1. Title- Lithium-ion battery thermal and aging model.

2. Objective –

- Design battery pack to simulate temperature effect on battery age.
- To simulate model for effect on battery at various charge and discharge rate and analyse the result.

3. Introduction –

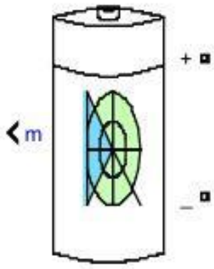
The electric vehicle is becoming popular because they have many benefits over conventional vehicle and green energy solution is most crucial one. The automobile industry has continued to develop various alternative fuel options, on o them is battery. The performance of electric vehicle closely depends on the battery pack and its design and it must be able to supply enough current for motor. Since single cell produces low voltage and has low capacity, in electric vehicle hundreds of cells can be connected in series to get high voltage and they can be connected into parallel to get high capacity. Lithium-ion batteries are mostly used in electric vehicle since they have high energy density and some other benefits over other types of cell, so battery pack is one of most important component of electric vehicle and it should be maintained for optimum performance because it is very sensitive to temperature, charge and discharge current etc.

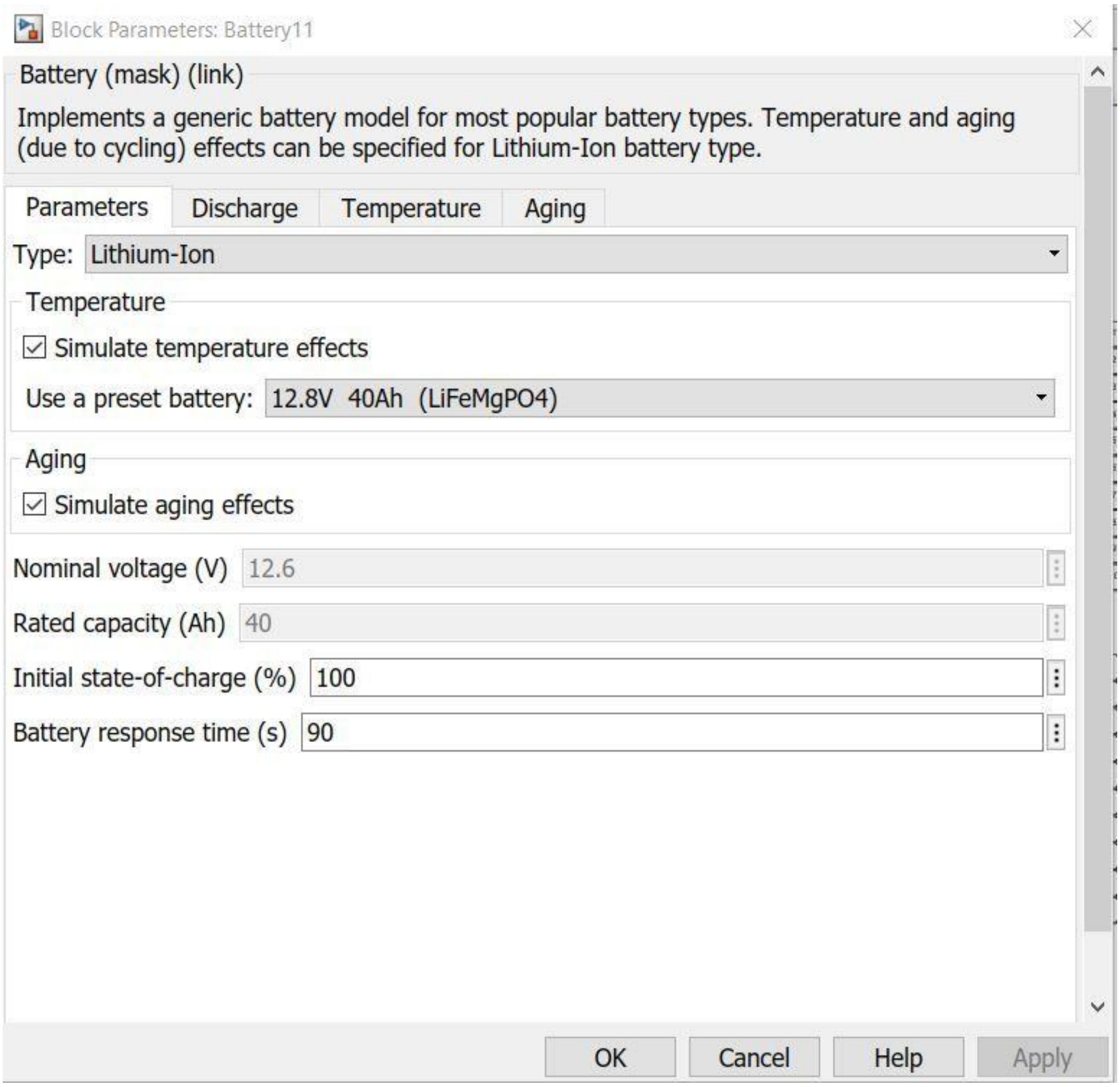
4. Description –

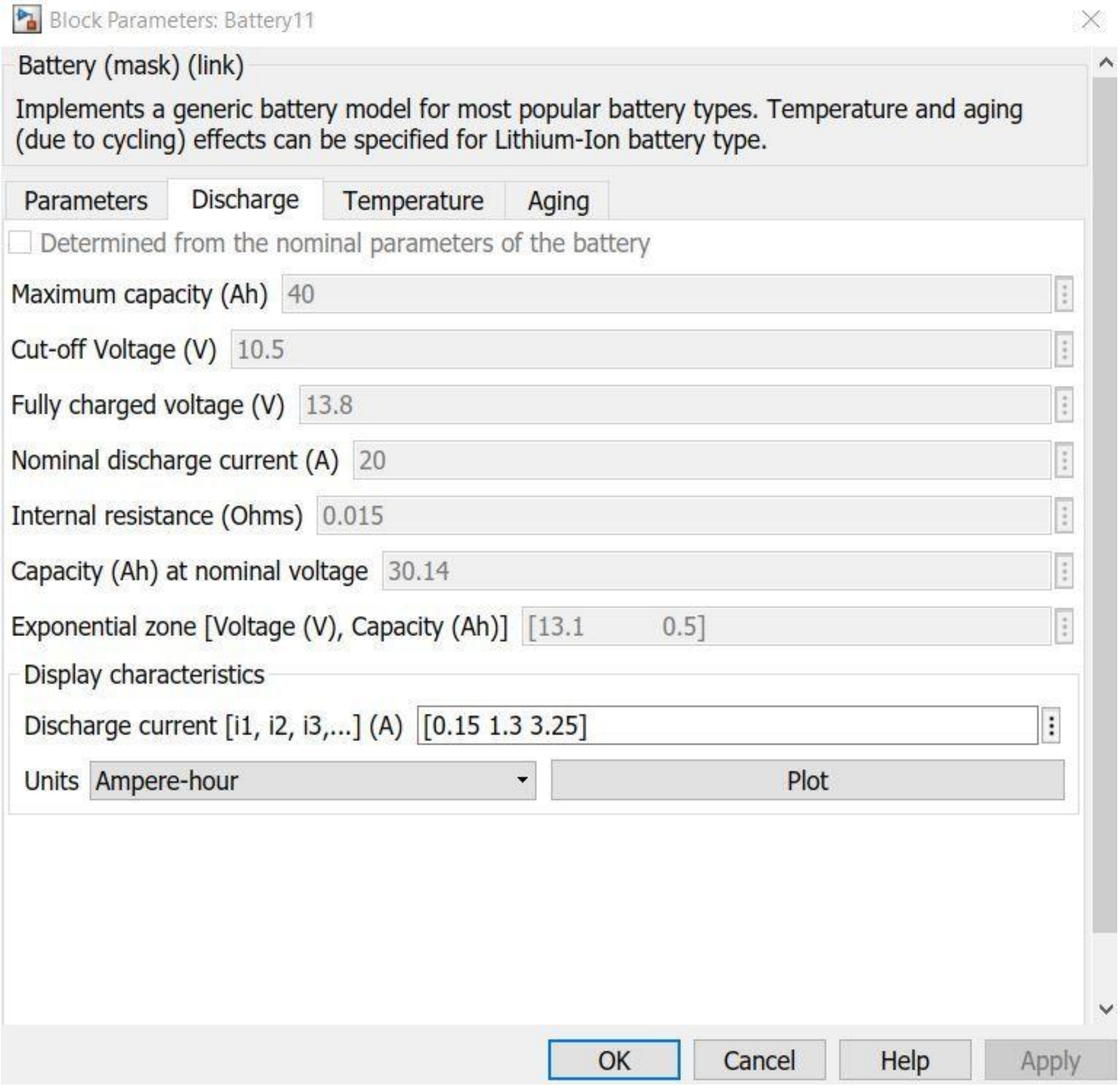
Simulation is an imitation of a real-world thing or thighs that are going to be real. Simulation is done for many purposes like for performance assessment, safety, testing etc. Simulation saves time, cost and efforts. In this project we are going to design the battery pack first and simulate for effect of temperature, charging and discharging result on age of battery. We will make a battery pack which consists 10 cells connected in series. In series connection current and capacity remains the same and voltage is the sum of cell voltage. Model will designed with two subsystems one will be battery pack and other one will be cycle generator.

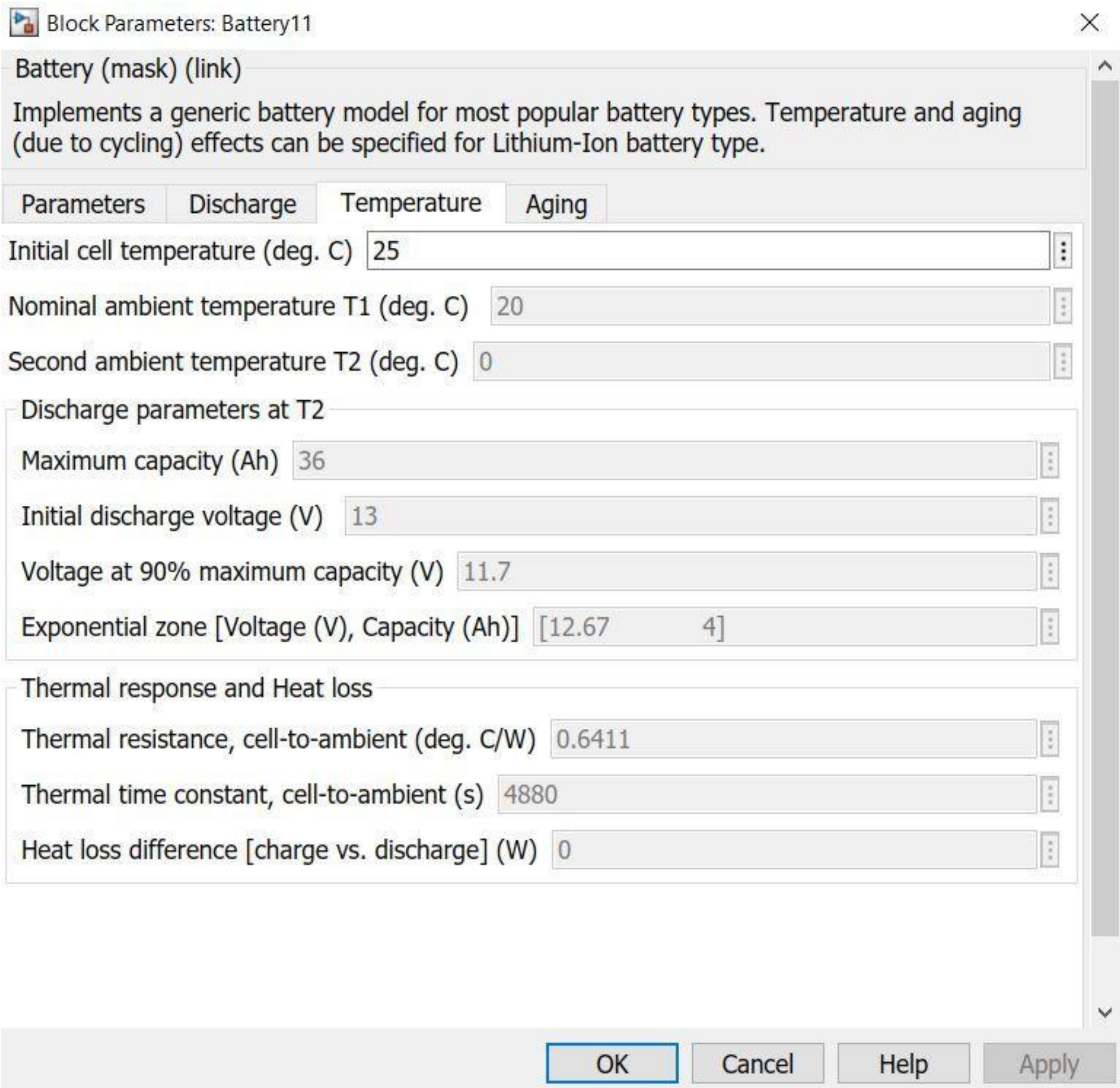
Blocks used –

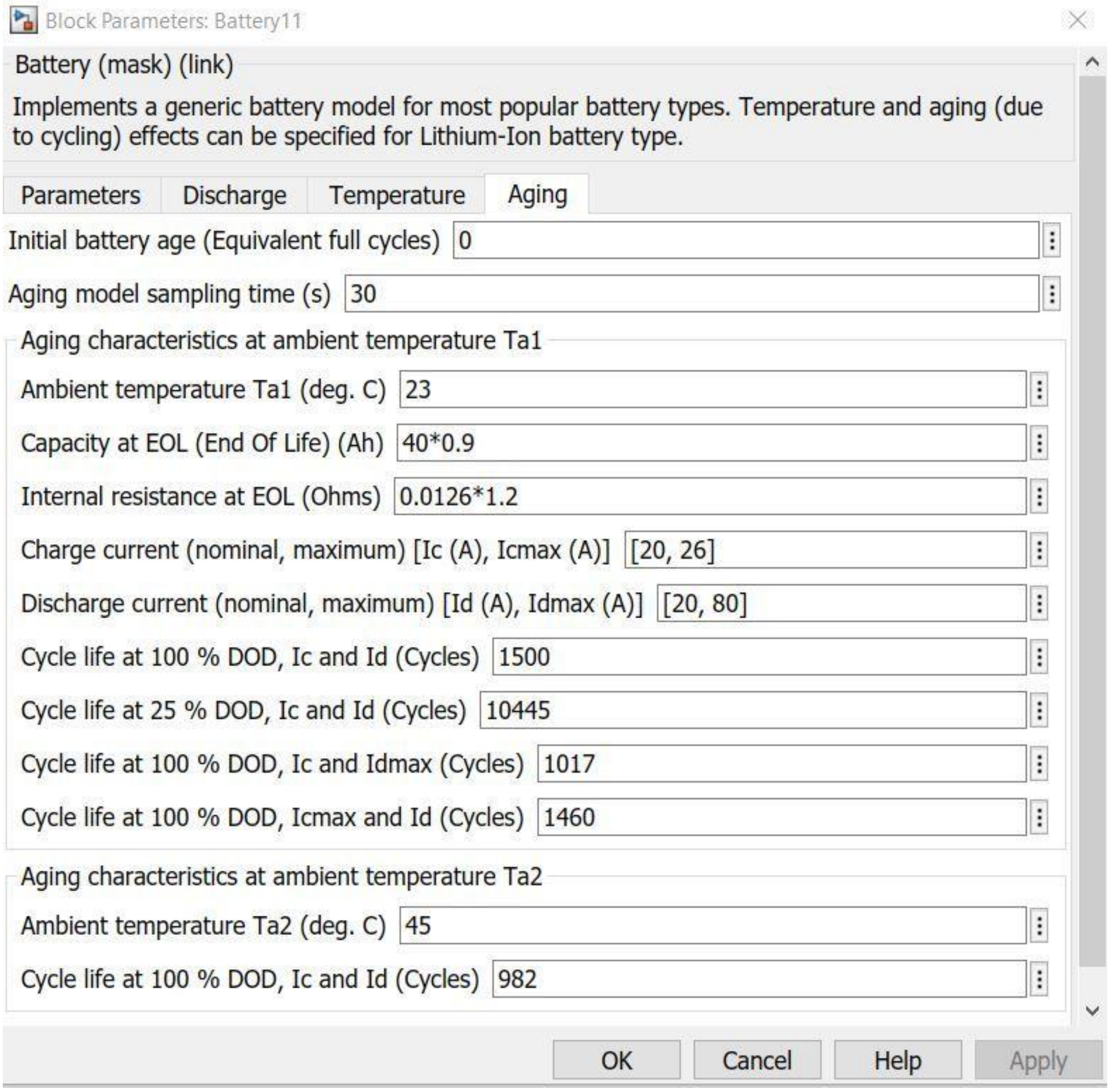
Battery – This block implements a generic battery model for most popular batteries like li-ion, Nickel-Cadmium, Lead-Acid and Nickel metal Hydrite. It is a equivalent circuit model and it can be simulated with various parameters related to battery aging, battery temperature, discharge and charge. This model has three input ports two of them are positive and negative which is connected with a controlled current source and third one take temperature values, when we want to simulate temperature effects.




Block Parameters: Battery11
Battery (mask) (link)
Implements a generic battery model for most popular battery types. Temperature and aging (due to cycling) effects can be specified for Lithium-Ion battery type.
Parameters
Discharge
Temperature
Aging
Type: Lithium-Ion
Temperature
Simulate temperature effects
Use a preset battery: 12.8V 40Ah (LiFeMgPO4)
Aging
Simulate aging effects
Nominal voltage (V) 12.6
Rated capacity (Ah) 40
Initial state-of-charge (%) 100
Battery response time (s) 90
OK
Cancel
Help
Apply

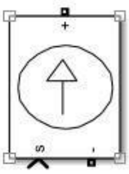

Block Parameters: Battery11
Battery (mask) (link)
Implements a generic battery model for most popular battery types. Temperature and aging (due to cycling) effects can be specified for Lithium-Ion battery type.
Parameters
Discharge
Temperature
Aging
Determined from the nominal parameters of the battery
Maximum capacity (Ah) 40
Cut-off Voltage (V) 10.5
Fully charged voltage (V) 13.8
Nominal discharge current (A) 20
Internal resistance (Ohms) 0.015
Capacity (Ah) at nominal voltage 30.14
Exponential zone [Voltage (V), Capacity (Ah)] [13.1 0.5]
Display characteristics
Discharge current [i1, i2, i3,...] (A) [0.15 1.3 3.25]
Units Ampere-hour
Plot
OK
Cancel
Help
Apply


Block Parameters: Battery11
Battery (mask) (link)
Implements a generic battery model for most popular battery types. Temperature and aging (due to cycling) effects can be specified for Lithium-Ion battery type.
Parameters
Discharge
Temperature
Aging
Initial cell temperature (deg. C)
25
Nominal ambient temperature T1 (deg. C)
20
Second ambient temperature T2 (deg. C)
0
Discharge parameters at T2
Maximum capacity (Ah)
36
Initial discharge voltage (V)
13
Voltage at 90% maximum capacity (V)
11.7
Exponential zone [Voltage (V), Capacity (Ah)]
[12.67 4]
Thermal response and Heat loss
Thermal resistance, cell-to-ambient (deg. C/W)
0.6411
Thermal time constant, cell-to-ambient (s)
4880
Heat loss difference [charge vs. discharge] (W)
0
OK
Cancel
Help
Apply



For this project we are using lithium iron phosphate battery which has 12.6V nominal voltage and 40Ah rated capacity. Since we are using a preset battery, we can't alter temperature and discharge parameters. In aging parameters most are used default ones. The following images shows the full details of parameters along with block -

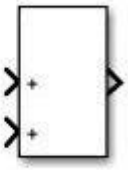
Controlled current source – This block converts input signal into equivalent current signal. This block can be used for AC or DC.



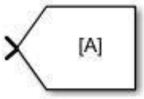
Matlab function – This block implements Matlab function. The input values can be given by constant block, stair block etc. the output values can be used by another block or they can be displayed.

Bus selector – This block helps use to select single information from a group basically a information bus. It has only one input port and output port changes according to information required.

Sum – using this block one can add and subtract input values. List of sign specifies number of inputs.

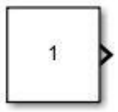


Goto – it passes the information to corresponding block. From and goto block should have same name tag to exchange information. Tag visibility can be changed between local and global. Information form goto block can be accessed anywhere in the model but goto block with local visibility tag is restricted to a subsystem or system in which it is used.

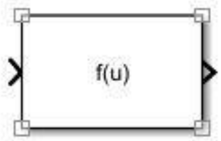


From – this block accepts signal from goto block which has same tag.

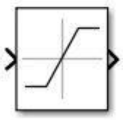
Constant – this block provides a constant signal input.



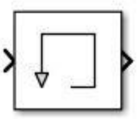
Fcn – this block implements a general algebraic expression.



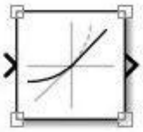
Saturation – this provides output signal by limiting input signal with upper and lower saturation values.



Memory – this block is used to delay input signal by one-time step. It takes one input and generates one output. This block can be used for discrete or continuous values.

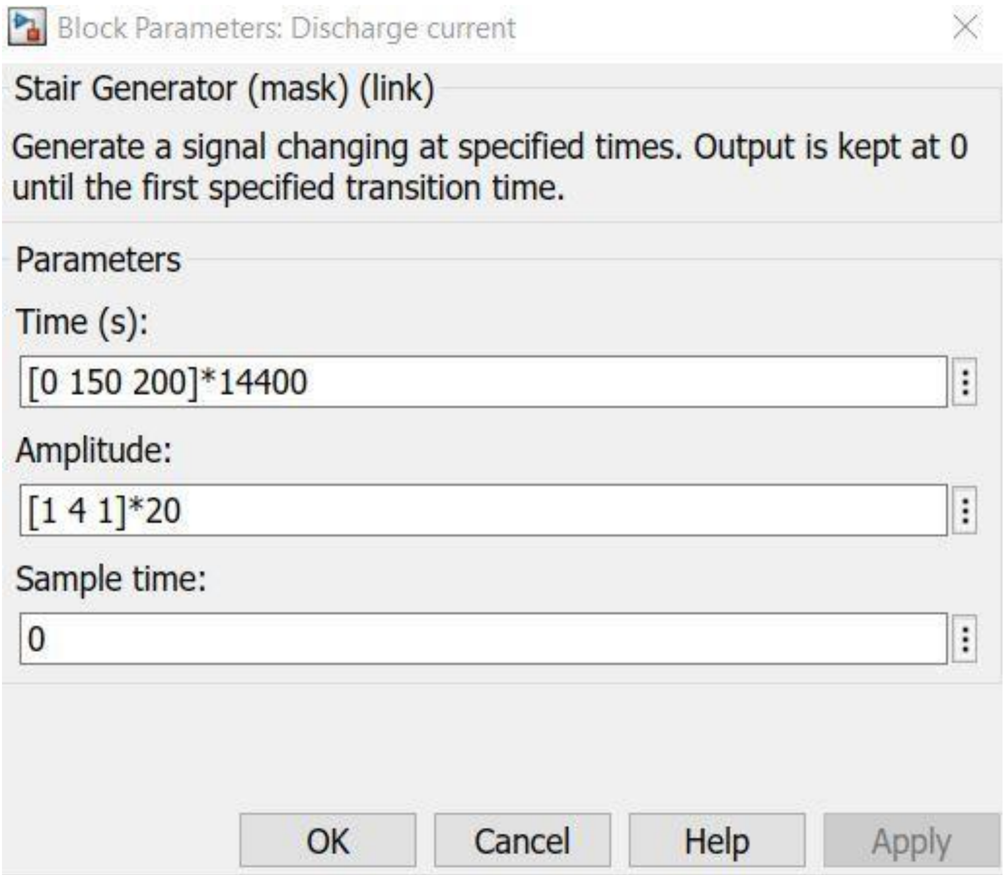


Rate limiter – this block limits the output with a specified limit.

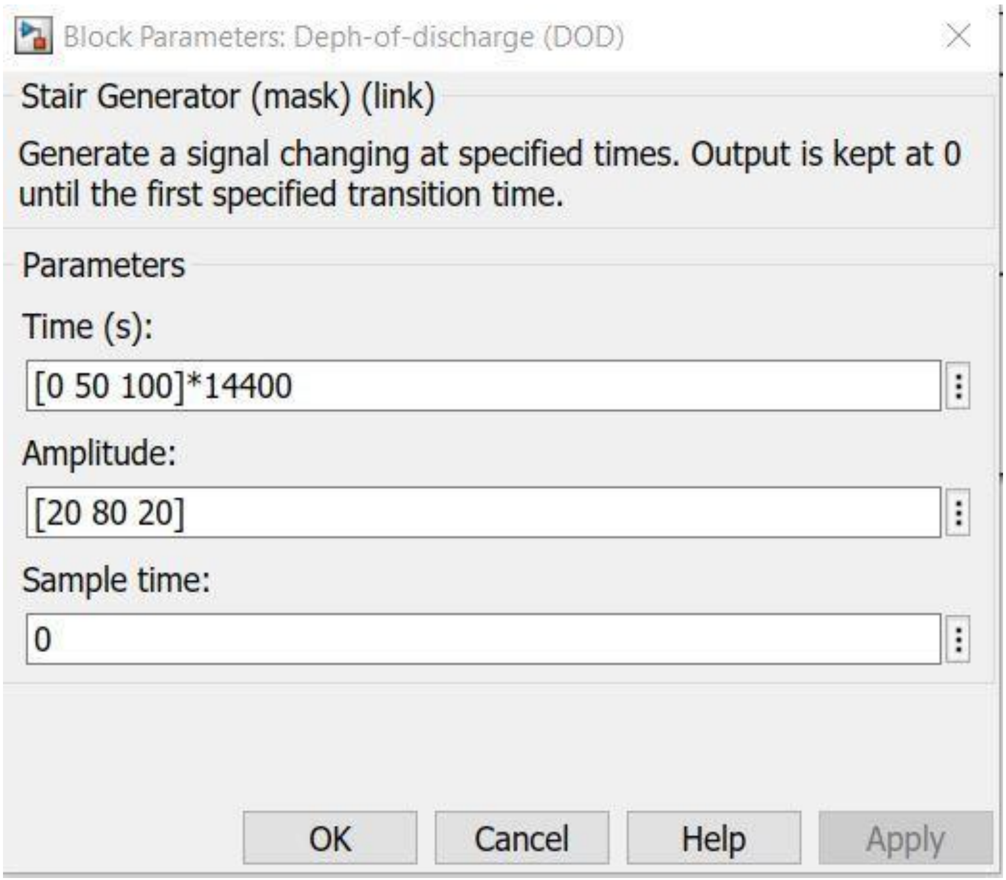


Stair generator – this block generates a stair with give time and amplitude values.

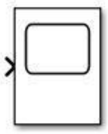
Discharge current values using stair generator



Depth of dischrge values using stair generator

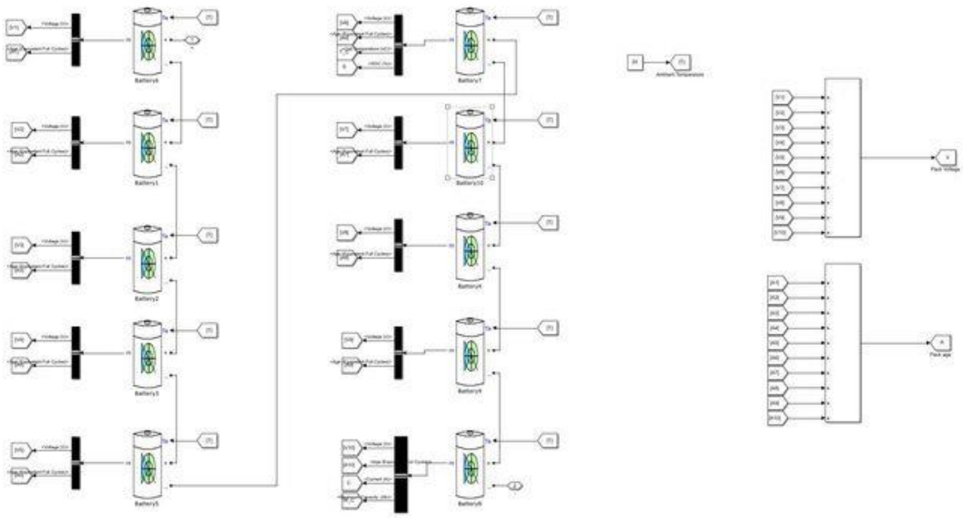


Scope – it displays generated signal.



Subsystems -

a. Battery Pack - This subsystem is generated with ten lithium-ion cells, which are connected in series connection. M port of cell model provides a bus of information, which is separated with bus selected. Goto block is used to give ambient temperature value to each cell and this block is used to pick voltage and life cycle values from each cell. Voltage and life cycle value is added with sum block, which is getting signal from, from block.



We are assuming that each cell develops same voltage, temperature and life cycle, so voltage of individual can be added to find pack level voltage, because they are connected in series connection. Similarly, life cycle can be also added for battery pack life cycle.

Pack level parameters –

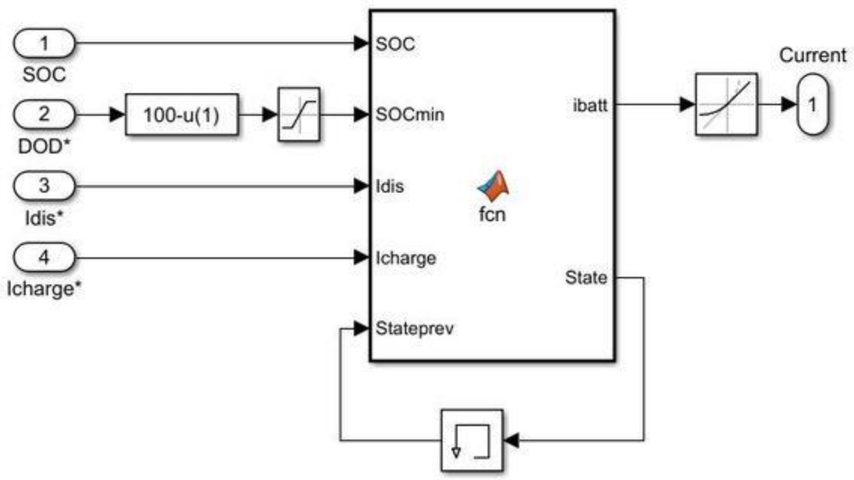
Battery pack nominal voltage = 10*12.6 = 126V

Battery nominal capacity = 40Ah

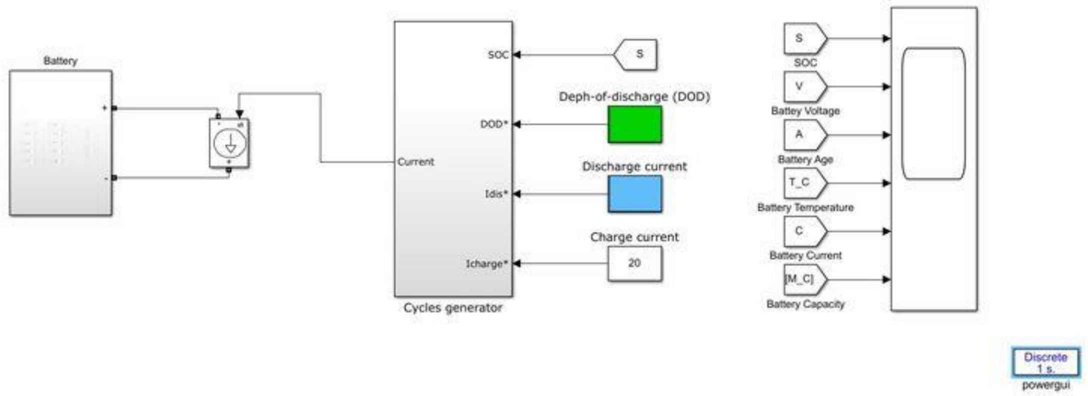
Battery discharge current (C rate) = 40amps

Battery internal resistance = 0.15ohm

b. Cycle generator – this subsystem has Matlab function block which generates current values according to value of state of charge, depth of discharge, charge current and discharge current. Generated value of current is directly feeded into controlled current source block.



Complete model -



Assumption -

Look at some assumption, which have taken into the account –

- All cells are providing same output voltage and they are discharged at constant current.
- Temperature rise of one cell can considered as temperature rise of whole battery pack, if we consider zeroth law of thermodynamics.
- State of charge of a cell is an indication of battery capacity at a particular time, so it will be more or less same with battery SOC.
- Cells are connected in series connection so we can consider current and capacity of signal cell can be considered equal to battery current and capacity.

- Cells have equal number of life cycles, so their sum can be considered as battery age.

Working of model –

First MATLAB script takes values of state of charge, depth of discharge, discharge current and discharge current values and generates battery current. Charging current is constant which is 20A and discharge current have three values [20 80 20] A at [0 2160000 2880000] seconds. Depth of discharge is [20 80 20] at [0 72000 1440000] seconds. State of charge values has taken from battery information port, it is more or less a feedback. Generated signal from MATLAB function block is converted into equivalent current signal by controlled current source block. Battery takes this signal and generates information like soc, battery voltage, current etc. the output of battery changes because is governed by different input values.

MATLAB script -

```
function [ibatt,State] = fcn(SOC,SOCmin,Idis,Icharge,Stateprev)

%#codegen

State=Stateprev;                    % set state

if(Stateprev==1 && SOC<=SOCmin)          % define condition for discharged battery

  State=0;

end

if(Stateprev==0 && SOC>=99)           % define condition for charged battery

  State=1;

end

if (Stateprev==1)                   % set battery current to discharge current when state is 1

  ibatt=Idis;

else

  ibatt=-Icharge;                   % set battery current to charge current when state is 0

end
```

Programme explanation –

1. A function has created with dependent variable - battery current and battery state and independent variable SOC, minimum SOC, previous state, discharge current and charge current.

2. Now set state to previous state which could be charged and discharged, we are going to check it further in program.

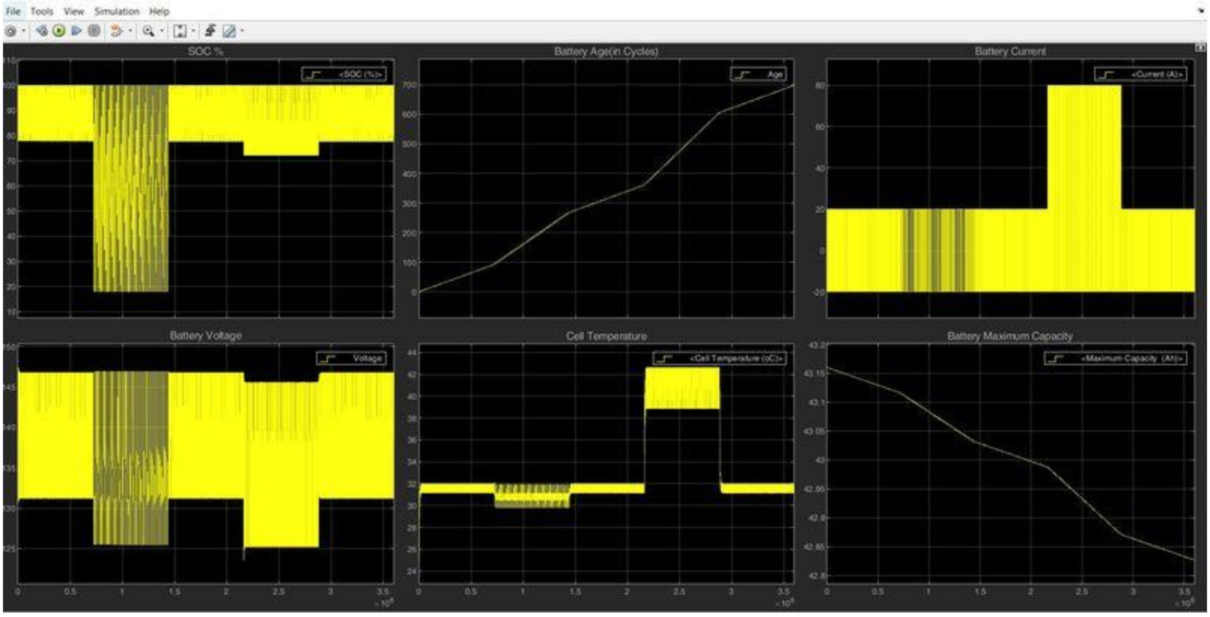
3. Use Condition statement to set state of charge. If previous state was 1(charged) and now SOC is below minimum SOC, set state equal to 0(discharged).

4. Use Condition statement again to set state of charge. If previous state was 0(discharged) and now SOC is above 99, set state equal to 1(charged).

5. Use conditional sentence to decide on battery current whether it have to give current or take current. If battery if previous state is 1 means it is able to give charge so set battery current to discharge current and if previous state is 0 means battery has drained it's all current and it need to be charged. It takes current value 20 which is given from constant block and it takes discharge current values from stair generator at different time.

Results –

The model has simulated for 1000hours (36e+5 seconds). The model has simulated to analyse the battery age at deep discharge and at various discharge rates. We can divide results into a group at different time range. Group means the result is going to same for whole time range.



1. At t =0s, Cycle starts and battery provides current at 0.5C rate means 20A . Till 200 hours battery provides current and its SOC becomes 80%. Ambient temperature is 25C given and in this time range battery temperature increase to 33C. During this battery's maximum capacity reduces to 43.12Ah from 43.16Ah and voltage fluctuates around 131V to 142V with a peak value of 146.V. the battery age increase to 92.34.

2. At t=200h, the battery is further discharge to 20% and it is charged to 100% in cyclic way for 200 hours. Now voltage fluctuates to grater depths from 126V to 146V and age of battery increases but rapidly if compare it to previous one. Now battery age is increased to 268.3. Battery maximum capacity further reduced to 43Ah. Battery current 20A because it is discharged and charged at 0.5C rate. Temperature is more or less same because of same discharge current rate.

3. At t=400h, Now, battery SOC is brought back to 80% previously it was 100%. Battery age increase but slowly and get value 360.5. battery voltage fluctuates same as first case and current and temperature values are similar to first case. Battery capacity decreases further till value 42.99.

4. At t=600h, Now battery is drained at 2C rate means at 80A for next 200hours. SOC changes from 100 to 80 in cyclic manner because it a charge and discharge cycle. Battery maximum capacity falls rapidly to 42.87 and battery age increases to 605. Current fluctuates from 80A to -20A because discharge current is 80A and charge current is 20A. Voltage fluctuates to deeper

values from 146V to 125V. Battery temperature becomes 43C because of high discharge current.

5.At t=800h, the discharge current bought back to 20A, so SOC at end of next 200h is 80%.Battery voltage, temperature and current has same values as in case 1. Battery age increases slowly to 698.2 and battery maximum capacity further reduces to 42.83Ah.

5. Conclusion -

The battery pack is significant part of electric vehicle. As demand increasing there is a requirement of batter performance in terms of reduced weight and cost, battery driving range and performance. In this project we saw how temperature, charge and discharge current is closely associate with life cycle of battery. Battery pack provide optimum range if they are used under some circumstances. Our model proved some theory like battery temperature increase at high rate of discharge current and charge and discharge rate significantly effects life cycle of battery.