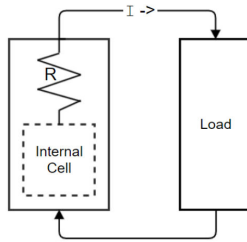


Derives Current based on Power

$$V_{OC} - V_{CC} = IR$$
$$P = IV_{CC}$$

$$I = \frac{V_{oc}}{2R} - \sqrt{\frac{V_{oc}^2}{4R^2} - \frac{P}{R}}$$



$P = I^2 R$  is the basis of losses due to heat, this is how you find the  $I$ . Current is dynamic and increases (for the same power) as the pack discharges

Quantities Based off data sheet and batemo

<https://www.batemo.com/products/batemo-cell-explorer/murata-us18650-vtc6/>

```
CellName = "VCT6";
CellHeight = 64.7/1000;%m
CellDiameter = 18.3/1000; %m
CellWeight = 47.3/1000; %kg
MassHeatCapacity = 900; %j/kg/k
HeatCapCell = 63;% j/k

MaxCellVoltage = 4.2;%volts
MinCellVoltage = 2.5;
VocCell = MaxCellVoltage;
DCresistance = 0.022;%ohms %this value is one from the datasheet, but will vary
based on the conditions of the cell.
%I want to see if keeping the cell in an optimal temperature range is
%worth it.
EnergyCell10ADraw = 34700;%this value was taken from the mit vt6 testing

%old 35800joules per batt, this value is abt 90% of the nominal capacity. 35800 was
determined from the
%lygte-info.dk website. The batemo power vs energy graph also shows about a
%10percent decrease in the range of 20kw to 30kw pack draws(28-43 per cell)

PackSeries = 138;
PackParralel = 5;
HeatCapPack = 63*PackSeries*PackParralel
```

HeatCapPack =

```
InitialPackTemp = 25;
PackMaxVoltage = PackSeries * MaxCellVoltage;
VocPack = PackMaxVoltage;
PackMin = PackSeries * MinCellVoltage
```

```
PackMin =
    345
```

```
PackImpedance = DCresistance * PackSeries / PackParralel
```

```
PackImpedance =
    0.6072
```

```
timeInput = [0 ; 1 ; 10 ; 100 ; 200 ;]
```

```
timeInput = 5×1
    0
    1
   10
  100
 200
```

```
PowerDemand = repmat(20000, height(timeInput), 1)
```

```
PowerDemand = 5×1
    20000
    20000
    20000
    20000
    20000
```

```
TotalPackEnergy = PackSeries * PackParralel * EnergyCell10ADraw;
% VccPack=PowerDemand/PackImpedance;
% PeakPackPower ;
% EnergyConsumption;
% EnergyCell;
```

<https://lygte-info.dk/review/batteries2012/>

[Sony%20US18650VTC6%203000mAh%20%28Green%29%20UK.html](https://lygte-info.dk/review/batteries2012/Sony%20US18650VTC6%203000mAh%20%28Green%29%20UK.html)

<https://www.e-cigarette-forum.com/threads/sony-vtc6-15a-3000mah-18650-bench-test-results-a-great-battery-equaling-hg2-30q.754649/>

[https://www.batemo.com/wp-content/uploads/general/performance\\_pictures/muRata\\_US18650VTC6\\_energy.png](https://www.batemo.com/wp-content/uploads/general/performance_pictures/muRata_US18650VTC6_energy.png)

```
ETPIAT = table();
ETPIAT.timeInput = timeInput
```

```
ETPIAT = 5×1 table
```

|   | timeInput |
|---|-----------|
| 1 | 0         |
| 2 | 1         |
| 3 | 10        |
| 4 | 100       |
| 5 | 200       |

ETPIAT.PowerDemand = PowerDemand%Example Pack entry

ETPIAT = 5x2 table

|   | timeInput | PowerDemand |
|---|-----------|-------------|
| 1 | 0         | 20000       |
| 2 | 1         | 20000       |
| 3 | 10        | 20000       |
| 4 | 100       | 20000       |
| 5 | 200       | 20000       |

ETPIAT.VocPack = repmat(VocPack, length(ETPIAT.timeInput), 1)

ETPIAT = 5x3 table

|   | timeInput | PowerDemand | VocPack |
|---|-----------|-------------|---------|
| 1 | 0         | 20000       | 579.6   |
| 2 | 1         | 20000       | 579.6   |
| 3 | 10        | 20000       | 579.6   |
| 4 | 100       | 20000       | 579.6   |
| 5 | 200       | 20000       | 579.6   |

ETPIAT.PackImpedance = repmat(PackImpedance, length(ETPIAT.timeInput), 1)

ETPIAT = 5x4 table

|   | timeInput | PowerDemand | VocPack | PackImpedance |
|---|-----------|-------------|---------|---------------|
| 1 | 0         | 20000       | 579.6   | 0.6072        |
| 2 | 1         | 20000       | 579.6   | 0.6072        |
| 3 | 10        | 20000       | 579.6   | 0.6072        |
| 4 | 100       | 20000       | 579.6   | 0.6072        |
| 5 | 200       | 20000       | 579.6   | 0.6072        |

## Table Creation

$$I = \frac{V_{oc}}{2R} - \sqrt{\frac{V_{oc}^2}{4R^2} - \frac{P}{R}}$$

```
%ETPIA(:,5) = ETPIA(:,3)./2./ETPIA(:,4) - sqrt(ETPIA(:,3).^2 ./4./ETPIA(:,4).^2 -
ETPIA(:,2)./ETPIA(:,4))
ETPIAT.Properties.VariableNames
```

```
ans = 1x4 cell
'timeInput' 'PowerDemand' 'VocPack' 'PackImpedance'
```

```
% Calculates Current using above formula and add it as a new column
ETPIAT.Current = ETPIAT.VocPack ./ 2 ./ ETPIAT.PackImpedance ...
- sqrt(ETPIAT.VocPack.^2 ./ 4 ./ ETPIAT.PackImpedance.^2 -
ETPIAT.PowerDemand ./ ETPIAT.PackImpedance)
```

```
ETPIAT = 5x5 table
```

|   | timeInput | PowerDemand | VocPack | PackImpedance | Current |
|---|-----------|-------------|---------|---------------|---------|
| 1 | 0         | 20000       | 579.6   | 0.6072        | 35.853  |
| 2 | 1         | 20000       | 579.6   | 0.6072        | 35.853  |
| 3 | 10        | 20000       | 579.6   | 0.6072        | 35.853  |
| 4 | 100       | 20000       | 579.6   | 0.6072        | 35.853  |
| 5 | 200       | 20000       | 579.6   | 0.6072        | 35.853  |

```
%I = VocPack./2/PackImpedance - sqrt(VocPack^2 /4/PackImpedance^2 - PowerDemand/
PackImpedance);
```

```
% This method of making this uses arrays. I think the ./ operator
%operator only means use values in the same row. the (:,5) or similar would
%mean cycling through all the column on the calculation. ./ makes it excel
%style math ish.
```

$$V_{cc} = \frac{P}{I}$$

```
%ETPIA(:,6) = ETPIA(:,2)./ETPIA(:,5)
ETPIAT.ClosedCircuitVoltage = ETPIAT.PowerDemand./ETPIAT.Current
```

ETPIAT = 5×6 table

...

|   | timeInput | PowerDemand | VocPack | PackImpedance | Current |
|---|-----------|-------------|---------|---------------|---------|
| 1 | 0         | 20000       | 579.6   | 0.6072        | 35.853  |
| 2 | 1         | 20000       | 579.6   | 0.6072        | 35.853  |
| 3 | 10        | 20000       | 579.6   | 0.6072        | 35.853  |
| 4 | 100       | 20000       | 579.6   | 0.6072        | 35.853  |
| 5 | 200       | 20000       | 579.6   | 0.6072        | 35.853  |

```
ETPIAT.ClosedCircuitVoltage(isnan(ETPIAT.ClosedCircuitVoltage)) = 0
```

ETPIAT = 5×6 table

...

|   | timeInput | PowerDemand | VocPack | PackImpedance | Current |
|---|-----------|-------------|---------|---------------|---------|
| 1 | 0         | 20000       | 579.6   | 0.6072        | 35.853  |
| 2 | 1         | 20000       | 579.6   | 0.6072        | 35.853  |
| 3 | 10        | 20000       | 579.6   | 0.6072        | 35.853  |
| 4 | 100       | 20000       | 579.6   | 0.6072        | 35.853  |
| 5 | 200       | 20000       | 579.6   | 0.6072        | 35.853  |

$$P_{pk} = V_{min} \frac{V_{oc} - V_{min}}{R}$$

```
%ETPIA(:,7) = PackMin .* (ETPIA(:,3)- PackMin)./ETPIA(:,4);
ETPIAT.PeakPower = PackMin .* (VocPack-PackMin)./ETPIAT.PackImpedance
```

ETPIAT = 5×7 table

...

|   | timeInput | PowerDemand | VocPack | PackImpedance | Current |  |
|---|-----------|-------------|---------|---------------|---------|--|
| 1 | 0         | 20000       | 579.6   | 0.6072        | 35.853  |  |
| 2 | 1         | 20000       | 579.6   | 0.6072        | 35.853  |  |
| 3 | 10        | 20000       | 579.6   | 0.6072        | 35.853  |  |
| 4 | 100       | 20000       | 579.6   | 0.6072        | 35.853  |  |
| 5 | 200       | 20000       | 579.6   | 0.6072        | 35.853  |  |

$$\Delta E = Pt$$

```
time_differences = diff(ETPIAT.timeInput)
```

```
time_differences = 4x1
    1
    9
   90
  100
```

```
% Calculates the differences in the first column between consecutive rows
ETPIAT.timeDiff = [0; time_differences] % Uses 0 to indicate no previous difference
for the first row
```

```
ETPIAT = 5x8 table
```

|   | timeInput | PowerDemand | VocPack | PackImpedance | Current |
|---|-----------|-------------|---------|---------------|---------|
| 1 | 0         | 20000       | 579.6   | 0.6072        | 35.853  |
| 2 | 1         | 20000       | 579.6   | 0.6072        | 35.853  |
| 3 | 10        | 20000       | 579.6   | 0.6072        | 35.853  |
| 4 | 100       | 20000       | 579.6   | 0.6072        | 35.853  |
| 5 | 200       | 20000       | 579.6   | 0.6072        | 35.853  |

...

```
ETPIAT.EnergyDiff = ETPIAT.timeDiff .* ETPIAT.PowerDemand
```

```
ETPIAT = 5x9 table
```

|   | timeInput | PowerDemand | VocPack | PackImpedance | Current |
|---|-----------|-------------|---------|---------------|---------|
| 1 | 0         | 20000       | 579.6   | 0.6072        | 35.853  |
| 2 | 1         | 20000       | 579.6   | 0.6072        | 35.853  |
| 3 | 10        | 20000       | 579.6   | 0.6072        | 35.853  |
| 4 | 100       | 20000       | 579.6   | 0.6072        | 35.853  |
| 5 | 200       | 20000       | 579.6   | 0.6072        | 35.853  |

...

```
JoulesTot = TotalPackEnergy;
```

```
% Calculates the cumulative sum of the EnergyDiff column
cumulativeEnergyConsumed = cumsum(ETPIAT.EnergyDiff, 'omitnan');
```

```
% Subtracts the cumulative energy consumed from the initial JoulesLeft
ETPIAT.JoulesLeft = JoulesTot - cumulativeEnergyConsumed;
```

Heat

$$Q_{gen} = I^2 R \quad Q = Q_{gen} t \quad \Delta T = \frac{Q}{m C_p}$$

```
ETPIAT.HeatGen = ETPIAT.Current.^2 .* ETPIAT.PackImpedance.*ETPIAT.timeDiff
```

ETPIAT = 5×11 table

...

|   | timeInput | PowerDemand | VocPack | PackImpedance | Current |
|---|-----------|-------------|---------|---------------|---------|
| 1 | 0         | 20000       | 579.6   | 0.6072        | 35.853  |
| 2 | 1         | 20000       | 579.6   | 0.6072        | 35.853  |
| 3 | 10        | 20000       | 579.6   | 0.6072        | 35.853  |
| 4 | 100       | 20000       | 579.6   | 0.6072        | 35.853  |
| 5 | 200       | 20000       | 579.6   | 0.6072        | 35.853  |

```
CumulativeHeatGen = cumsum(ETPIAT.HeatGen,'omitNaN');  
ETPIAT.HeatEnergy = CumulativeHeatGen
```

ETPIAT = 5×12 table

...

|   | timeInput | PowerDemand | VocPack | PackImpedance | Current |
|---|-----------|-------------|---------|---------------|---------|
| 1 | 0         | 20000       | 579.6   | 0.6072        | 35.853  |
| 2 | 1         | 20000       | 579.6   | 0.6072        | 35.853  |
| 3 | 10        | 20000       | 579.6   | 0.6072        | 35.853  |
| 4 | 100       | 20000       | 579.6   | 0.6072        | 35.853  |
| 5 | 200       | 20000       | 579.6   | 0.6072        | 35.853  |

```
ETPIAT.TempRise = ETPIAT.HeatEnergy/HeatCapPack
```

ETPIAT = 5×13 table

...

|   | timeInput | PowerDemand | VocPack | PackImpedance | Current |
|---|-----------|-------------|---------|---------------|---------|
| 1 | 0         | 20000       | 579.6   | 0.6072        | 35.853  |
| 2 | 1         | 20000       | 579.6   | 0.6072        | 35.853  |
| 3 | 10        | 20000       | 579.6   | 0.6072        | 35.853  |
| 4 | 100       | 20000       | 579.6   | 0.6072        | 35.853  |
| 5 | 200       | 20000       | 579.6   | 0.6072        | 35.853  |

