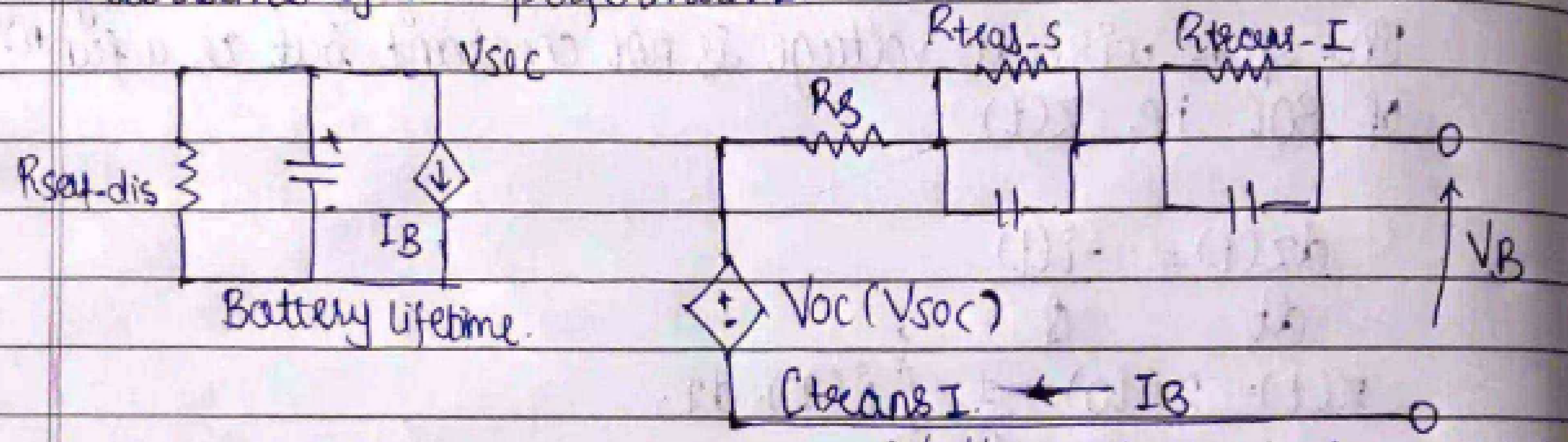


:1. Uses a series resistor (Rs) & 2 RC parallel network (Rtran & Ctran) to predict battery ~~rsp~~ response to transient load events at a particular state of charge (SOC), by assuming the OC voltage [Voc(SOC)] is const

2. Unfortunately, this assumption prevents it from capturing steady-state battery voltage variations (i.e. dc response) as well as runtime information. (VI - characteristics).

3) Improved Model.

Battery model capable of predicting both the runtime & I-V performance.



Voltage current characteristics

1. On the left, a capacitor (Ccapacity) & a current-controlled current source, inherited from runtime-based models, model the capacity, SOC, & runtime of battery.

2. The RC network, similar to that in Thevenin-based models simulates the transient response.

3. To incorporate SOC dependence on OC voltage, a voltage controlled voltage source Voc(SOC) is used.

4. Mathematical dependency of each parameter on SOC:

$$\boxed{C_{capacity} = 3600 \cdot Capacity \cdot f_1(cycle) \cdot f_2(Temp)}$$

Capacity - charge cap in Amphr. $f_1(cycle)$ a factor accounting battery degrade with no. of cycles usage. $f_2(Temp)$: Temp dependent capacity correction factor.

Date

5. The non-linear relation between the OC voltage Voc & SOC is included in the model with a VCVS Voc (SOC) & expressed in eqn:

$$Voc(SOC) = -1.031 \cdot e^{(-35 \cdot SOC)} + 3.685 + 0.2156 \cdot SOC - 0.1178 SOC^2 + 0.3201 \cdot SOC^3.$$

SOC value anywhere between 0 to 1.0 depending on SOC%.

6. The electrical network consists of series resistors R_S & two RC ∥ networks composed of R_{trans_S}, C_{tran_S}, R_{tran_l} & C_{tran_l}.

$$R_S(SOC) = 0.1562 \cdot e^{-24.37 \cdot SOC} + 0.07446.$$
$$R_{tran\_S}(SOC) = 0.3208 \cdot e^{-29.14 \cdot SOC} + 0.04669.$$
$$C_{tran\_S}(SOC) = -752.9 \cdot e^{-13.51 \cdot SOC} + 703.6.$$
$$R_{tran\_l}(SOC) = 6.603 \cdot e^{-155.2 \cdot SOC} + 0.04984.$$
$$C_{tran\_l}(SOC) = -6056 \cdot e^{-27.12 \cdot SOC} + 4475$$