**Advanced Energy Storage Systems Project**



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2022

**(a)SOC-OCV Data plotting:**

The general code for plotting the given data table is shown blow. The x-axis and y-axis are SOC and OCV of the respective battery (1,2,3 and 4).

**Table

Description automatically generated**

clc

clear

load Data. Mat

%Converting the given table into array. This way we convert it into a matrix with 32 rows and 8 columns.

data= table2array (Data);

Battery1SOC= data (1:32,1);

Battery1OCV= data (1:32,2);

Battery2SOC= data (1:32,3);

Battery2OCV= data (1:32,4);

Battery3SOC= data (1:32,5);

Battery3OCV= data (1:32,6);

Battery4SOC= data(1:32,7);

Battery4OCV= data(1:32,8);

%Figure1 (1 to 4)

figure;

subplot(2,2,1);

plot(Battery1SOC,Battery1OCV)

grid on

subplot(2,2,2);

plot(Battery2SOC,Battery2OCV);

grid on

subplot(2,2,3);

plot(Battery3SOC,Battery3OCV);

grid on

subplot(2,2,4);

plot(Battery4SOC,Battery4OCV);

grid on

Graphs :

Chart, line chart

Description automatically generated

**(b) Plot OCV-SOC model (s vs. V◦(s) for all 8 models)**

In the following code, the s vs V◦(s) is considered using two ways. Initially, the s values are scaled for 32 iterations in order to find the ‘k’ values.

Secondly, the scaled s value has been graphed along with the voltage values, for s from 0 to 1 with 1000 steps in between.

Battery Modelling:

Battery modelling is necessary for the efficient development of BMS.The reason for considering mathematical modelling of a battery is the significance of accuracy they have, when compared with the equivalent circuit models. These models track the non-linear relationship between the battery's real-time operation and the discharge rate without considering the recovery impact [1].

In the current project different models have been discussed. The observations and measurements have been made using MATLAB algorithm and programming from given OCV(Open circuit voltage ) and SOC( State of charge) data of four different batteries.

**1.Linear Model:**

**Description:**

**Code:**

%**All the even numbered graphs in the subplot belong to (s vs v1) [0,1])-Linear model**

E=0.175.

%Plotting **Battery1SOC Vs V1** using 32 values of s for **Linear model (Battery 1)**

ScaledSOCb1= ((1-(2\*E)) \*Battery1SOC) + E;

for i=1:32

b1(i, :)= [1 ScaledSOCb1(i)];

end

k= ((b1'\*b1) ^(-1)) \*(b1'\*Battery1OCV);

V1=b1\*k;

figure;

subplot (4,2,1)

plot (Battery1SOC, V1)

**%Plotting s vs v1 belongs where s belongs to [0,1] for Linear Model (Battery 1)**

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

for i=1:1001

b11(i,:)=[1 s\_dash(i)];

end

v1=b11\*k ;

subplot(4,2,2)

plot(s,v1)

%Plotting **Battery2SOC Vs V2** using 32 values of s for **Linear model(Battery 2)**

ScaledSOCb2= ((1-(2\*E))\*Battery2SOC)+ E;

for i=1:32

b2(i,:)=[1 ScaledSOCb2(i)];

end

k= ((b2'\*b2)^(-1))\*(b2'\*Battery2OCV);

V2=b2\*k ;

subplot(4,2,3)

plot(V2,Battery2SOC)

**%Plotting s vs v2 belongs where s belongs to [0,1] for Linear Model (Battery2)**

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

for i=1:1001

b12(i,:)=[1 s\_dash(i)];

end

v2=b12\*k ;

subplot(4,2,4)

plot(s,v2)

**%Plotting** **Battery3SOC Vs V3** using 32 values of s for **Linear model(Battery 3)**

ScaledSOCb3= ((1-(2\*E))\*Battery3SOC)+ E;

for i=1:32

b3(i,:)=[1 ScaledSOCb3(i)];

end

k= ((b3'\*b3)^(-1))\*(b3'\*Battery3OCV);

V3=b3\*k ;

subplot(4,2,5)

plot(V3,Battery3SOC)

**%Plotting s vs v3 belongs where s belongs to [0,1] for Linear Model(Battery3)**

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

for i=1:1001

b13(i,:)=[1 s\_dash(i)];

end

v3=b13\*k ;

subplot(4,2,6)

plot(s,v3)

**%Plotting** **Battery4SOC Vs V4** using 32 values of s for **Linear model(Battery 4)**

ScaledSOCb4= ((1-(2\*E))\*Battery4SOC)+ E;

for i=1:32

b4(i,:)=[1 ScaledSOCb4(i)];

end

k= ((b4'\*b4)^(-1))\*(b4'\*Battery4OCV);

V4=b4\*k ;

subplot(4,2,7)

plot(V4,Battery4SOC)

**%Plotting s vs v4 belongs where s belongs to [0,1] for Linear Model(Battery4)**

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

for i=1:1001

b14(i,:)=[1 s\_dash(i)];

end

v4=b14\*k ;

subplot(4,2,8)

plot(s,v4)

**Error Graphs:**

**Graphical user interface

Description automatically generated**

**Chart, line chart

Description automatically generated**

**Conclusion:**

**2.Shepherd Model:**

**Description:**

**Code:**

E=0.175;

**%Plotting** **Battery1SOC Vs V1** using 32 values of s for **Shepherd model(Battery 1)**

ScaledSOCb1= ((1-(2\*E))\*Battery1SOC)+ E;

for i=1:32

b1(i,:)=[1 1/ScaledSOCb1(i)];

end

k= ((b1'\*b1)^(-1))\*(b1'\*Battery1OCV);

V1=b1\*k ;

figure ;

subplot(4,2,1)

plot(Battery1SOC,V1)

% **Plotting s vs v1 belongs where s belongs to [0,1] for Shepherd Model(Battery1)**

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

for i=1:1001

b13(i,:)=[1 1/s\_dash(i)];

end

v1=b13\*k ;

subplot(4,2,2)

plot(s,v1)

**%Plotting** **Battery2SOC Vs V2** using 32 values of s for **Shepherd model(Battery 2)**

ScaledSOCb2= ((1-(2\*E))\*Battery2SOC)+ E;

for i=1:32

b2(i,:)=[1 1/ScaledSOCb2(i)];

end

k= ((b2'\*b2)^(-1))\*(b2'\*Battery2OCV);

V2=b2\*k ;

subplot(4,2,3)

plot(Battery1SOC,V2)

% **Plotting s vs v2belongs where s belongs to [0,1] for Shepherd Model (Battery2)**

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

for i=1:1001

b12(i,:)=[1 1/s\_dash(i)];

end

v2=b12\*k ;

subplot(4,2,4)

plot(s,v2)

**%Plotting** **Battery3SOC Vs V3** using 32 values of s for **Shepherd model(Battery 3)**

ScaledSOCb3= ((1-(2\*E))\*Battery3SOC)+ E;

for i=1:32

b3(i,:)=[1 1/ScaledSOCb3(i)];

end

k= ((b3'\*b3)^(-1))\*(b3'\*Battery3OCV);

V3=b3\*k ;

subplot(4,2,5)

plot(Battery3SOC,V3)

% **Plotting s vs v3 belongs where s belongs to [0,1] for Shepherd Model (Battery3)**

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

for i=1:1001

b13(i,:)=[1 1/s\_dash(i)];

end

v3=b13\*k ;

subplot(4,2,6)

plot(s,v3)

**%Plotting** **Battery4SOC Vs V4** using 32 values of s for **Shepherd model(Battery 4)**

ScaledSOCb4= ((1-(2\*E))\*Battery4SOC)+ E;

for i=1:32

b4(i,:)=[1 1/ScaledSOCb4(i)];

end

k= ((b4'\*b4)^(-1))\*(b4'\*Battery4OCV);

V4=b4\*k ;

subplot(4,2,7)

plot(Battery4SOC,V4)

% **Plotting s vs v4 belongs where s belongs to [0,1] for Shepherd Model (Battery4)**

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

for i=1:1001

b14(i,:)=[1 1/s\_dash(i)];

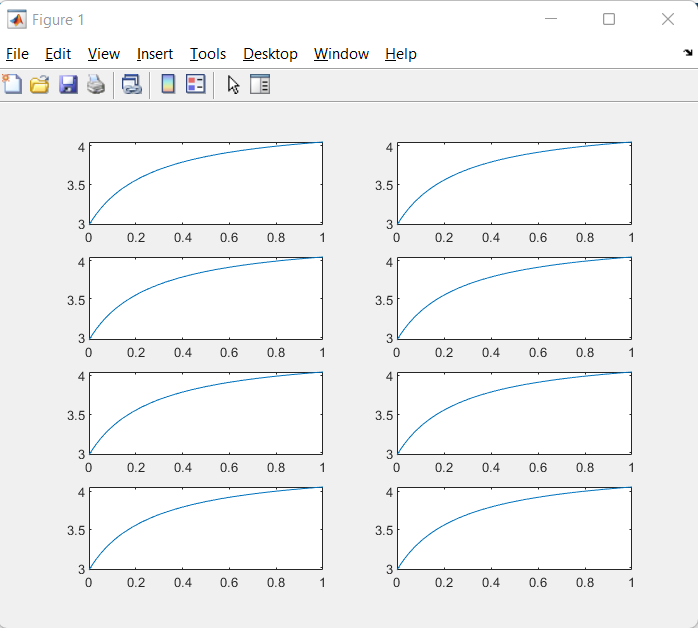
end

v4=b14\*k ;

subplot(4,2,8)

plot(s,v4)

**Graphs:**



**Error graph:**

**Graphical user interface

Description automatically generated**

**3.Nernst Model:**

**Description:**

**Code:**

E=0.175;

**%Plotting** **Battery1SOC Vs V1** using 32 values of s for **Nernst model(Battery 1)**

ScaledSOCb1= ((1-(2\*E))\*Battery1SOC)+ E;

b1=zeros(32,3);

for i=1:32

b1(i,:)=[1 log(ScaledSOCb1(i)) log(1-(ScaledSOCb1(i)))];

end

k= ((b1'\*b1)^(-1))\*(b1'\*Battery1OCV);

V1=b1\*k ;

figure;

subplot(4,2,1)

plot(Battery1SOC,V1)

% **Plotting s vs v1 belongs where s belongs to [0,1] for Shepherd Model (Battery1)**

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

b11=zeros(32,3);

for i=1:1001

b11(i,:)=[1 log(s\_dash(i)) log(1-(s\_dash(i)))];

end

v1=b11\*k ;

subplot(4,2,2)

plot(s,v1)

**%Plotting** **Battery2SOC Vs V2** using 32 values of s for **Nernst model(Battery 2)**

ScaledSOCb2= ((1-(2\*E))\*Battery2SOC)+ E;

b2=zeros(32,3);

for i=1:32

b2(i,:)=[1 log(ScaledSOCb2(i)) log(1-(ScaledSOCb2(i)))];

end

k= ((b2'\*b2)^(-1))\*(b2'\*Battery2OCV);

V2=b2\*k ;

subplot(4,2,3)

plot(Battery2SOC,V2)

% **Plotting s vs v2 belongs where s belongs to [0,1] for Nernst Model (Battery2)**

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

b12=zeros(32,3);

for i=1:1001

b12(i,:)=[1 log(s\_dash(i)) log(1-(s\_dash(i)))];

end

v2=b12\*k ;

subplot(4,2,4)

plot(s,v2)

**%Plotting** **Battery3SOC Vs V3** using 32 values of s for **Nernst model(Battery 3)**

ScaledSOCb3= ((1-(2\*E))\*Battery3SOC)+ E;

b3=zeros(32,3);

for i=1:32

b3(i,:)=[1 log(ScaledSOCb3(i)) log(1-(ScaledSOCb3(i)))];

end

k= ((b3'\*b3)^(-1))\*(b3'\*Battery3OCV);

V3=b3\*k ;

subplot(4,2,5)

plot(Battery3SOC,V3)

% **Plotting s vs v3 belongs where s belongs to [0,1] for Nernst Model (Battery3)**

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

b13=zeros(32,3);

for i=1:1001

b13(i,:)=[1 log(s\_dash(i)) log(1-(s\_dash(i)))];

end

v3=b13\*k ;

subplot(4,2,6)

plot(s,v3)

**%Plotting** **Battery4SOC Vs V4** using 32 values of s for **Nernst model(Battery 4)**

ScaledSOCb4= ((1-(2\*E))\*Battery4SOC)+ E;

b4=zeros(32,3);

for i=1:32

b4(i,:)=[1 log(ScaledSOCb4(i)) log(1-(ScaledSOCb4(i)))];

end

k= ((b4'\*b4)^(-1))\*(b4'\*Battery4OCV);

V4=b4\*k ;

subplot(4,2,7)

plot(Battery4SOC,V4)

% **Plotting s vs v4 belongs where s belongs to [0,1] for Nernst Model (Battery4)**

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

b14=zeros(32,3);

for i=1:1001

b14(i,:)=[1 log(s\_dash(i)) log(1-(s\_dash(i)))];

end

v4=b14\*k ;

subplot(4,2,8)

plot(s,v4)

**Code for calculating errors:**

**Graphs:**

**Line chart

Description automatically generated**

**Error graphs:**

**Graphical user interface

Description automatically generated with medium confidence**

**4.Combined model:**

**Description:**

**Code:**

**%Plotting** **Battery1SOC Vs V1** using 32 values of s for **Combined model(Battery 1)**

E=0.175;

ScaledSOCb1= ((1-(2\*E))\*Battery1SOC)+ E;

b1=zeros(32,5);

for i=1:32

b1(i,:)=[1 1/(ScaledSOCb1(i)) ScaledSOCb1(i) log(ScaledSOCb1(i)) log(1-ScaledSOCb1(i))];

end

k= ((b1'\*b1)^(-1))\*(b1'\*Battery1OCV);

V1=b1\*k ;

figure;

subplot(2,2,1)

plot(Battery1SOC,V1)

% **Plotting s vs v1 belongs where s belongs to [0,1] for Combined Model (Battery1)**

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

b11=zeros(32,5);

for i=1:1001

b11(i,:)=[1 1/(s\_dash(i)) s\_dash(i) log(s\_dash(i)) log(1-s\_dash(i))];

end

v1=b11\*k ;

subplot(4,2,6)

plot(s,v1)

**%Plotting** **Battery1SOC Vs V1** using 32 values of s for **Combined model(Battery 1)**

ScaledSOCb2= ((1-(2\*E))\*Battery2SOC)+ E;

b2=zeros(32,5);

for i=1:32

b2(i,:)=[1 1/(ScaledSOCb2(i)) (ScaledSOCb2(i)) log(ScaledSOCb2(i)) log(1-ScaledSOCb2(i))];

end

k= ((b2'\*b2)^(-1))\*(b2'\*Battery2OCV);

V2=b2\*k ;

subplot(2,2,2)

plot(Battery2SOC,V2)

% **Plotting s vs v2 belongs where s belongs to [0,1] for Combined Model (Battery2)**

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

b12=zeros(32,5);

for i=1:1001

b12(i,:)=[1 1/(s\_dash(i)) s\_dash(i) log(s\_dash(i)) log(1-s\_dash(i))];

end

v2=b12\*k ;

subplot(4,2,6)

plot(s,v2)

**%Plotting** **Battery3SOC Vs V3** using 32 values of s for **Combined model(Battery 3)**

ScaledSOCb3= ((1-(2\*E))\*Battery3SOC)+ E;

b3=zeros(32,5);

for i=1:32

b3(i,:)=[1 1/(ScaledSOCb3(i)) (ScaledSOCb3(i)) log(ScaledSOCb3(i)) log(1-(ScaledSOCb3(i)))];

end

k= ((b3'\*b3)^(-1))\*(b3'\*Battery3OCV);

V3=b3\*k ;

subplot(2,2,3)

plot(Battery3SOC,V3)

% **Plotting s vs v3 belongs where s belongs to [0,1] for Combined Model (Battery3)**

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

b13=zeros(32,5);

for i=1:1001

b13(i,:)=[1 1/(s\_dash(i)) s\_dash(i) log(s\_dash(i)) log(1-s\_dash(i))];

end

v3=b13\*k ;

subplot(4,2,6)

plot(s,v3)

**%Plotting** **Battery4SOC Vs V4** using 32 values of s for **Combined model(Battery 4)**

ScaledSOCb4= ((1-(2\*E))\*Battery4SOC)+ E;

b4=zeros(32,5);

for i=1:32

b4(i,:)=[1 1/(ScaledSOCb4(i)) (ScaledSOCb4(i)) log(ScaledSOCb4(i)) log(1-(ScaledSOCb4(i)))];

end

k= ((b4'\*b4)^(-1))\*(b4'\*Battery4OCV);

V4=b4\*k ;

subplot(2,2,4)

plot(Battery4SOC,V4)

% **Plotting s vs v4 belongs where s belongs to [0,1] for Combined Model (Battery4)**

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

b14=zeros(32,5);

for i=1:1001

b14(i,:)=[1 1/(s\_dash(i)) s\_dash(i) log(s\_dash(i)) log(1-s\_dash(i))];

end

v4=b14\*k ;

subplot(4,2,6)

plot(s,v4)

**Code for calculating errors:**

N=32;

M=length(k);

Vbarb1\_Combinedmodel=sum(V1)/N;

%Calculation of BF

BFb1\_Combinedmodel=(1-(norm(V1-Battery1OCV)/norm(Battery1OCV-Vbarb1\_Combinedmodel)))\*100;

%Calculation of R^2

R2b1\_Combinedmodel=(1-(((norm(V1-Battery1OCV))^2/((norm(Battery1OCV-Vbarb1\_Combinedmodel))^2))))\*100;

%Calculation of ME

MEb1\_Combinedmodel=max(abs(Battery1OCV-V1));

%Calculation of RMS

RMSb1\_Combinedmodel=norm(Battery1OCV-V1)/sqrt(N-M);

errorb1\_polynomial=abs(Battery1OCV-V1);

%Calculation of AIC

S2b1\_Combinedmodel=sum(errorb1\_polynomial.^2);

AICb1\_Combinedmodel=(N\*(log(S2b1\_Combinedmodel/N)))+(2\*(M+1));

figure;

subplot(2,2,1)

plot(Battery1SOC,errorb1\_polynomial)

%Calculation of Vbar for Battery 2 Combined model

N=32;

M=length(k);

Vbarb2\_Combinedmodel=sum(V2)/N;

%Calculation of BF

BFb2\_Combinedmodel=(1-(norm(V2-Battery2OCV)/norm(Battery2OCV-Vbarb2\_Combinedmodel)))\*100;

%Calculation of R^2

R2b2\_Combinedmodel=(1-(((norm(V2-Battery2OCV))^2/((norm(Battery2OCV-Vbarb2\_Combinedmodel))^2))))\*100;

%Calculation of ME

MEb2\_Combinedmodel=max(abs(Battery2OCV-V2));

%Calculation of RMS

RMSb2\_Combinedmodel=norm(Battery2OCV-V2)/sqrt(N-M);

errorb2\_Combinedmodel=abs(Battery2OCV-V2);

%Calculation of AIC

S2b2\_Combinedmodel=sum(errorb2\_Combinedmodel.^2);

AICb2\_Combinedmodel=(N\*(log(S2b2\_Combinedmodel/N)))+(2\*(M+1));

subplot(2,2,2)

plot(Battery2SOC,errorb2\_Combinedmodel)

%Calculation of Vbar for Battery 3 Combined model

N=32;

M=length(k);

Vbarb3\_Combinedmodel=sum(V3)/N;

%Calculation of BF

BFb3\_Combinedmodel=(1-(norm(V3-Battery3OCV)/norm(Battery3OCV-Vbarb3\_Combinedmodel)))\*100;

%Calculation of R^2

R2b3\_Combinedmodel=(1-(((norm(V3-Battery3OCV))^2/((norm(Battery3OCV-Vbarb3\_Combinedmodel))^2))))\*100;

%Calculation of ME

MEb3\_Combinedmodel=max(abs(Battery3OCV-V3));

%Calculation of RMS

RMSb3\_Combinedmodel=norm(Battery3OCV-V3)/sqrt(N-M);

errorb3\_Combinedmodel=abs(Battery3OCV-V3);

%Calculation of AIC

S2b3\_Combinedmodel=sum(errorb3\_Combinedmodel.^2);

AICb3\_Combinedmodel=(N\*(log(S2b3\_Combinedmodel/N)))+(2\*(M+1));

subplot(2,2,3)

plot(Battery3SOC,errorb3\_Combinedmodel)

%Calculation of Vbar for Battery 4 Combined model

N=32;

M=length(k);

Vbarb4\_Combinedmodel=sum(V4)/N;

%Calculation of BF

BFb4\_Combinedmodel=(1-(norm(V4-Battery4OCV)/norm(Battery4OCV-Vbarb4\_Combinedmodel)))\*100;

%Calculation of R^2

R2b4\_Combinedmodel=(1-(((norm(V4-Battery4OCV))^2/((norm(Battery4OCV-Vbarb4\_Combinedmodel))^2))))\*100;

%Calculation of ME

MEb4\_Combinedmodel=max(abs(Battery4OCV-V4));

%Calculation of RMS

RMSb4\_Combinedmodel=norm(Battery4OCV-V4)/sqrt(N-M);

errorb4\_Combinedmodel=abs(Battery4OCV-V4);

%Calculation of AIC

S2b4\_Combinedmodel=sum(errorb4\_Combinedmodel.^2);

AICb4\_Combinedmodel=(N\*(log(S2b4\_Combinedmodel/N)))+(2\*(M+1));

subplot(2,2,4)

plot(Battery4SOC,errorb4\_Combinedmodel)

**Graphs:**

**5.Combinedplus3 Model:**

**Description:**

**Code for s vs V(s):**

E=0.175;

% Plotting Battery1SOC vs V1-Combined+3 model

ScaledSOCb1= ((1-(2\*E))\*Battery1SOC)+ E;

b1=zeros(32,8);

for i=1:32

b1(i,:)=[1 1/(ScaledSOCb1(i)) ScaledSOCb1(i) 1/((ScaledSOCb1(i))^2) 1/((ScaledSOCb1(i))^3) 1/((ScaledSOCb1(i))^4) log(ScaledSOCb1(i)) log(1-ScaledSOCb1(i)) ];

end

k= ((b1'\*b1)^(-1))\*(b1'\*Battery1OCV);

V1=b1\*k ;

figure;

subplot(4,2,1)

plot(Battery1SOC,V1)

%Plotting using s vs v1 belongs to [0,1]-Battery 1-Combined model

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

b11=zeros(32,8);

for i=1:1001

b11(i,:)=[1 1/(s\_dash(i)) s\_dash(i) 1/((s\_dash(i))^2) 1/((s\_dash(i))^3) 1/((s\_dash(i))^4) log(s\_dash(i)) log(1-s\_dash(i)) ];

end

v1=b11\*k ;

subplot(4,2,2)

plot(s,v1)

% Plotting Battery2SOC vs V2-Combined+3 model

ScaledSOCb2= ((1-(2\*E))\*Battery2SOC)+ E;

b2=zeros(32,8);

for i=1:32

b2(i,:)=[1 1/(ScaledSOCb2(i)) ScaledSOCb2(i) 1/((ScaledSOCb2(i))^2) 1/((ScaledSOCb2(i))^3) 1/((ScaledSOCb2(i))^4) log(ScaledSOCb2(i)) log(1-ScaledSOCb2(i)) ];

end

k= ((b2'\*b2)^(-1))\*(b2'\*Battery2OCV);

V2=b2\*k ;

subplot(4,2,3)

plot(Battery2SOC,V2)

%Plotting using s vs v2 belongs to [0,1]-Battery 2-Combined model

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

b12=zeros(32,8);

for i=1:1001

b12(i,:)=[1 1/(s\_dash(i)) s\_dash(i) 1/((s\_dash(i))^2) 1/((s\_dash(i))^3) 1/((s\_dash(i))^4) log(s\_dash(i)) log(1-s\_dash(i)) ];

end

v2=b12\*k ;

subplot(4,2,4)

plot(s,v2)

% Plotting Battery3SOC vs V3-Combined+3 model

ScaledSOCb3= ((1-(2\*E))\*Battery3SOC)+ E;

b3=zeros(32,8);

for i=1:32

b3(i,:)=[1 1/(ScaledSOCb3(i)) ScaledSOCb3(i) 1/((ScaledSOCb3(i))^2) 1/((ScaledSOCb3(i))^3) 1/((ScaledSOCb3(i))^4) log(ScaledSOCb3(i)) log(1-ScaledSOCb3(i)) ];

end

k= ((b3'\*b3)^(-1))\*(b3'\*Battery3OCV);

V3=b3\*k ;

subplot(4,2,5)

plot(Battery3SOC,V3)

%Plotting using s vs v3 belongs to [0,1]-Battery 2-Combined model

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

b13=zeros(32,8);

for i=1:1001

b13(i,:)=[1 1/(s\_dash(i)) s\_dash(i) 1/((s\_dash(i))^2) 1/((s\_dash(i))^3) 1/((s\_dash(i))^4) log(s\_dash(i)) log(1-s\_dash(i)) ];

end

v3=b13\*k ;

subplot(4,2,6)

plot(s,v3)

% Plotting Battery4SOC vs V4-Combined+3 model

ScaledSOCb4= ((1-(2\*E))\*Battery4SOC)+ E;

b4=zeros(32,8);

for i=1:32

b4(i,:)=[1 1/(ScaledSOCb4(i)) ScaledSOCb4(i) 1/((ScaledSOCb4(i))^2) 1/((ScaledSOCb4(i))^3) 1/((ScaledSOCb4(i))^4) log(ScaledSOCb4(i)) log(1-ScaledSOCb4(i)) ];

end

k= ((b4'\*b4)^(-1))\*(b4'\*Battery4OCV);

V4=b4\*k ;

subplot(4,2,7)

plot(Battery4SOC,V4)

%Plotting using s vs v4 belongs to [0,1]-Battery 2-Combined model

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

b14=zeros(32,8);

for i=1:1001

b14(i,:)=[1 1/(s\_dash(i)) s\_dash(i) 1/((s\_dash(i))^2) 1/((s\_dash(i))^3) 1/((s\_dash(i))^4) log(s\_dash(i)) log(1-s\_dash(i)) ];

end

v4=b14\*k ;

subplot(4,2,8)

plot(s,v4)

%Fig 11( 4 subplots)

%Calculation of Vbar of Battery1

N=32;

M=length(k);

Vbarb1\_Combinedmodel3=sum(V1)/N;

%Calculation of BF

BFb1\_Combinedmodel3=(1-(norm(V1-Battery1OCV)/norm(Battery1OCV-Vbarb1\_Combinedmodel3)))\*100;

%Calculation of R^2

R2b1\_Combinedmodel3=(1-(((norm(V1-Battery1OCV))^2/((norm(Battery1OCV-Vbarb1\_Combinedmodel3))^2))))\*100;

%Calculation of ME

MEb1\_Combinedmodel3=max(abs(Battery1OCV-V1));

%Calculation of RMS

RMSb1\_Combinedmodel3=norm(Battery1OCV-V1)/sqrt(N-M);

errorb1\_Combinedmodel3=abs(Battery1OCV-V1);

%Calculation of AIC

S2b1\_Combinedmodel3=sum(errorb1\_Combinedmodel3.^2);

AICb1\_Combinedmodel3=(N\*(log(S2b1\_Combinedmodel/N)))+(2\*(M+1));

figure;

subplot(2,2,1)

plot(Battery1SOC,errorb1\_Combinedmodel3)

**Code for calculating errors:**

%Calculation of Vbar for Battery 2

N=32;

M=length(k);

Vbarb2\_Combinedmodel3=sum(V2)/N;

%Calculation of BF

BFb2\_Combinedmodel3=(1-(norm(V2-Battery2OCV)/norm(Battery2OCV-Vbarb2\_Combinedmodel3)))\*100;

%Calculation of R^2

R2b2\_Combinedmodel3=(1-(((norm(V2-Battery2OCV))^2/((norm(Battery2OCV-Vbarb2\_Combinedmodel3))^2))))\*100;

%Calculation of ME

MEb2\_Combinedmodel3=max(abs(Battery2OCV-V2));

%Calculation of RMS

RMSb2\_Combinedmodel3=norm(Battery2OCV-V2)/sqrt(N-M);

errorb2\_Combinedmodel3=abs(Battery2OCV-V2);

%Calculation of AIC

S2b2\_Combinedmodel3=sum(errorb2\_Combinedmodel3.^2);

AICb2\_Combinedmodel3=(N\*(log(S2b2\_Combinedmodel/N)))+(2\*(M+1));

subplot(2,2,2)

plot(Battery2SOC,errorb2\_Combinedmodel3)

%Calculation of Vbar for Battery 3

N=32;

M=length(k);

Vbarb3\_Combinedmodel3=sum(V3)/N;

%Calculation of BF

BFb3\_Combinedmodel3=(1-(norm(V3-Battery3OCV)/norm(Battery3OCV-Vbarb3\_Combinedmodel3)))\*100;

%Calculation of R^2

R2b3\_Combinedmodel3=(1-(((norm(V3-Battery3OCV))^2/((norm(Battery3OCV-Vbarb3\_Combinedmodel3))^2))))\*100;

%Calculation of ME

MEb3\_Combinedmodel3=max(abs(Battery3OCV-V3));

%Calculation of RMS

RMSb3\_Combinedmodel3=norm(Battery3OCV-V3)/sqrt(N-M);

errorb3\_Combinedmodel3=abs(Battery3OCV-V3);

%Calculation of AIC

S2b3\_Combinedmodel3=sum(errorb3\_Combinedmodel3.^2);

AICb3\_Combinedmodel3=(N\*(log(S2b3\_Combinedmodel/N)))+(2\*(M+1));

subplot(2,2,3)

plot(Battery3SOC,errorb3\_Combinedmodel3)

%Calculation of Vbar for Battery 4

N=32;

M=length(k);

Vbarb4\_Combinedmodel3=sum(V4)/N;

%Calculation of BF

BFb4\_Combinedmodel3=(1-(norm(V4-Battery3OCV)/norm(Battery4OCV-Vbarb4\_Combinedmodel3)))\*100;

%Calculation of R^2

R2b4\_Combinedmodel3=(1-(((norm(V4-Battery3OCV))^2/((norm(Battery4OCV-Vbarb4\_Combinedmodel3))^2))))\*100;

%Calculation of ME

MEb4\_Combinedmodel3=max(abs(Battery4OCV-V4));

%Calculation of RMS

RMSb4\_Combinedmodel3=norm(Battery4OCV-V4)/sqrt(N-M);

errorb4\_Combinedmodel3=abs(Battery4OCV-V4);

%Calculation of AIC

S2b4\_Combinedmodel3=sum(errorb4\_Combinedmodel3.^2);

AICb4\_Combinedmodel3=(N\*(log(S2b4\_Combinedmodel/N)))+(2\*(M+1));

subplot(2,2,4)

plot(Battery4SOC,errorb4\_Combinedmodel3)

**Graphs:**

**Chart, line chart

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**Error graphs:**

**Graphical user interface

Description automatically generated**

**6.Polynomial**

**Code for s vs V(s)**

E=0.175;m=3;n=2;

%Plotting battery1soc vs V1 using 32 iterations Polynomial model

ScaledSOCb1= ((1-(2\*E))\*Battery1SOC)+ E;

b1=zeros(32,6);

for i=1:32

b1(i,:)=[1 (ScaledSOCb1(i)^1) (ScaledSOCb1(i)^2) (ScaledSOCb1(i)^3) 1/((ScaledSOCb1(i))^1) 1/((ScaledSOCb1(i))^2) ];

end

k= ((b1'\*b1)^(-1))\*(b1'\*Battery1OCV);

V1=b1\*k ;

figure;

subplot(4,2,1)

plot(Battery1SOC,V1)

%Plotting s vs v1 for 1000 points Polynomial model

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

b11=zeros(32,6);

for i=1:1001

b11(i,:)=[1 ((s\_dash(i))) ((s\_dash(i))^2) (s\_dash(i)^3) 1/((s\_dash(i))^1) 1/((s\_dash(i))^2) ];

end

v1=b11\*k ;

subplot(4,2,2)

plot(s,v1)

%Plotting battery2soc vs V2 using 32 iterations Polynomial model

ScaledSOCb2= ((1-(2\*E))\*Battery2SOC)+ E;

b2=zeros(32,6);

for i=1:32

b2(i,:)=[1 (ScaledSOCb2(i)^1) (ScaledSOCb2(i)^2) (ScaledSOCb2(i)^3) 1/((ScaledSOCb2(i))^1) 1/((ScaledSOCb2(i))^2) ];

end

k= ((b2'\*b2)^(-1))\*(b2'\*Battery2OCV);

V2=b2\*k ;

subplot(4,2,3)

plot(Battery2SOC,V2)

%Plotting s vs v2 for 1000 points Polynomial model

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

b12=zeros(32,6);

for i=1:1001

b12(i,:)=[1 (s\_dash(i)^1) (s\_dash(i)^2) (s\_dash(i)^3) 1/((s\_dash(i))^1) 1/((s\_dash(i))^2) ];

end

v2=b12\*k ;

subplot(4,2,4)

plot(s,v2)

%Plotting battery3soc vs V3 using 32 iterations Polynomial model

ScaledSOCb3= ((1-(2\*E))\*Battery3SOC)+ E;

b3=zeros(32,6);

for i=1:32

b3(i,:)=[1 (ScaledSOCb3(i)^1) (ScaledSOCb3(i)^2) (ScaledSOCb3(i)^3) 1/((ScaledSOCb3(i))^1) 1/((ScaledSOCb3(i))^2) ];

end

k= ((b3'\*b3)^(-1))\*(b3'\*Battery3OCV);

V3=b3\*k ;

subplot(4,2,5)

plot(Battery3SOC,V3)

%Plotting s vs v3 for 1000 points Polynomial model

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

b12=zeros(32,6);

for i=1:1001

b12(i,:)=[1 (s\_dash(i)^1) (s\_dash(i)^2) (s\_dash(i)^3) 1/((s\_dash(i))^1) 1/((s\_dash(i))^2) ];

end

v3=b12\*k ;

subplot(4,2,6)

plot(s,v3)

%Plotting battery4soc vs V4 using 32 iterations Polynomial model

ScaledSOCb4= ((1-(2\*E))\*Battery4SOC)+ E;

b4=zeros(32,6);

for i=1:32

b4(i,:)=[1 (ScaledSOCb4(i)^1) (ScaledSOCb4(i)^2) (ScaledSOCb4(i)^3) 1/((ScaledSOCb4(i))^1) 1/((ScaledSOCb4(i))^2) ];

end

k= ((b4'\*b4)^(-1))\*(b4'\*Battery4OCV);

V4=b4\*k ;

subplot(4,2,7)

plot(Battery4SOC,V4)

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

b14=zeros(32,6);

for i=1:1001

b14(i,:)=[1 (s\_dash(i)^1) (s\_dash(i)^2) (s\_dash(i)^3) 1/((s\_dash(i))^1) 1/((s\_dash(i))^2) ];

end

v4=b14\*k ;

subplot(4,2,8)

plot(s,v4)

**Code for calculating errors:**

%Calculation of Vbar of Battery1 Polynomial model

N=32;

M=length(k);

Vbarb3\_polynomial=sum(V1)/N;

%Calculation of BF

BFb1\_polynomial=(1-(norm(V1-Battery1OCV)/norm(Battery1OCV-Vbarb3\_polynomial)))\*100;

%Calculation of R^2

R2b1\_polynomial=(1-(((norm(V1-Battery1OCV))^2/((norm(Battery1OCV-Vbarb3\_polynomial))^2))))\*100;

%Calculation of ME

MEb1\_polynomial=max(abs(Battery1OCV-V1));

%Calculation of RMS

RMSb1\_polynomial=norm(Battery1OCV-V1)/sqrt(N-M);

errorb1\_polynomial=abs(Battery1OCV-V1);

%Calculation of AIC

S2b1\_polynomial=sum(errorb1\_polynomial.^2);

AICb1\_polynomial=(N\*(log(S2b1\_polynomial/N)))+(2\*(M+1));

subplot(2,2,1)

plot(Battery1SOC,errorb1\_polynomial)

%Calculation of Vbar for Battery 2 Polynomial model

N=32;

M=length(k);

Vbarb2\_polynomial=sum(V2)/N;

%Calculation of BF

BFb2\_polynomial=(1-(norm(V2-Battery2OCV)/norm(Battery2OCV-Vbarb2\_polynomial)))\*100;

%Calculation of R^2

R2b2\_polynomial=(1-(((norm(V2-Battery2OCV))^2/((norm(Battery2OCV-Vbarb2\_polynomial))^2))))\*100;

%Calculation of ME

MEb2\_polynomial=max(abs(Battery2OCV-V2));

%Calculation of RMS

RMSb2\_polynomial=norm(Battery2OCV-V2)/sqrt(N-M);

errorb2\_polynomial=abs(Battery2OCV-V2);

%Calculation of AIC

S2b2\_polynomial=sum(errorb2\_polynomial.^2);

AICb2\_polynomial=(N\*(log(S2b2\_polynomial/N)))+(2\*(M+1));

subplot(2,2,2)

plot(Battery2SOC,errorb2\_polynomial)

%Calculation of Vbar for Battery 3 Polynomial model

N=32;

M=length(k);

Vbarb3\_pb3olynomial=sum(V3)/N;

%Calculation of BF

BFb3\_polynomial=(1-(norm(V3-Battery3OCV)/norm(Battery3OCV-Vbarb3\_polynomial)))\*100;

%Calculation of R^2

R2b3\_polynomial=(1-(((norm(V3-Battery3OCV))^2/((norm(Battery3OCV-Vbarb3\_polynomial))^2))))\*100;

%Calculation of ME

MEb3=max(abs(Battery3OCV-V3));

%Calculation of RMS

RMSb3\_polynomial=norm(Battery3OCV-V3)/sqrt(N-M);

errorb3\_polynomial=abs(Battery3OCV-V3);

%Calculation of AIC

S2b3\_polynomial=sum(errorb3\_polynomial.^2);

AICb3\_polynomial=(N\*(log(S2b3\_polynomial/N)))+(2\*(M+1));

subplot(2,2,3)

plot(Battery3SOC,errorb3\_polynomial)

%Calculation of Vbar for Battery 4 Polynomial model

N=32;

M=length(k);

Vbarb4\_polynomial=sum(V4)/N;

%Calculation of BF

BFb4\_polynomial=(1-(norm(V4-Battery4OCV)/norm(Battery4OCV-Vbarb4\_polynomial)))\*100;

%Calculation of R^2

R2b4\_polynomial=(1-(((norm(V4-Battery4OCV))^2/((norm(Battery4OCV-Vbarb4\_polynomial))^2))))\*100;

%Calculation of ME

MEb4=max(abs(Battery4OCV-V4));

%Calculation of RMS

RMSb4\_polynomial=norm(Battery4OCV-V4)/sqrt(N-M);

errorb4\_polynomial=abs(Battery4OCV-V3);

%Calculation of AIC

S2b4\_polynomial=sum(errorb4\_polynomial.^2);

AICb4\_polynomial=(N\*(log(S2b4\_polynomial/N)))+(2\*(M+1));

subplot(2,2,4)

plot(Battery4SOC,errorb4\_polynomial)

**Graphs:**

**Chart, line chart

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**Error graphs:**

**Graphical user interface, chart, histogram

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**7.Exponential**

**Code for soc vs V:**

e=2.718;

E=0.175;m=3;n=2;

%Plotting Battery1soc vs V1- Exponential model

ScaledSOCb1= ((1-(2\*E))\*Battery1SOC)+ E;

b1=zeros(32,4);

for i=1:32

b1(i,:)=[1 (e^(ScaledSOCb1(i)^1)) (e^(ScaledSOCb1(i)^2)) 1/(e^(ScaledSOCb1(i)))];

end

k= ((b1'\*b1)^(-1))\*(b1'\*Battery1OCV);

V1=b1\*k ;

figure;

subplot(4,2,1)

plot(Battery1SOC,V1)

%Plotting s vs v1 -Exponential model -battery 1

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

b11=zeros(32,4);

for i=1:1001

b11(i,:)=[1 (e^(s\_dash(i)^1)) (e^(s\_dash(i)^2)) 1/(e^(s\_dash(i))) ];

end

v1=b11\*k ;

subplot(4,2,2)

plot(s,v1)

%Plotting Battery2Soc vs V2-Exponential model

ScaledSOCb2= ((1-(2\*E))\*Battery2SOC)+ E;

b2=zeros(32,4);

for i=1:32

b2(i,:)=[1 (e^(ScaledSOCb2(i)^1)) (e^(ScaledSOCb2(i)^2)) 1/(e^(ScaledSOCb2(i)))];

end

k= ((b2'\*b2)^(-1))\*(b2'\*Battery2OCV);

V2=b2\*k ;

subplot(4,2,3)

plot(Battery2SOC,V2)

%Plotting s vs v2 for 1000 points Exponential model

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

b12=zeros(32,4);

for i=1:1001

b12(i,:)=[1 (e^(s\_dash(i)^1)) (e^(s\_dash(i)^2)) 1/(e^(s\_dash(i))) ];

end

v2=b12\*k ;

subplot(4,2,4)

plot(s,v2)

%Plotting Battery3Soc vs V3-Exponential model

ScaledSOCb3= ((1-(2\*E))\*Battery3SOC)+ E;

b3=zeros(32,4);

for i=1:32

b3(i,:)=[1 (e^(ScaledSOCb1(i)^1)) (e^(ScaledSOCb1(i)^2)) 1/(e^(ScaledSOCb1(i)))];

end

k= ((b3'\*b3)^(-1))\*(b3'\*Battery3OCV);

V3=b3\*k ;

subplot(4,2,5)

plot(Battery3SOC,V3)

%Plotting s vs v3 for 1000 points exponential model

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

b13=zeros(32,4);

for i=1:1001

b13(i,:)=[1 (e^(s\_dash(i)^1)) (e^(s\_dash(i)^2)) 1/(e^(s\_dash(i))) ];

end

v3=b13\*k ;

subplot(4,2,6)

plot(s,v3)

%Plotting battery4Soc vs V4-Exponential model

ScaledSOCb4= ((1-(2\*E))\*Battery4SOC)+ E;

b4=zeros(32,4);

for i=1:32

b4(i,:)=[1 (e^(ScaledSOCb1(i)^1)) (e^(ScaledSOCb1(i)^2)) 1/(e^(ScaledSOCb1(i)))];

end

k= ((b4'\*b4)^(-1))\*(b4'\*Battery4OCV);

V4=b4\*k ;

subplot(4,2,7)

plot(Battery4SOC,V4)

%Plotting s vs v4 for 1000 points exponential model

s=0:0.001:1;

s\_dash= ((1-(2\*E))\*s)+ E;

b14=zeros(32,4);

for i=1:1001

b14(i,:)=[1 (e^(s\_dash(i)^1)) (e^(s\_dash(i)^2)) 1/(e^(s\_dash(i))) ];

end

v4=b14\*k ;

subplot(4,2,8)

plot(s,v4)

**Code for calculating errors:**

N=32;

M=length(k);

Vbarb1\_nernst=sum(V1)/N;

%Calculation of BF

BFb1\_exponential=(1-(norm(V1-Battery1OCV)/norm(Battery1OCV-Vbarb1\_nernst)))\*100;

%Calculation of R^2

R2b1\_exponential=(1-(((norm(V1-Battery1OCV))^2/((norm(Battery1OCV-Vbarb1\_nernst))^2))))\*100;

%Calculation of ME

MEb1\_exponential=max(abs(Battery1OCV-V1));

%Calculation of RMS

RMSb1\_exponential=norm(Battery1OCV-V1)/sqrt(N-M);

errorb1\_exponential=abs(Battery1OCV-V1);

%Calculation of AIC

S2b1\_exponential=sum(errorb1\_polynomial.^2);

AICb1\_exponential=(N\*(log(S2b1\_exponential/N)))+(2\*(M+1));

figure;

subplot(2,2,1)

plot(Battery1SOC,errorb1\_exponential)

%Calculation of Vbar for Battery 2 Exponential model

N=32;

M=length(k);

Vbarb2\_exponential=sum(V2)/N;

%Calculation of BF

BFb2\_exponential=(1-(norm(V2-Battery2OCV)/norm(Battery2OCV-Vbarb2\_exponential)))\*100;

%Calculation of R^2

R2b2\_exponential=(1-(((norm(V1-Battery2OCV))^2/((norm(Battery2OCV-Vbarb1\_nernst))^2))))\*100;

%Calculation of ME

MEb2\_exponential=max(abs(Battery2OCV-V2));

%Calculation of RMS

RMSb2\_exponential=norm(Battery2OCV-V2)/sqrt(N-M);

errorb2\_exponential=abs(Battery1OCV-V2);

%Calculation of AIC

S2b2\_exponential=sum(errorb2\_exponential.^2);

AICb2\_exponential=(N\*(log(S2b2\_exponential/N)))+(2\*(M+1));

subplot(2,2,2)

plot(Battery2SOC,errorb2\_exponential)

%Calculation of Vbar for Battery 3 Exponential model

N=32;

M=length(k);

Vbarb3\_exponential=sum(V3)/N;

%Calculation of BF

BFb3\_exponential=(1-(norm(V3-Battery3OCV)/norm(Battery3OCV-Vbarb3\_exponential)))\*100;

%Calculation of R^2

R2b3\_exponential=(1-(((norm(V1-Battery3OCV))^2/((norm(Battery3OCV-Vbarb3\_exponential))^2))))\*100;

%Calculation of ME

MEb3\_exponential=max(abs(Battery3OCV-V3));

%Calculation of RMS

RMSb3\_exponential=norm(Battery3OCV-V3)/sqrt(N-M);

errorb3\_exponential=abs(Battery3OCV-V3);

%Calculation of AIC

S2b3\_exponential=sum(errorb3\_polynomial.^2);

AICb3\_exponential=(N\*(log(S2b3\_exponential/N)))+(2\*(M+1));

subplot(2,2,3)

plot(Battery3SOC,errorb3\_exponential)

%Calculation of Vbar for Battery 4 Exponential model

N=32;

M=length(k);

Vbarb4\_exponential=sum(V4)/N;

%Calculation of BF

BFb4\_exponential=(1-(norm(V4-Battery4OCV)/norm(Battery4OCV-Vbarb4\_exponential)))\*100;

%Calculation of R^2

R2b4\_exponential=(1-(((norm(V4-Battery4OCV))^2/((norm(Battery4OCV-Vbarb4\_exponential))^2))))\*100;

%Calculation of ME

MEb4\_exponential=max(abs(Battery4OCV-V2));

%Calculation of RMS

RMSb4\_exponential=norm(Battery4OCV-V2)/sqrt(N-M);

errorb4\_exponential=abs(Battery4OCV-V2);

%Calculation of AIC

S2b4\_exponential=sum(errorb4\_exponential.^2);

AICb4\_exponential=(N\*(log(S2b4\_exponential/N)))+(2\*(M+1));

subplot(2,2,4)

plot(Battery4SOC,errorb4\_exponential)

**Graphs:**

**Line chart

Description automatically generated**

**Error graphs:**

**A picture containing graphical user interface

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|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Battery 1** | **Individual Metrics** | | | | |
| OCV Model | AIC | RMSE | R^2 | BF | Max Error |
| Linear Model | -134.2380 | 0.1154 | 89.6692 | 67.8585 | 0.5463 |
| Shepherd Model | -143.6238 | 0.0997 | 92.2954 | 72.24 | 0.2758 |
| Nernst Model | -145.6438 | 0.0952 | 93.2049 | 73.9326 | 0.4255 |
| Combined Model | -178.7006 | 0.0553 | 97.86 | 85.3905 | 0.1850 |
| Combined+3 Model | -172.7006 | 1.2521e-04 | 100.000 | 99.968 | 4.334e-04 |
| Polynomial (4th order) | -205.7623 | 0.0358 | 99.1393 | 90.722 | 0.0881 |
| Exponential Model | -209.7623 | 0.0968 | 93.2148 | 73.9517 | 0.4063 |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Battery 2** | **Individual Metrics** | | | | |
| OCV Model | AIC | RMSE | R^2 | BF | Max Error |
| Linear Model | -134.0416 | 0.1158 | 89.6525 | 67.8325 | 0.5482 |
| Shepherd Model | -143.6151 | 0.0997 | 92.3281 | 73.3017 | 0.2760 |
| Nernst Model | -145.5532 | 0.0954 | 93.2164 | 73.9547 | 0.4262 |
| Combined Model | -178.7011 | 0.05533 | 97.8753 | 85.4236 | 0.1848 |
| Combined+3 Model | -172.7011 | 1.1777e-04 | 100.000 | 99.968 | 4.4466e-04 |
| Polynomial (4th order) | -205.8450 | 0.0357 | 99.1454 | 90.7555 | 0.0881 |
| Exponential Model | -143.8764 | 0.0970 | 93.1831 | 73.9708 | 0.4069 |

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| **Battery 3** | **Individual Metrics** | | | | |
| OCV Model | AIC | RMSE | R^2 | BF | Max Error |
| Linear Model | -135.1353 | 0.1138 | 89.9374 | 68.2783 | 0.5386 |
| Shepherd Model | -143.2351 | 0.0993 | 92.3507 | 72.34 | 0.2691 |
| Nernst Model | -146.5850 | 0.0938 | 93.3904 | 74.2909 | 0.4193 |
| Combined Model | -179.6014 | 0.0545 | 97.9213 | 85.5822 | 0.1826 |
| Combined+3 Model | -173.6014 | 1.1777e-04 | 100.000 | 99.9706 | 3.8385e-04 |
| Polynomial (4th order) | -206.3090 | 0.0355 | 99.1524 | 90.7935 | 0.0879 |
| Exponential Model | -210.3090 | 0.0954 | 93.4023 | 74.3153 | 0.4003 |

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| **Battery 4** | **Individual Metrics** | | | | |
| OCV Model | AIC | RMSE | R^2 | BF | Max Error |
| Linear Model | -137.9862 | 0.1089 | 90.9261 | 69.8771 | 0.5165 |
| Shepherd Model | -144.5950 | 0.0982 | 92.6193 | 72.8325 | 0.2410 |
| Nernst Model | -149.7950 | 0.0892 | 94.1064 | 75.7232 | 0.3981 |
| Combined Model | -183.9944 | 0.0501 | 98.2687 | 86.840 | 0.1670 |
| Combined+3 Model | -178.9944 | 4.238e-05 | 99.8256 | 95.8239 | 7.655e-05 |
| Polynomial (4th order) | -201.4064 | 0.03300 | 99.2788 | 91.5074 | 0.0804 |
| Exponential Model | -144.9550 | 0.0949 | 93.6926 | 74.8854 | 0.3675 |

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| **Battery 1** | **Individual Metrics** | | | | |
| OCV Model | AIC | RMSE | R^2 | BF | Max Error |
| Linear Model | -137.9862 | 0.1089 | 90.9261 | 69.8771 | 0.5165 |
| Shepherd Model | -144.5950 | 0.0982 | 92.6193 | 72.8325 | 0.2410 |
| Nernst Model | -149.7950 | 0.0892 | 94.1064 | 75.7232 | 0.3981 |
| Combined Model | -183.9944 | 0.0501 | 98.2687 | 86.840 | 0.1670 |
| Combined+3 Model | -178.9944 | 4.238e-05 | 99.8256 | 95.8239 | 7.655e-05 |
| Polynomial (4th order) | -201.4064 | 0.03300 | 99.2788 | 91.5074 | 0.0804 |
| Exponential Model | -144.9550 | 0.0949 | 93.6926 | 74.8854 | 0.3675 |

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| **Individual Rankings** | | | | |
| OCV Model | AIC | RMSE | R^2 | BF | Max Error |
| Linear Model |  |  |  |  |  |
| Shepherd Model |  |  |  |  |  |
| Nernst Model |  |  |  |  |  |
| Combined Model |  |  |  |  |  |
| Combined+3 Model |  |  |  |  |  |
| Polynomial Model |  |  |  |  |  |
| Exponential Model |  |  |  |  |  |

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| **Individual Rankings** | | | | |
| OCV Model | AIC | RMSE | R^2 | BF | Max Error |
| Linear Model |  |  |  |  |  |
| Shepherd Model |  |  |  |  |  |
| Nernst Model |  |  |  |  |  |
| Combined Model |  |  |  |  |  |
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| Polynomial Model |  |  |  |  |  |
| Exponential Model |  |  |  |  |  |

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| **Individual Rankings** | | | | |
| OCV Model | AIC | RMSE | R^2 | BF | Max Error |
| Linear Model |  |  |  |  |  |
| Shepherd Model |  |  |  |  |  |
| Nernst Model |  |  |  |  |  |
| Combined Model |  |  |  |  |  |
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| **Individual Rankings** | | | | |
| OCV Model | AIC | RMSE | R^2 | BF | Max Error |
| Linear Model |  |  |  |  |  |
| Shepherd Model |  |  |  |  |  |
| Nernst Model |  |  |  |  |  |
| Combined Model |  |  |  |  |  |
| Combined+3 Model |  |  |  |  |  |
| Polynomial Model |  |  |  |  |  |
| Exponential Model |  |  |  |  |  |

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