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Modelling and simulation of lithium-ion battery with temperature effects using MATLAB/Simulink

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Abstract
The presence of a lithium-ion battery in almost all portable electronics, electric vehicle, and aerospace applications proves that it is the 21-st century energy source. The lithium-ion battery is seen as the alternative method for powering various systems because of its benefits like high energy density, small size, and less maintenance cost, thus also boosting the fight against climate change. The design of accurate and efficient battery models puts into the account the parameters is very essential. In this paper, a battery model is developed using Matlab/Simulink considering the temperature effects. The battery model is explained, developed and presented as well as validated with experimental results. From the developed model, voltage, State-of-charge, and current are measured under the influence of temperature effects. This model has captured only temperature parameter, but can be improved to capture other parameters.

Keywords: modelling, simulation, electric vehicles, lithium-ion battery, state-of-charge

1. Introduction
Lithium-ion batteries (LIBs) are gaining popularity day by day due to their high efficiency, small weight, less volume, high temperature sensitivity, low self-discharge, rapid charge capability, and low maintenance [1][2][3][4], which make their applications to span from portable electronics, electric vehicles, military, and aerospace applications. Energy storage systems based on lithium ion batteries have a wide range of sizes and usages. From small applications like portable batteries (cell phones, laptops, etc.) to bigger ones like batteries for electric mobility (bikes, electric vehicles (EVs), trains, etc.) to large battery groups for grid applications [5]. Lithium rechargeable batteries provide energy devices as described above with capacities ranging from just a few Watt hours to megawatt hour.

Apart from these benefits, the LIB technology has received a boost from many nations which are looking at alternative methods of powering vehicles so as to cut costs, and also eliminate the challenge of fossil fuel usage hat has brought about global warming and environmental pollution [6]. However developing and deploying lithium-ion battery management with state-of-charge (SOC) estimation in EV application has become a major challenge due to its complicated electro-chemical reactions and performance degradation over time caused by various internal and external factors [7]. This paper is organized as follows: section two gives a background information about the battery model, and model parameters; section three explains about LIB modeling assumptions, charge/discharge model and characterization; section four provides the simulation results with some explanations, finally section five provides information about the conclusion.

2. The battery Model
The battery model is required to define and study voltage *u*, current *I*, SOC, temperature [8] and other battery parameter. Several literatures proposes many battery models which are made of the equivalent circuit combination of capacitance and resistance. These models include Thevenin equivalent circuit model (ECM), resistance capacitance model, the resistor-capacitor (RC) model, internal resistance model, and the partnership for a new generation of vehicles (PNGV) capacitance model [9][10][11]. Taking temperature into consideration the study of Thevenin ECM will be applied as shown in Figure 1. The Thevenin ECM is chosen because it is the best applicable when you want to get the LiFePO4 battery behaviour under charging and discharging conditions [12][13][14]. To ensure optimum compatibility between the ECM and the electrochemical model, a 2RC Thevenin model is chosen [15]. This is because according to the electrochemical reactions, the diffusions and migration at the electrodes are assumed to be realized by paralleled resistance and capacitance parts respectively and the added resistance compensates the changes of the electrolyte [16].

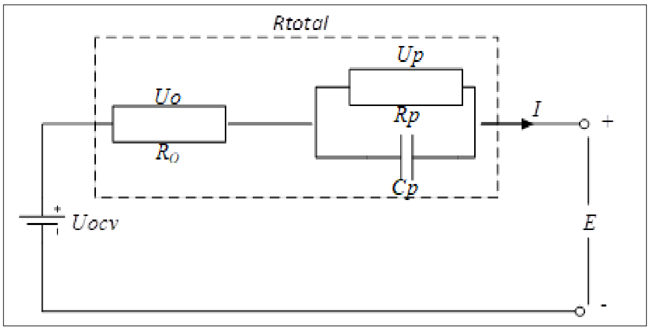

Fig 1: Thevenin battery model

The Thevenin battery model from Figure 1 is used to analyse the battery discharging process.

Where:
Uocv = is the open circuit voltage
R_O =represents the ohmic resistance
Uo = is the voltage on R_O
Cp =is the polarization capacitance
Rp =is the polarization resistance
Up =is the voltage on C*p and* R*p*
E =is the terminal voltage
I =is the discharging current
Rtotal= R_O +*Cp*+*Rp*
There are heat sources that are associated with LIB batteries which includes the reaction heat, reversible heat, irreversible heat, ohmic heat, and external contact resistance heat [17]. This heat has to be dissipated to the air as quick as possible otherwise it will lead to the increase of cell temperature. The battery on itself generates heat which is either reversible or irreversible heat. The reversible heat commonly known as the reaction heat, refers to the energy that is released or absorbed in the electrochemical reaction to maintain the energy balance of the reaction. According to author [18][19], this reversible heat originates from the entropy change associated with electrochemical reactions or entropic change in the electrodes resulting from the structural changes caused by the intercalation of Li-ions during charging and discharging [20], thus it is known as reaction or entropic heat. Therefore the entropy change characteristics can be either exothermic or endothermic, depending on the SOC and direction of the current [17]. While the irreversible heat includes the Joule heat and the concentration polarization heat. The simplified heat generation equation according to [21] is:

$$Q_t = Q_j + Q_r = I(E - U_{ocv}) + IT\frac{\partial U_{ocv}}{\partial T} \quad (1)$$

$$Q_j = I(E - U_{ocv}) = I^2R \quad (2)$$

Where
I=operating current of the battery
E= battery voltage
U_{ocv}= open circuit voltage
Q_t= total heat generation power
Q_j= irreversible heat generation power
Q_r=is the reaction heat or reversible entropy heat
The irreversible heat generation power Q_j is generally the sum of heat generated by ohmic resistance when current if flowing, and the heat generated by concentration difference through material transfer in the battery. Q_j can be expressed as the difference between the battery terminal voltage and the OCV voltage results from the voltage that is generated by the internal resistance when the current flows as shown in Eqn. 2, where *R* is the equivalent internal resistance of the battery. While the reaction heat Q_r is the reversible entropy heat which depends on the direction of current and the sign of entropy coefficient, he entropy potential varies significantly with different chemical composition and is greatly influenced by SOC [21].
Three parameters namely heat generation, thermal diffusion, and heat conduction are found to majorly influence the battery temperature. The battery distributes heat to the exterior when it works under low temperatures, in addition to heat production. Thermal convection and heat radiation are basically the main approaches to battery heat loss. This thermal radiation is usually ignored because it is usually very small as compared to thermal convection. The dissipated heat can be expressed as:

$$Q_{dis} = -hA(T - T_\infty) \quad (3)$$

Where *h* is the equivalent heat transfer coefficient, *A* is the surface area of the battery, *T* is the battery temperature, and *T*∞ is the ambient temperature. This makes the heat balance equation to be obtained as follows:

$$mc\frac{dT}{dt} = Q_j + Q_r + Q_{dis} = I^2R + IT\frac{\partial U_{ocv}}{\partial T} - hA(T - T_\infty) \quad (4)$$

Where *m* is the mass of the battery and *c* is the specific heat capacity.
From Eqn. 4 we can resolve that the total heat generated from by the battery is basically influenced by resistance, current, entropy potential, the equivalent heat transfer coefficient, and battery temperature. The higher the current and resistance the greater the heat generated, and the higher the equivalent transfer coefficient, and battery temperature, the greater the heat dissipation, resulting into the reduction in the total heat generated. The battery model developed in this research will take into account changes in resistance, entropy coefficient during battery heating process, and the changes in load vibration frequencies so as to guarantee accuracy.
From Eqn. 4, we can get the linear differential equation relating to the battery temperature as follows;

$$\frac{dT(t)}{dt} = \left(\frac{I\frac{\partial U_{ocv}}{\partial T}}{mc} - \frac{hA}{mc}\right)T(t) + \frac{I^2R}{mc} + \frac{hA_\infty}{mc} \quad (5)$$

By using the Laplace transform, Eqn. 5 can be rewritten in discrete time as:

$$sT(s) - T(t_0) = \left(\frac{I\frac{\partial U_{ocv}}{\partial T}}{mc} - \frac{hA}{mc}\right)T(s) + \left(\frac{I^2R}{mc} + \frac{hAT_\infty}{mc}\right)\frac{1}{s} \quad (6)$$

Where t_0 is the initial time, and *t* is the current time. Under periodic sampling conditions, $t_0=kT_0$, $t=(k+1)T_0$, and $k = 0,1,2,3,\ldots n$. Replacing t_0 with kT_0, Eqn. 6 becomes:

$$sT(s) - T(KT_0) = \left(\frac{I\frac{\partial U_{ocv}}{\partial T}}{mc} - \frac{hA}{mc}\right)T(s) + \left(\frac{I^2R}{mc} + \frac{hAT_\infty}{mc}\right)\frac{1}{s} \quad (7)$$

If Eqn. 7 is further simplified, it becomes:

$$T(s) = \frac{T(kT_0)}{\frac{s+hA-I\frac{\partial U_{ocv}}{\partial T}}{mc}} + \frac{1}{\frac{s(s+hA-I\frac{\partial U_{ocv}}{\partial T})}{mc}} + \frac{I^2R+hAT_\infty}{mc} \quad (8)$$

By applying the inverse of the Laplace transform in Eqn. 8, we get:

$$T\left((k+1)T_0\right) = e^{-\frac{hA - I\frac{\partial U_{ocv}}{\partial T}}{mc}t} T(KT_0) + \frac{mc}{hA - I\frac{\partial U_{ocv}}{\partial T}}\left(1 - e^{-\frac{hA - \frac{I\partial U_{ocv}}{\partial T}}{mc}t}\right) I^2 R + \frac{hAT_\infty}{mc} \quad (9)$$

3. Lithium-ion battery modeling

A battery model is used to study the relationship between external characteristics and the internal states of a battery by establishing a mathematical model [12]. LIBs modeling has a significant impact on accurate estimation of SOC, safety performance and durability. Various battery model have been proposed and developed to achieve these factors, but they suffer from lack of accuracy and adaptability to operate in different operating conditions making research on battery modeling a noble venture. The simplicity, ease of parameterization, and real-time feasibility have made the ECM to be commonly used to simulate the voltage of individual battery cell [22][23], and also the simulation time based on ECM is negligible [13][24]. Equally the ECM based on external dynamic characteristics can simulate the working characteristics of different kinds of batteries thereby avoiding detailed calculations of internal electrochemical processes [12]. According to Omar *et al.* [25], the exercise of modelling faces one major challenge in the reflecting of the different relationships inside a battery.

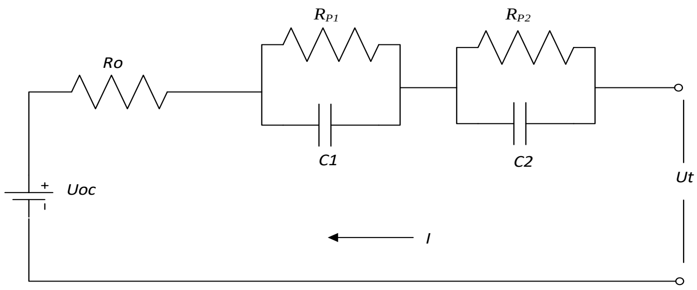

Fig 2: The second-order resistor-capacitor (RC) equivalent circuit model

Figure 2 is showing the schematic diagram of the second-order *RC* model, where *Uoc* is the open circuit voltage of the battery, R_O is the ohmic resistance, R_{P1} and R_{P2} denotes the polarization resistance, *C1* and *C2* denotes the polarization capacitance, *U* is the terminal voltage of the LIB, and *I* is the flow of current. According to research conducted by Zhang *et al.* [24], the parallel RC network describes the non-linear polarization response of the LIB, and *I* is positive for discharging and negative for charging. In this research we employ the use of the second-order model, because according to various research, this model is credible and could achieve a desirable SOC estimation accuracy [26].

In this paper the LIB model demonstrates the effect of temperature parameter on the lithium-ion battery A1 of 3.3V as nominal voltage, and capacity of 2.23Ah. This is because the battery temperature is the primary parameter that is affecting the performance and life of the battery pack [17][27]. This LIB is compared with the pre-set battery in the battery generic model of 7.4V and 5.4Ah. The model includes the impact of internal and ambient temperature on the state-of-charge *(SOC)*, voltage *V*, and current *A*. during the discharge and charging process, the battery performance is compared with the battery A2 which is without temperature effect. The output of voltage, current, and SOC of the two batteries are observed to check on the battery that gives right performance values. After performing the simulations, further the battery lab experiments are performed to aid in verifying the results obtained from the simulations.

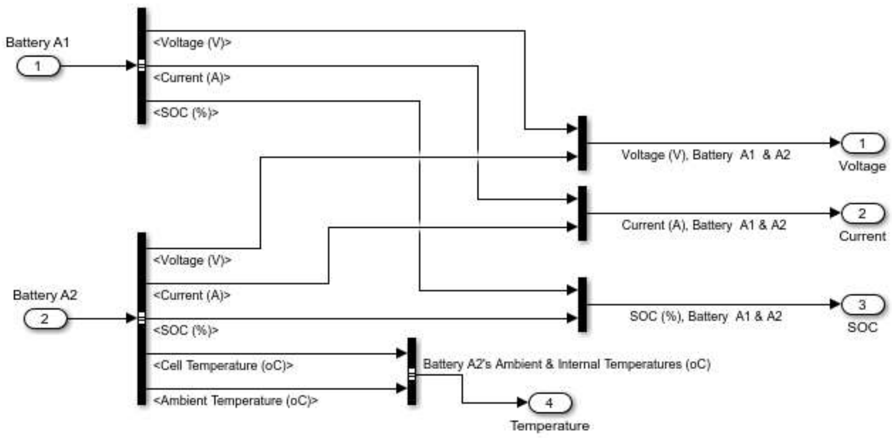

Fig 3: The LIB model with temperature effects

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3.1 The model assumptions

There are several assumptions of the battery model in Matlab/Simulink, as shown below:

a. The parameters of the model are deduced from discharging characteristics and assumed to be the same for charging.
b. The internal resistance is supposed to be constant during the charging and the discharging cycles and does not vary with the different amplitude of the current.
c. The self-discharge of the battery is not represented and the battery has no memory effect.
d. The model takes temperature into account because it affects the models behavior
e. The model does not take vibration into account even if it affects the models behavior

3.2 Charge model

Battery charging is the process of replenishing or replacing the electrical charge in a rechargeable cell or battery. There are various charging methods namely; constant current, constant voltage, pulsed charge, taper current, burp charging, float charge, trickle charge current-voltage-current (IUI) charging, and random charging. Equation 10 shows the charge model:

$$f_1(it, i*, i) = E_0 - K.\frac{Q}{it+0.1.Q}.i* - K.\frac{Q}{Q-it}.it + A.\exp(-B.it) \quad (10)$$

Where,
E_0 = Constant voltage (V)
Exp(s) = Exponential zone dynamics (V)
K = Polarization constant (Ah^{-1}) or Polarization resistance (Ohms)
$i*$ = Low frequency current dynamics (A)
i = Battery current (A)
it = Extracted capacity (Ah)
Q = Maximum battery capacity (Ah)
A = Exponential voltage (V)
B = Exponential capacity $(Ah)^{-1}$
Frequently charging and discharging causes ambient temperature and unbalancing charge issue in the battery pack. This unbalancing charge cannot provide the required power demand during EV in traction and can even cause fire or explosion [28]. However, the battery pack needs to be provided safety and protection parameters from any hazardous circumstances.

3.3 Discharge model

During the process of battery discharge, the positive lithium-ions from the negative electrode diffuse towards the positive electrode thus reducing the stored charge. The cell and pack voltages are highly dependent on the charging and dis- charging current rates, which makes the whole charge and discharge sustain period contemplated with the required safe period [29]
The discharge model is shown in Equation 11.

$$f_2(it, i*, i) = E_0 - K.\frac{Q}{Q-it}.i* - K.\frac{Q}{Q-it}.it + A.\exp(-B.it) \quad (11)$$

3.4 Charge/discharge characteristics

The LiFePO4 battery is represented by the parameters of the EC based on discharge characteristics. It forms a typical discharge curve that is composed of three sections namely: full charge area, nominal area and exponential areas. The exponential area represents the voltage drop when the battery is fully charged. The nominal area represents the charge that can be extracted from the battery until the voltage drops below the nominal voltage, and the final section represents the total discharge of the battery when the voltage drops rapidly. Apart from the discharge curve at the nominal current other discharge curves are shown at different current rates as seen in Figure 3. Table 1 represents the battery parameter values for the LiFePO4 battery used in the simulations.

Table 1: LiFePO4 (A123) battery parameters characteristics

Discharge Parameters	Values
Nominal Voltage (V)	3.3
Rated capacity (Ah)	2.23
Initial SOC (%)	100
Max. Capacity (Ah)	2.23
Cut-off Voltage (V)	2.475
Full-charged voltage (V)	3.8412
Nominal Discharge Current (A)	0.96957
Internal resistance (Ohms)	0.014798
Capacity of Nominal Voltage (Ah)	2.0167
Exponential Zone	[3.5653 0. 10956]
Discharge current (i1, i2, i3…….)	[4.5 13.5 22.5]

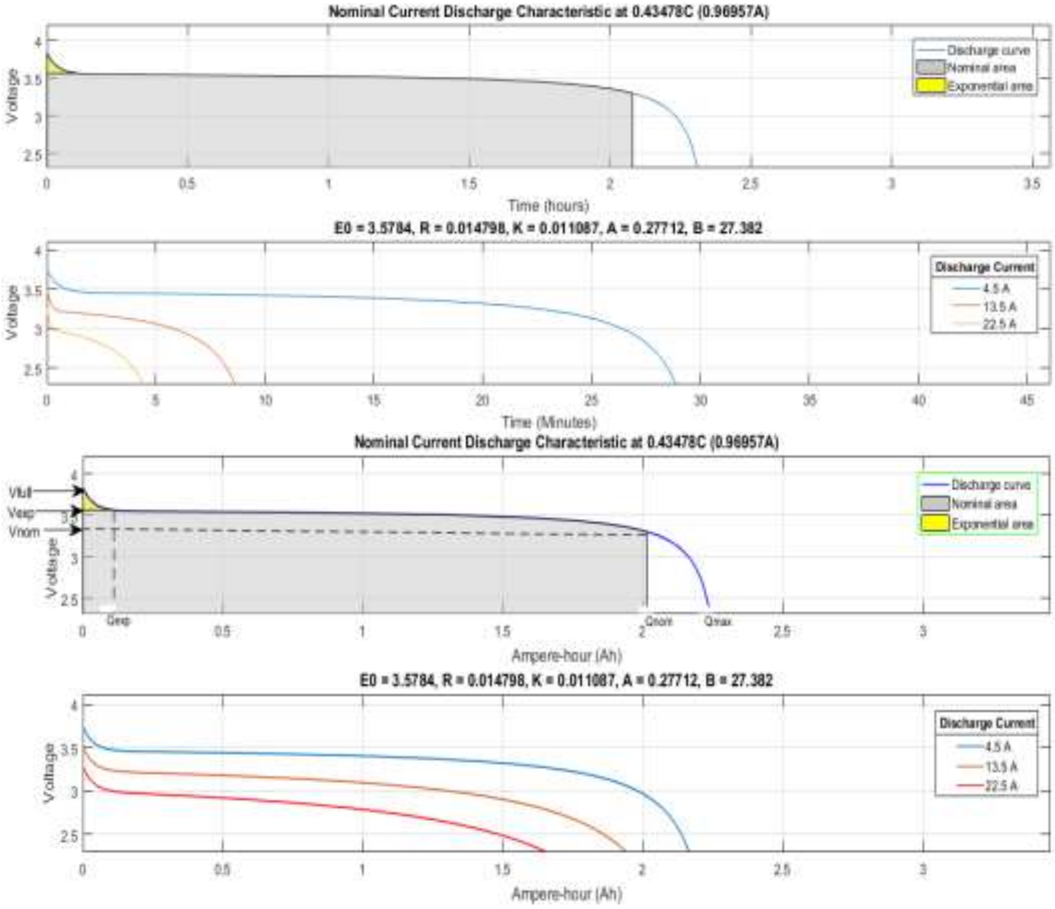


Fig 4: Discharge curve at nominal current and different current rates

From Figure 4, the maximum voltage *Vfull* for the battery is *3.8V, the exponential voltage Vexp is 3.55V,* while the nominal voltage *Vnom is 3.3V,* which corresponds with *Qmax* of 2.25Ah, *Qnom* of 2.05Ah, and *Qexp* of 0.1Ah. The battery remains at a steady capacity for while discharging until it reaches the *Qnom* level, where the battery experiences drastic voltage drop until the battery reaches the maximum capacity state of *Qmax.*

3.5 Lithium-ion battery modelling with temperature effects

The characteristics of individual cell differ from cell to cell because of ambient temperature variation. The power, energy and lifecycle of the battery cell is affected when the temperatures are lower or higher than room temperature. As the battery pack always undergoes the charging and discharging process the battery capacity and lifecycle decrease gradually over time. Especially, high chemical reaction occurs throughout the discharging process while a large amount of current drawing by the traction motor and increases the battery cell internal temperature [10].

The ambient and internal temperature of batteries is one of the parameter that affects the battery performance [17][18] [30]. Excessive temperature variation increases internal resistance, self-discharge rate and voltage. If the internal temperature of battery cell continues to increase, the eventual consequence may be an explosion and/or fire [31]. In order to identify the abnormalities in battery and fault analysis, an intelligent data control system is required where historical data to be stored and an alarm signal to be provided before any fault occurs [32]. The effect of temperature parameter for LIBs is represented in the charge/discharge models as shown.

For the temperature charge model:

$$f_1(it, i*, i, T, T_\propto) = E_0(T) - K(T).\frac{Q(T_\propto)}{it+0.1.Q(T_\propto)}.i* - K(T).\frac{Q(T_\propto)}{Q(T_\propto)-it}.it + A.\exp(-B.it) \quad (12)$$

$$V_{batt}(T) = f_1(it, i*, i, T, T_\propto) - R(T).i \quad (13)$$

For the temperature discharge model:

$$f_2(it, i*, i, T, T_\propto) = E_0(T) - K(T).\frac{Q(T_\propto)}{Q(T_\propto)-it}.i* - K(T).\frac{Q(T_\propto)}{Q(T_\propto)-it}.it + A.\exp(-B.it) - C.it \quad (14)$$

$$V_{batt}(T) = f_1(it, i*, i, T, T_\propto) - R(T).i \quad (15)$$

With

$$E_0(T) = E_0|_{T_{ref}} + \frac{\partial E}{\partial T}(T - T_{ref}) \quad (16)$$

$$K(T) = K|_{T_{ref}}.\exp\left(\propto\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right) \quad (17)$$

$$Q(T_\propto) = Q|_{T_\propto} + \frac{\Delta Q}{\Delta T}.(T_\propto - T_{ref}) \quad (18)$$

$$R(T) = R|_{T_{ref}}.\exp\left(\beta\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right) \quad (19)$$

Where
E_{Batt} = Nonlinear voltage (V)
T_{ref} = Nominal ambient temperature (K)
T = Cell or internal temperature (K)
T_a = Ambient temperature (K)
E/T = Reversible voltage temperature coefficient (V/K)
α = Arrhenius rate constant for the polarization resistance
β= Arrhenius rate constant for the internal resistance
$\Delta Q/\Delta T$ = Maximum capacity temperature coefficient (Ah/K)
C = Nominal discharge curve slope (V/Ah). For lithium-ion batteries with less pronounced discharge curves (such as lithium iron phosphate batteries), this parameter is set to zero.
The cell or internal temperature (T) at any given time (t) is expressed as:

$$T(t) = L^{-1}\left(\frac{P_{loss}R_{th} + T_\alpha}{1+s.t_c}\right) \quad (21)$$

Where
R_{th} is thermal resistance, cell to ambient (°C/W), t_c is thermal time constant, cell to ambient (s), and P_{loss} is the overall heat generated (W) during charge/discharge process and is given by

$$P_{loss} = \left(E_0(T) - V_{batt}(T)\right).i + \frac{\partial E}{\partial T}.i.T \quad (22)$$

Part of the overall heat loss is consumed by polarization effects and this can lead to inefficiency in heat conversion.

4. Simulation Results

When the temperature effects are simulated in the generic battery model the model parameters and its values are set as shown in Table 2.

Table 2: Discharge parameters at second ambient temperatures (T2)

Parameter	**Values**
Initial cell temp (ºC)	20
Nominal ambient temp T1(ºC)	20
Second ambient temp T2 (ºC)	-10
Maximum capacity (Ah)	2.0
Initial discharge (V)	3.2
Voltage at 90% max. capacity (v)	2.97
Exponential zone	[3.2 0.10956]
Thermal resistance (ohms)	0.6
Thermal time constant	2000
Heat loss	0

When the discharge parameters of ambient temperatures T2 are set as shown in Table 2, it yields the Figure 4. It will be observed that between Figure 3 and Figure 4, the values for constant voltage *E0* and polarization constant *K* decreases slightly, while the value of exponential voltage *A* increase, but values of resistance *R* and exponential capacity *B* remains constant. This can be attributed to the decline of maximum capacity due to the introduction of ambient temperature *T2* to the model.

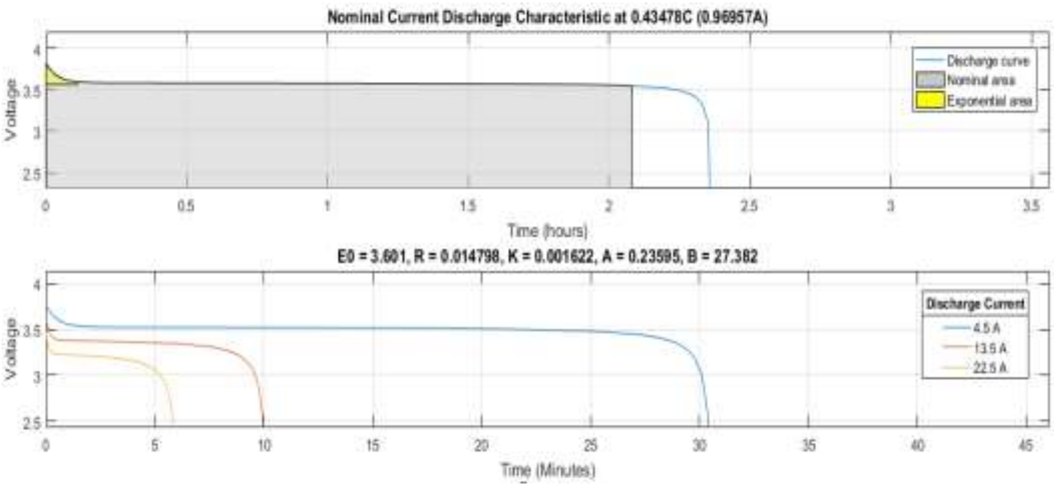


Fig 5: Discharge curves at nominal current and other discharge currents

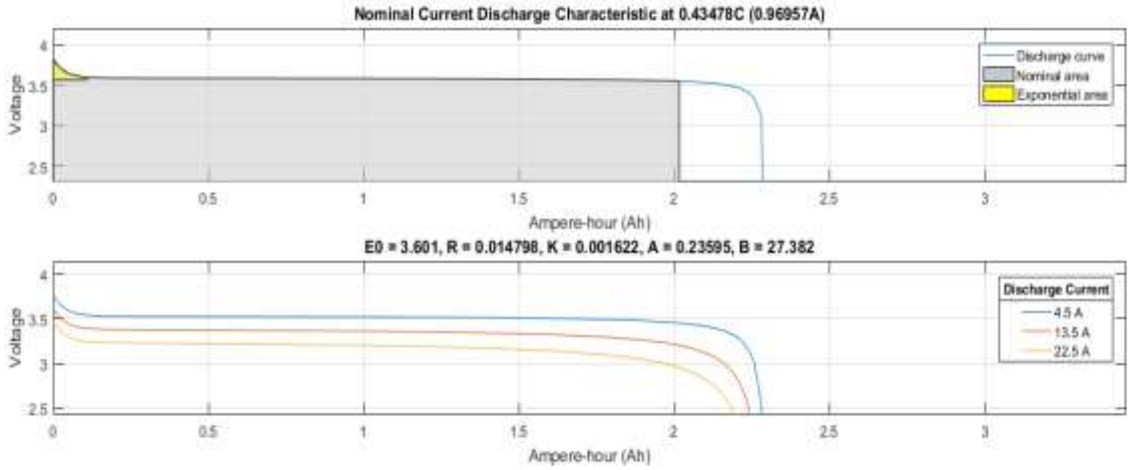
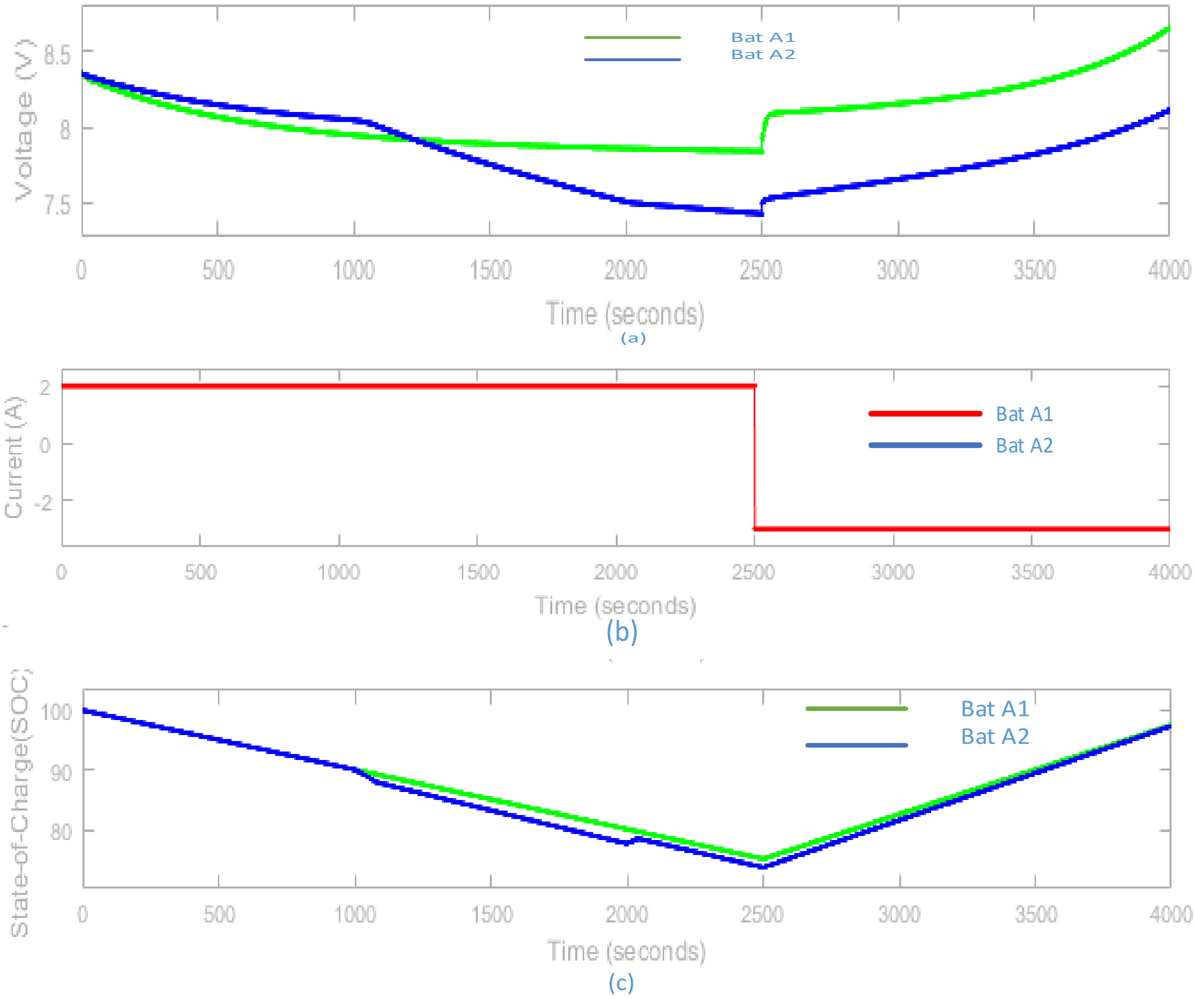


Fig 6: Discharge curves at nominal current and different current Rates for discharge parameter T2

When the LiFePO4 battery is simulated with the temperature effects, changes occur in the battery's SOC, Voltage, current and internal and ambient temperature states. Figure 5 and Figure 6 illustrates the performance of LiFePO4 simulations at nominal current and different discharge rates. Figure 7. (a), (b), (c), and (d) illustrates the simulation results of LIB with, and without temperature effects.



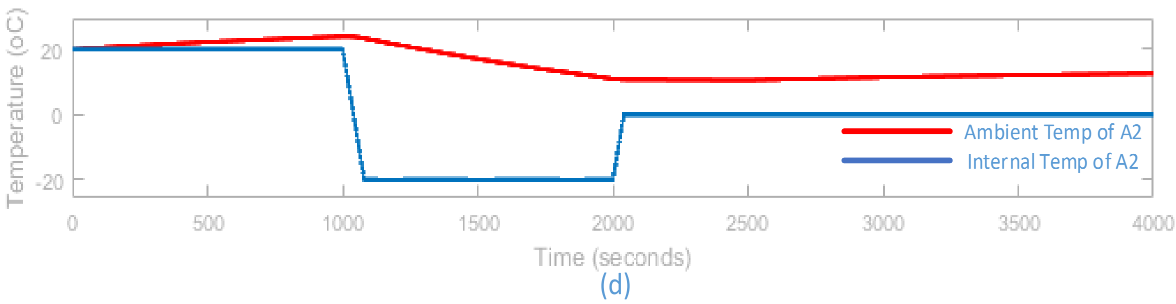


Fig 7: (a) Voltage, (b) Current, (c) SOC, (d) Temperature: for Lithium-ion battery simulations with, and without temperature effects

From Figure 7 the simulation results of two LIBs models is shown. LIB *A2*is simulated when subjected to an ambient temperature from -20ºC to 20ºC, while in the case of battery *A1*, the effect of temperature is neglected. From the signals it will be noticed that discharge voltage *V* of both batteries *A1* and *A2* keeps decreasing, the same with *SOC (%)* up to around the *t=2500*, at constant current *2A*, where the temperature is set to be 20ºC.
At *t=2500*, the discharge has reached the maximum discharge voltage, and then charging start to take place. Here the two batteries have minimum realized *SOC* and as charging starts the batteries *SOC (%)* starts to increase. The performance shows that the *SOC* does not come below 75%, which is the minimum *SOC* for the batteries to operate well.
The heat loss from the discharge process, at t = 1500, causes the internal temperature to increase to its steady state value of around 26ºC, causing a slight increase in the output voltage of Battery *A2*, while battery *A1* output voltage continues to decrease steadily since it is not affected by the ambient temperature.
At t = 1100 s, the ambient temperature is decreased to -20ºC leading to a great decrease of the output voltage of Battery *A2* as the internal temperature decreases rapidly. Consequently the SOC of Battery *A2* decreases due to the reduction of battery capacity, on the other hand the output voltage of battery *A1* continues to decrease slowly to its steady voltage state.
At *t = 2100*, the ambient temperature is increased from -20 degrees C to 0 degrees C. As the internal temperature increases, the output voltage of Battery *A2* increases. Also, as the capacity increases, the SOC of Battery A increases. The Battery *A1* output voltage remains constant to its steady state value.
At t = 2500 s, the Battery *A1* and *A2* are charged with 3A at ambient temperature of 0 degrees C. This causes the internal temperature to increase due to heat losses during the charge process, which increases the charging voltage of Battery *A2*. Thereafter battery *A1* and *A2* continue to charge up until they reach full charged state and slightly constant internal temperature.
To model a battery with three cells, the cell parameter and their corresponding parameter values for the cells in series and in parallel is shown in Table 3 below. Here basically for cells in series the nominal voltage of one cell is multiplied by the total number of battery cells while the capacity rating remains the same for one cell. For parallel cells the nominal voltage remains the same as for one cell while the capacity can be increased by multiplying the capacity for a single cell to the number of cells. For our study we put the number of cell *n=3.*
Therefore:
Total voltage for three cells in series = voltage for a single cell *3;
Total capacity for three cells in parallel = capacity for a single cell *3,
The physical representation of the battery cells connected in series and in parallel is shown in Figure 8.

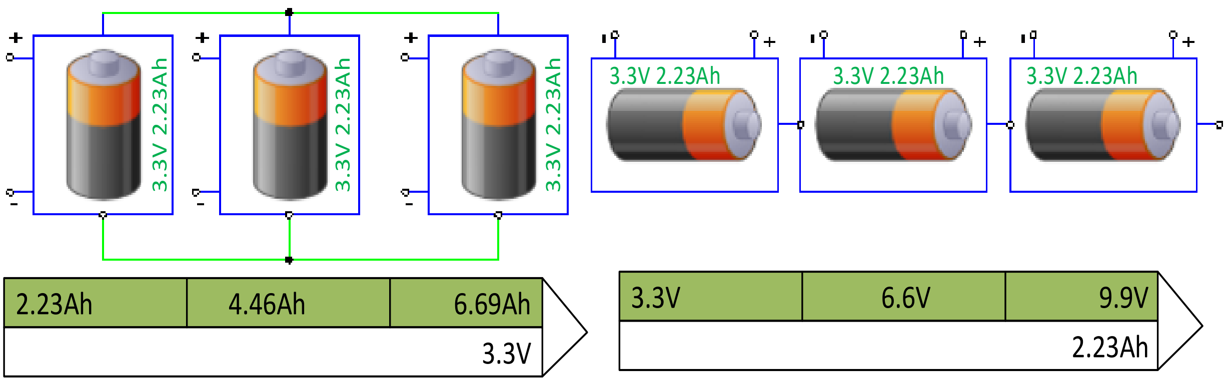


Fig 8: (a) connection of the batteries in parallel, (b) connection of batteries in series

From Fig.8 the batteries connected in parallel shows the capacity increase with constant voltage, while the batteries connected in series shows the voltage increase with constant capacity. So in any connection to realize maximum or high voltage and high capacity, it is recommended to have a blend of series and parallel connection. For a typical pure electric vehicle, BMWi3 a total of 96 battery cells are installed. Twelve cells are combined into one module, and eight modules are put together in the form of a battery pack to go into the electric vehicle. Table 3 represents battery pack parameter values for LiFePO4 batteries that have voltage of 3.75V, thus a total nominal voltage for the 96 battery cells is 360V.

Table 3: Parameter values for series connected batteries of BMW i3 Electric Vehicle

Parameter	Value for Series connection
Nominal voltage	360V
Rated capacity	94Ah
Maximum capacity	94Ah
Cut-off voltage	270V
Full charge voltage	419.035V
Nominal discharge current	40.869A
Internal resistance	0.0383Ohms
Capacity at nominal voltage	85.009
Exponential zone[Voltage (V), Capacity (Ah)]	[388.9389 4.618261]
Discharge current (i1, i2, i3....)	[4.5 13.5 22.5]

To gain higher capacity and higher voltage, the parallel and series connections are blended together to obtain a hybrid kind of connection. However the interconnection of series and parallel connection is usually costly as it involves a lot of circuitry.

5. Conclusion

A Matlab/Simulink battery model dependent on temperature is has been proposed and validated to characterize the dynamic parameters of the battery. A battery model for LiFePO4 battery has been developed and the accuracy of the proposed model has been proven with experiment results. It is expected that the model can be usable in other types of batteries. This model in simulation platform will eventually accelerate the development of energy storage systems in the green energy technology applications. From the simulations the internal and ambient temperature have adverse effect in the battery chemistry. The voltage of battery A2, and its associated SOC dropped lower than that of the battery A1 without the temperature effect. This temperature rise or drop for batteries can some damage of the batteries if it is not controlled. Batteries for EVs in hot or cold environments should therefore be guarded from the drastic change in temperature to avoid their damage. For example forced air or water cooling should be applied to ensure that the LIBs operates under ideal temperatures to avoid damages and costs associated with the procurement of new batteries.

Conflict of Interest: The Author declares that there is no conflict of interest regarding the publication of this paper.

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