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Battery Management System and Control Strategy for Hybrid and Electric Vehicle

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Abstract— Battery management system (BMS) is an integral part of any electrical vehicle, which ensures that the batteries are not subjected to conditions outside their specified safe operating conditions. Thus the safety of the battery as well as of the passengers depend on the design of the BMS. In the present work a preliminary work is carried out to simulate a typical BMS for hybrid electrical vehicle. The various functional blocks of the BMS are implemented in SIMULINK toolbox of MATLAB. The BMS proposed is equipped with a battery model in which SOC is used as one of the states to overcome the limitation of stand-alone coulomb counting method for SOC estimation. The parameters of the battery are extracted from experimental results and incorporated in the model. The simulation results are validated by experimental results.

Keywords - Battery mangement system, SOC and SOH

I. INTRODUCTION

The batteries are the most widely used electrical energy storage devices at present in vehicles. A battery functions due to the chemical reactions that take place every time it is connected to a load or a source. The chemical action unfortunately causes damages to the inherent structure of a battery resulting in gradual reduction in the capacity of the battery to a point when the battery is unable to sustain any load. The battery weakening process can be enhanced or delayed simply by altering the way the battery is subjected to loading conditions. For example a battery subjected to extreme temperature ranges or repeated charge-discharge cycles has lower operating life than the one which is operated at favorable conditions. Batteries are safe as long as they are operating within their safe operating conditions and any violations of the limits will present a great danger to the safety of the passengers. So, the key to safe operation and long life of the battery is to ensure that the battery is always subjected to its safe specified operating conditions thereby keeping the battery current under charging or discharging modes within the specified limit under all specified temperature conditions. However, ensuring the safe operation of the battery is not straight forward as it depends on the knowledge of the present state of the battery that is known as state of charge (SOC). The SOC is defined as the present capacity of the battery expressed in terms of its rated capacity. The SOC can be used to prevent unintentional abuse of batteries thereby ensuring safety. Unfortunately there is no direct measurement technique using which the SOC can be measured. The SOC can only be estimated by knowing the current, voltage, temperature and other information pertaining to the particular battery under consideration. The SOC estimated is used to prevent the battery from discharging large current at low SOC and to prevent charging when the SOC is full. Thus the charging and discharging current can be programmed to follow a law depending on the SOC and thereby the battery is protected from damage. The SOC estimation algorithm requires the battery to be modeled in order to correct the SOC estimation by coulomb counting method that is known for causing error accumulation when used stand-alone. The chemical reaction in the cells of a battery causes rise in temperature which in turn affects the available capacity of the battery. So, the temperature of the battery must be monitored and regulated to prevent damages to the cells. A battery usually is made of number of cells in series and/or parallel combination to meet the load voltage and power requirement. Due to the differences among different cells the SOC of each cell will be different, thereby causing voltage imbalances among the cells. Since the cells cannot be overcharged the charging has to be stopped in the event that any cell is found to be fully charged even if the remaining cells are partially charged. Thus cell imbalance reduces the overall capacity of a healthy battery resulting in loss of capacity. So, a system is needed to achieve cell balancing to prevent this loss of capacity. As the cell ages, its capacity and the duration for which the cell is designed to support the load decreases. So, a cell with 100% SOC may not necessarily indicate the capability of the cell to last for its designed duration. Therefore, SOC measurement must be accompanied by a constant monitoring of the true capacity of the cell to reflect the actual capability of the cell to meet the variable demand from a vehicle. From the above discussion it is clear that, safe and efficient operation of a battery can only be ensured when all the concerns raised about the operation and monitoring are addressed by an independent system known as the battery management system or BMS. A battery management system is essentially a group of integrated individual system that caters to a particular operation of the system. A general BMS architecture is presented and the function of each block is given in [1]. A preliminary model was first attempted in the project based on the generic model developed in SIMULINK reference model [2]. The parameters represented in the model were extracted from the discharge curves of the chosen LiFePO4 battery. The model in [2] was found to be not suitable for HEV operation and so a model based on state-space representation [4] was implemented in the project. The paper is organized as follows. The proposed BMS is discussed in II, SOC estimation technique is presented in III, the simulation results are discussed in IV followed by concluding remarks in V.

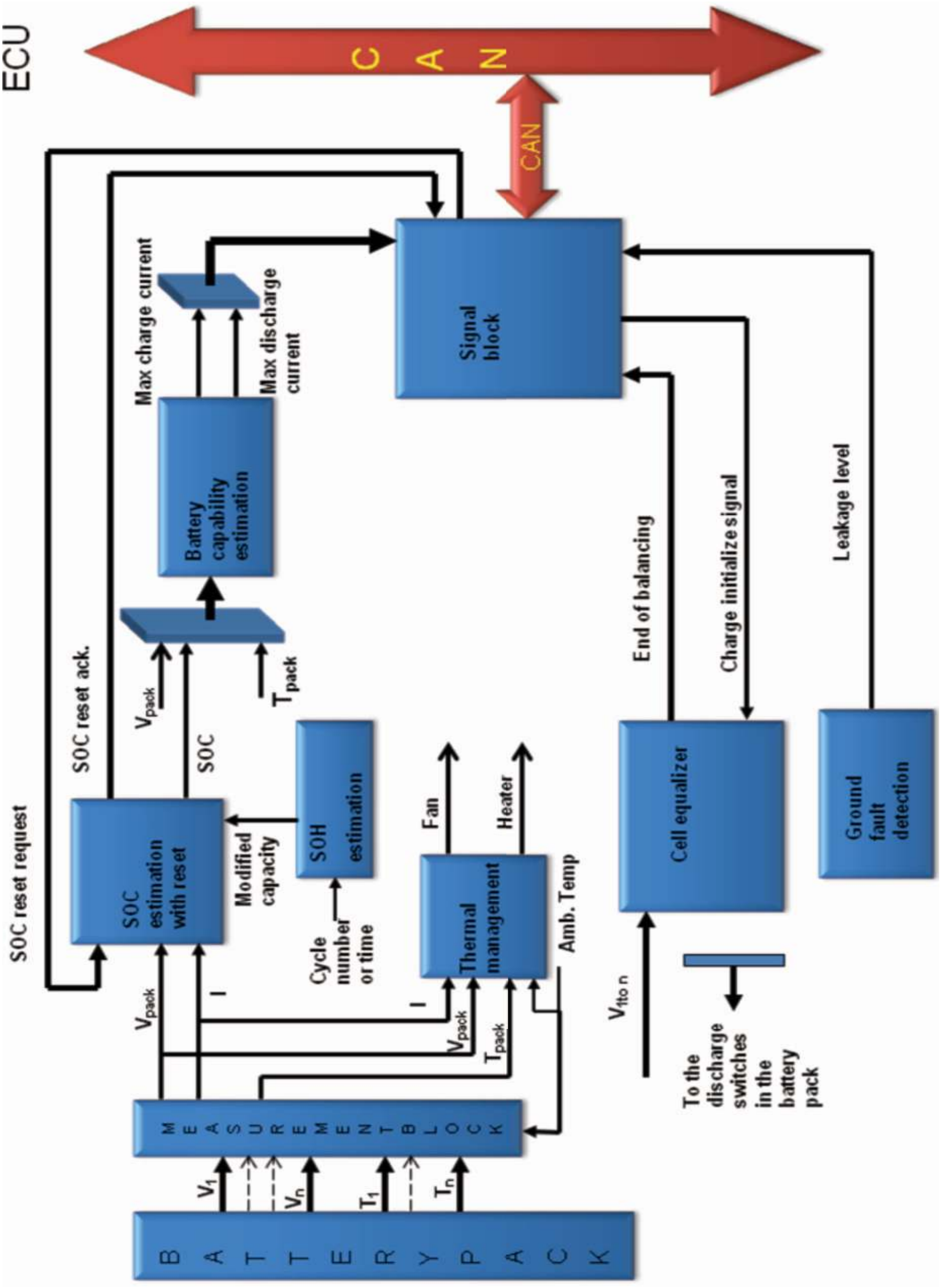

Fig. 1: Block diagram of BMS

II. BMS REPRESENTATION

The block diagram of the proposed BMS is given in fig.1. and the functional details of each of the blocks are described below:

A. *Measurement block*

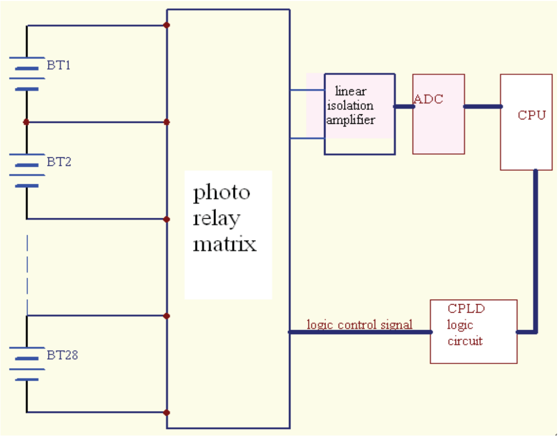

Fig. 2: Measurement block

It converts individual cell voltages, battery current and battery temperature at different points of the battery pack into digital values. All of these data is then used to estimate battery status in later stages.

B. *Battery algorithm block*

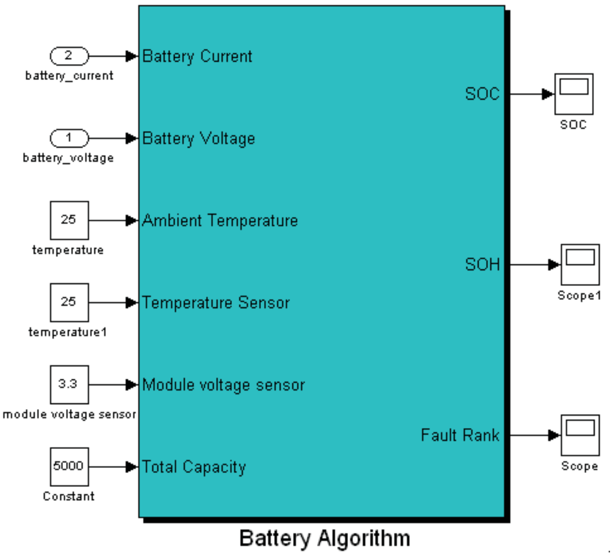

Fig. 3: SOC and SOH estimation block

The main task of this block is to estimate SoC and SOH using the measured battery variables such as battery voltage, current and temperature. The SOC is defined as the capacity of a battery expressed as a percentage of its rated capacity. It can be viewed as a "fuel gauge" of an EV or HEV.

C. *Capability estimation block*

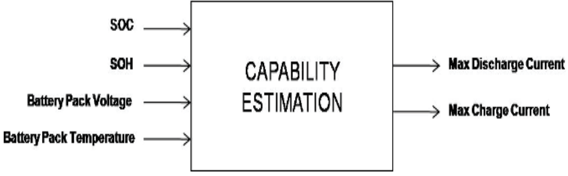

Fig. 3: Demand management block

After SOC and SOH are determined, the BMS has to deduce maximum charge and discharge current at any instant in accordance with an algorithm. The output of this block is provided to the vehicle ECU so that the battery is not subjected to charge or discharge beyond the specified limits.

D. *Cell equalization block*

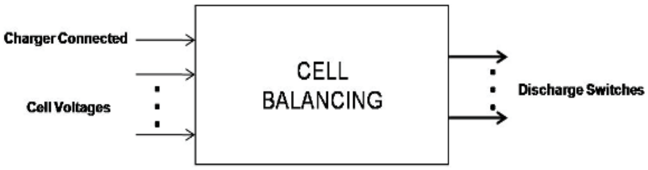

Fig. 4: Cell equalizer

Due to the limitation of current manufacturing processes all cells are not created equal. The variation in cell capacity within the range of a few percents to fifteen percents is common. Other variations such as internal resistance and charge / discharge characteristic are unavoidable. Cell balancing is vital to maximize the usable battery pack capacity and lifetime.

E. *Ground fault detection block*

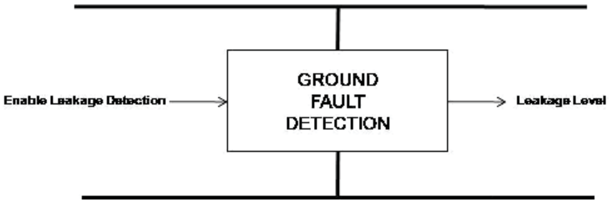

Fig. 5: Leakage detection block

Since the battery pack voltage is as high as 200-300 volts on an EV or HEV, any leakage into the chassis is highly dangerous. Therefore, an effective ground fault detection system is required to ensure electrical safety.

This is a safety requirement and especially important for high voltage DC.

F. *Thermal management block*

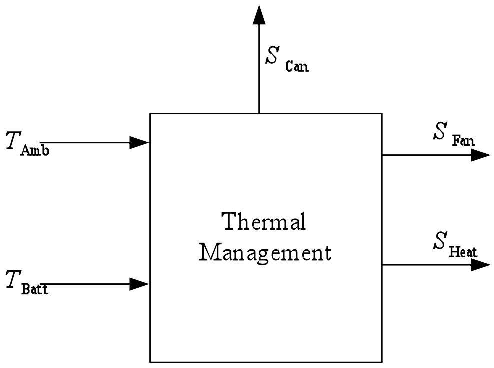

Fig. 6: Thermal management block

Thermal management refers to monitoring and controlling the battery temperature so that the battery is not harmed by over / under temperature.

The outputs of this block control a fan and an electric heater which attempt to keep the battery temperature within optimal range.

G. *CAN tranceiver block*

This is a physical communication module which manages all input and output signals of the BMS. Due to the amount of data being transmitted and received, high speed CAN protocol shall be used which permits data rate up to 1Mbps.

III. SOC ESTIMATION

A. *State space model of the battery [4]*

The state space representation of a typical battery is given in (5)

$$\begin{bmatrix} S_{oc}(k+1) \\ S_{op}(k+1) \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} S_{oc}(k) \\ S_{op}(k)\exp(-\left|\frac{i(k)\Delta t}{Q_d}\right|) + s_k M(1-\exp(-\left|\frac{i(k)\Delta t}{Q_d}\right|)) \end{bmatrix}$$
$$+ \begin{bmatrix} \left(\frac{\eta_i \Delta t}{Q_R}\right) \\ 0 \end{bmatrix} i(k) \qquad (5)$$

The battery terminal voltage is defined in (6)

$$V_{bat}(\mathrm{k}) = OCV(S_{oc}(k)) + S_{op}(k) + R_n i_k \qquad (6)$$

Where:

SOC is the state of charge (%), The available capacity in a battery expressed as a percentage of actual capacity. This is normally referenced to a constant current discharge at the certain rate, Range (0-100) %, Initial value: from the EEPROM.

S_{op}: state of polarization (V), State of polarization indicate the battery polarization voltage, Range: (-M~+M), Initial value: 0

Q_d : double layer capacitor(Ah);

R_n : internal resistance(Ohms);

I_k : current(A) , Positive when charge, negative when discharge, Range: (-500 ~ +500) (according to the manufacture);

Δt: Sample period (second);

Q_R : rated capacity(Ah);

OCV: open circuit voltage (V);

OCV is obtained by modeling the curve depicting the relation between SoC and OCV as in (7)

$$OCV(\mathrm{S_{oc}}(k)) = b(1)\mathrm{S_{oc}}^4(k) + b(2)\mathrm{S_{oc}}^3(k) + b(3)\mathrm{S_{oc}}^2(k) + b(4)\mathrm{S_{oc}}^1(k) + b(5) \qquad (7)$$

M: the maximum polarization voltage (V), The maximum polarization voltage depends on the double layer capacity of the battery as in (8).

$$M = a + b\ln|i| + c\Delta S_{oc} \qquad (8)$$

S_k: sign (0,-1,+1)

ε is a little positive quantity

ΔS_{oc} is the increment/decrement of Soc during charging or discharging conditions respectively and ΔSoc=0 when the mode changes from charge to discharge or vice versa.

The SOC estimation in the present work is carried out using coulomb counting method with SOC reset mechanism to over come the inherent error accumulation problem with stand alone coulomb counting method. Accordingly, the SOC correction factor is introduced based on the relation between the OCV and SOC.

IV. SIMULATION RESULTS

The BMS model in Simulink developed for a 40Ah LiFePO4 type of battery. Several battery experiments have been performed at 23 ^{0}C and 40 ^{0}C to collect estimate battery parameters and also to compare the results from the simulation. Experiments are done to extract the parameters of the battery. Experiments including constant current charging, constant current discharging, pulse current charging, pulse current discharging, and variable current charging/discharging. The parameters for the battery model in (5) & (8) are listed below:

1. The coefficients of the polynomial OCV
2. Battery internal resistance: R_n (ohm)
3. Battery rated capacity(Ah)
4. Double layer capacitor: Q_d (Ah)
5. Polarization coefficients a,b,c

Some of the parameters can be extracted from the experiment data, and the remaining from the specification of the manufactures. The parameter extractions are explained below:

(1)The coefficients of the polynomial in the OCV expression:

$$OCV(\mathrm{S_{oc}}(k)) = b(1)\mathrm{S_{oc}}^4(k) + b(2)\mathrm{S_{oc}}^3(k) + b(3)\mathrm{S_{oc}}^2(k) + b(4)\mathrm{S_{oc}}^1(k) + b(5) \qquad (9)$$

From the charge and discharge experiments data, the V-I data of the battery is obtained, and then a plot of OCV versus SOC can be obtained and from which a polynomial function can be fitted to extract the parameters.

(2) Battery internal resistance:

From the battery data and to use equation

$$R_n = \frac{\Delta V}{\Delta I} \qquad (10)$$

the battery internal resistance can be obtained

(3) The parameter Q_R is the rated capacity(Ah) , and since Q_R is dependent on the battery temperature, it would be adjusted accordingly in a lookup table.

(4) Q_d : double layer capacitor(Ah)

From the pulse charge or pulse discharge curve, Q_d is derived from the battery voltage rise time.

Q_d = rise time * current;

(5)M: maximum polarization voltage (V), can be calculated using (9)

$$M = a + b\ln|i| + c\Delta S_{oc}\,. \qquad (11)$$

The parameters a and b can be extracted from pulse charge data as shown in fig. 7. The following figure shows M at 20A pulse charge curve. In the same way, obtain M for a different pulse load, to calculate the coefficients a and b. The extracted parameters are listed in Table 1 in the appendix.

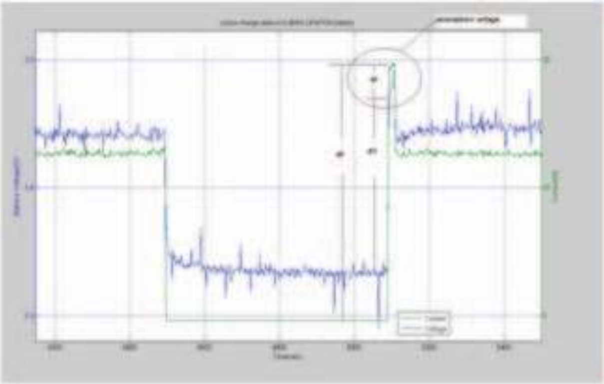

Fig. 7: Pulse load test plot to extract parameters

Figure 8 shows the plots of battery voltage versus SOC during charging charge at 0.1C, 0.2C and 0.25C.

The % error between the experimental and the simulated results are shown in figure 9 for charging. The small error confirms the ability of the Kalman filter to predict the SOC and the battery voltage accurately.

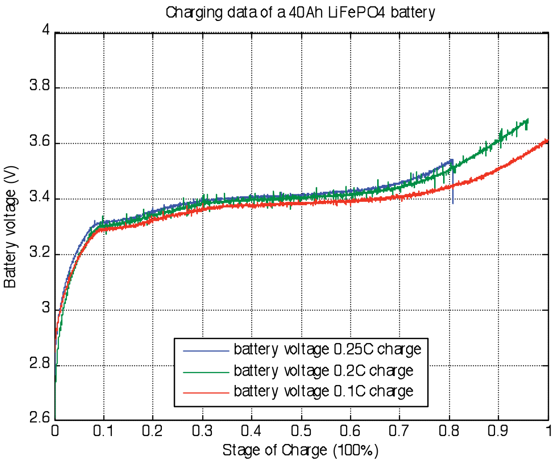

Fig. 8: Charging data of a 40Ah LiFePO4 battery at 23 ^{0}C

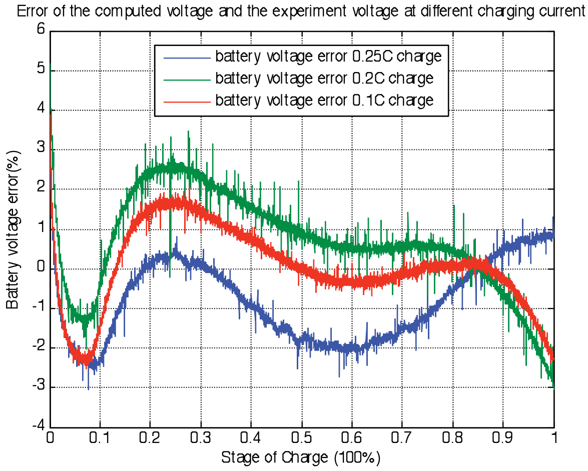

Fig. 9: Error between the computed voltage and the experiment voltage at different charging currents

A simulation is carried out to test the SOC estimation algorithm. Accordingly the battery is charged with 10 A and with an initial SOC setting of 0.5, but the true SOC of the battery was 0. The following figure shows the simulation results during charging. After Kalman filtering process (about 2000seconds later), the estimated SOC becomes equal to the real SOC thus proving the dynamic adjustability of the Kalman filtering method.

V. CONCLUDING REMARKS

In the present investigation a BMS model in Simulink has been developed. The BMS model includes blocks such as SOC estimation, battery modeling, thermal management and battery capability estimation blocks. The SOC estimation and reset have been implemented using coulomb counting and open circuit voltage methods thereby eliminating the limitation of the stand-alone coulomb counting method. SOC estimation is carried out by modeling the battery with SOC as one of the state variables and correcting the SOC estimation by using Kalman filtering method. The use of Kalman filter in the battery algorithm greatly improves SOC estimation accuracy as depicted by experimental and simulation results.

The proposed model is typically useful for HEVs and the same can be extended with modifications to other types of EVs. Further investigation is under progress to improve the model.

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