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Model Development For Electric Vehicle Powertrain Thermal Management System

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Abstract

The rapidly growing electric vehicle market has emerged as a key participant in the fight against environmental degradation and the oil shortage.[14] Effective heat management systems are crucial as these cars are developed in order to guarantee battery safety, maximize energy efficiency, and increase vehicle lifespan. With today's technology, thermal energy in electric cars can be used and controlled more effectively. Temperature is to be optimized between components such as battery, charger, DC-DC converter, inverter, and electric motor [7] In this work, a comprehensive assessment of several thermal management methodologies at component level is to be done with a particular emphasis on the components using a variable fan and variable flow coolant pump. It is also proposed to add an AC chilling system to the battery and charger to safeguard the components if something happens beyond the temperature. Then the vehicle may be safe to run the components at its optimal efficiency and may reduce the range anxiety [13] . The time and cost for designing these complicated systems can be significantly decreased with a suitable system simulation tool. A simulation model will be useful for assessing different control algorithms and should be able to effectively co-simulate with vehicle simulation programs.[12] As MATLAB/Simulink dynamic system software performs effective simulations [5] , it may be used to achieve the requirements. This work will be completed with the assistance of Gannet Engineering Private Limited, Bengaluru.

Keywords: Electric Vehicle Powertrain Thermal Management System, MATLAB/Simulink, Battery.

I. INTRODUCTION

Electric Vehicle Powertrain Thermal Management System [15] is a part of Electric vehicle thermal management system [8]. It consists of a Coolant circuit, which includes coolant pump, powertrain components, radiator, coolant and cooling fan. All powertrain components [6], which includes Battery, On-board charger, DC_DC converter, Inverter and motor are connected through common coolant, pump and radiator. Frequent use of inlet and outlet terms are referring to coolant flow [3] . At each component inlet side placed analog temperature sensors. Cooling fan used in this system contains three speed settings as 0, 1, and 2. The System monitors temperature of each component and calculate temperature raise and heat energy of each component. Based on temperature at motor outlet and total heat energy, it decides speeds of both coolant pump and cooling [1] . The system monitors all component's temperature raise and also checks component temperature change exceeds its threshold value or not. If it exceeds corresponding switching logic to be activated in circuit

II. FUNCTIONS

1) THE THERMAL MANAGEMENT SYSTEM in an electric vehicle (EV) plays a crucial role in maintaining the optimal operating temperature of various components within the electric powertrain [2]. Unlike internal combustion engine (ICE) vehicles, EVs do not have waste heat from an engine to help regulate temperatures. Therefore, athermal management system is even more critical in EVs to ensure efficient and safe operation. Here are the primary functions of an electric vehicle powertrain thermal management system

2) BATTERY COOLING: Maintaining the proper temperature of the battery pack is crucial for its performance, safety, and lifespan. The thermal management system helps cool the battery during high-demand activitieslike fast charging and discharging excess heat generated during operation. It may also warm the battery in cold weather to optimize performance.

3) MOTOR COOLING: Electric motors generate heat during operation. The thermal management system ensuresthat the motor remains within its optimal temperature range to maximize efficiency and longevity.

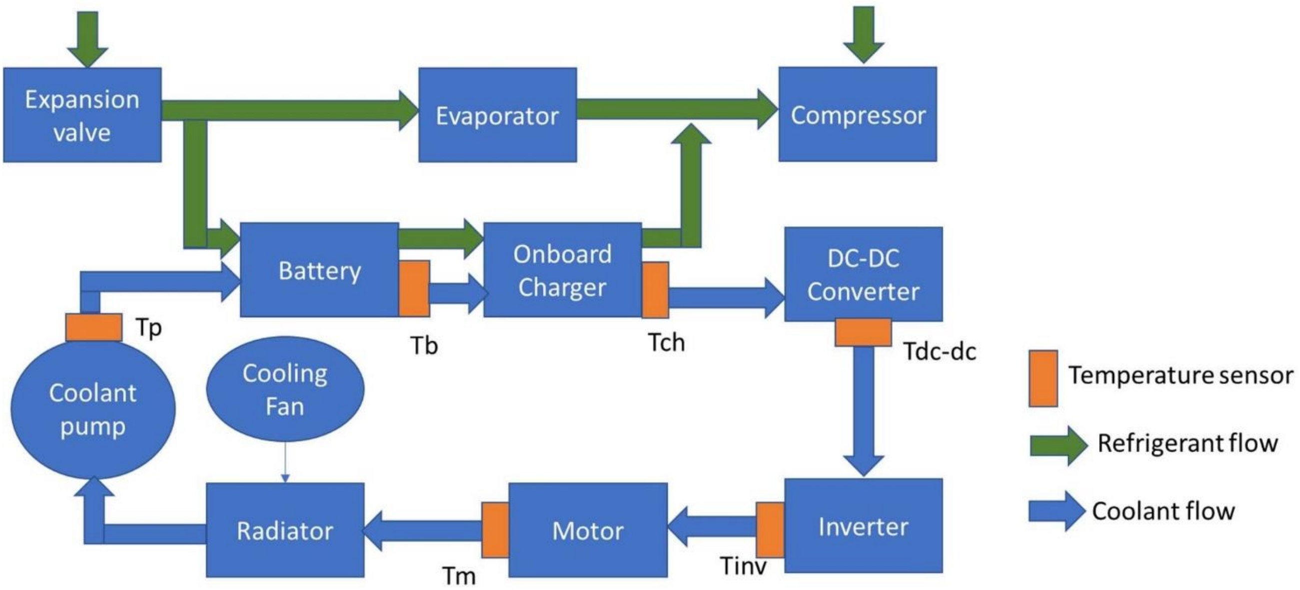
4) POWER ELECTRONICS COOLING: power electronics, including inverters and converters, are responsible for managing the flow of electricity between the battery and the motor. These components can get hot, and thethermal management system cools them to prevent overheating and maintain efficiency [4] .

5) CHARGING SYSTEM COOLING: During fast charging or rapid DC charging, the charging equipment can generate asignificant amount of heat. The thermal management system helps cool the charging components to ensuresafety and charging efficiency.

6) MOTOR AND INVERTER PRECONDITIONING: Preconditioning may also extend to the electric motor and inverter, ensuring they are at an ideal temperature for maximum performance when you begin driving.

III. Methods

Layout of Electric vehicle powertrain thermal management system



A) REQUIREMENTS DEVELOPMENT FOR EV POWERTRAIN CONTROL SYSTEM

Sensors

Hardware Input sensors for the Component Cooling TMS in EV are: Six Analog Temperature sensors, Analog inputs of all temperature sensors are connected at various positionsthat are given below

i. After Pump Outlet
ii. After Battery
iii. After Charger
iv. After DC_DC converter
v. After Inverter
vi. After motor

B) ACTUATORS

i. Coolant PUMP PWM OUTPUT – 0 to 100%
ii. Coolant Fan Low speed – Relay output – 0 or 1
iii. Coolant Fan High speed – Relay output – 0 or 1
iv. AC Compressor – Relay output – 0 or 1
v. AC By-pass valve – relay output – 0 or 1

C) FUNCTIONAL REQUIREMENTS

In this model, three subsystems are presented and listed below

1. **Input Subsystem Operation**: Six temperature sensors are positioned at each component. When an Electric vehicle is in running condition,the temperature rise is detected and sends those values to the output block.

2. State identifier

2.1. Delta-T & Delta-Q Calculator Subsystem Operation:

The input side of this subsystem is connected to the input subsystem and the output side gives out the total temperature rise and total heat energy generated.

Input: input subsystem

Output: Total heat and temperature rise of each systemLogic used:

Temperature rise = Temperature at the outlet (T_{out}) - Temperature at the inlet (T_{in})Heat energy = m*C_p*(T_{out} – T_{in})

m = mass flow rate of coolant

C_p = specific heat capacity=1(in this model)

m value calculations completely based on pump speed

2.2 State identification Subsystem Operation:

This system input side is connected to Delta-T & Delta-Q Calculator Subsystem using logic it gives outdifferent signals: State of system, Fan speed, and pump speed.

3. **Output Subsystem Operation:** Normal means coolant speed normal

Critical means coolant speed at maximum value by operating motor at high speed

Super Critical means in this stage pump speed is at maximum value and additional cooling is provided by the refrigerant to critical components such as the battery and onboard charger

D) LOGIC USED

Step1:

Each component contains a threshold value of temperature risein this system threshold values are listed below:
All temperature values indicate temperature raise

Table 1: Temperature Values of Each Component

Component	Threshold Value	Critical Value
Battery	40 C	50 C
Charger	30 C	40 C
Dc-Dc converter	20 C	-
Inverter	30 C	-
Motor	30 C	-

Supercritical: It applies to battery and charger circuits only.

To decide whether the circuit is supercritical or not in the following steps
First, it checks the temperature rise across the battery and on-board charger critical values if a raise in temperature exceeds the critical value then output super critical value as logic 1 See **Error! Reference source not found.**

Table 2: Output Pin Conditions

Condition	Output pin
If the system detects any temperature raise value exceeds a threshold value	Normal/Critical pin:Logic 1
Else	Normal/Critical pin:Logic 0
If a change in temperature raise exceeds the Critical value then output supercritical value as logic 1	Supercritical pin: Logic1
Else	Supercritical pin: Logic 0

Step 2:

Fan Speed and Pump speed in case of Normal/Critical pin ==1

If output is logic 1:

Then set the pump speed to maximum value [100] and cooling fan speed to maximum value [2]

Else:
Pump speed and fan speed values calculations in step3 See **Error! Reference source not found.**

Table 3: Output Pin Conditions For Fan &Pump Speeds

Condition	**Output pin**
Normal/Critical pin ==1	Fan speed = 2
Normal/Critical pin ==1	Pump speed = 100

Step 3:
Fan Speed and Pump speed in case of Normal/Critical pin ==0
Fan speed depends on the temperature at the outlet of the motor
Pump speed depends on the total heat value generated from each component See **Error! Reference source not found.**

Table 4: Output Pin Conditions for Fan &Pump Speeds Based On Final Temperature &Heat Values

Condition	**Output Pin**
Final temperature <40	Fan speed = 0
40<=Final temperature<70	Fan speed = 1
Final temperature>70	Fan speed = 2
Total heat = [0-100]	Pump seed = [0-100]

See Error! Reference source not found.**for** Output Pin Conditions for Fan &Pump Speeds Based On Final Temperature &Heat Values

IV. MATLAB MODEL DEVELOPMENT

A). **System Architecture model**

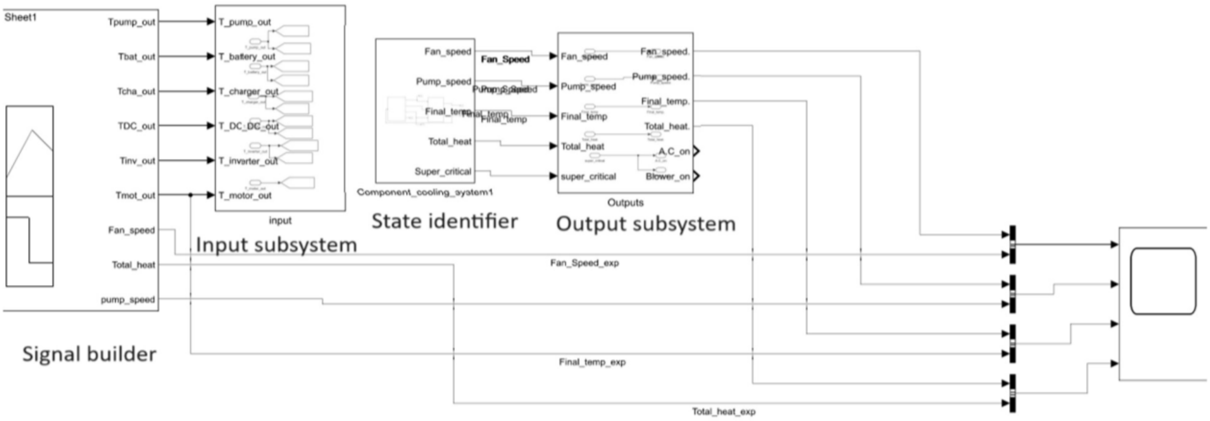


Figure 1Powertrain Model

Figure 1Powertrain Model

B). State Identifier Subsystem

This subsystem comprises two blocks, the Delta-T & Delta-Q Calculator Subsystem and the Stateidentification Subsystem.

I.State identification Subsystem:

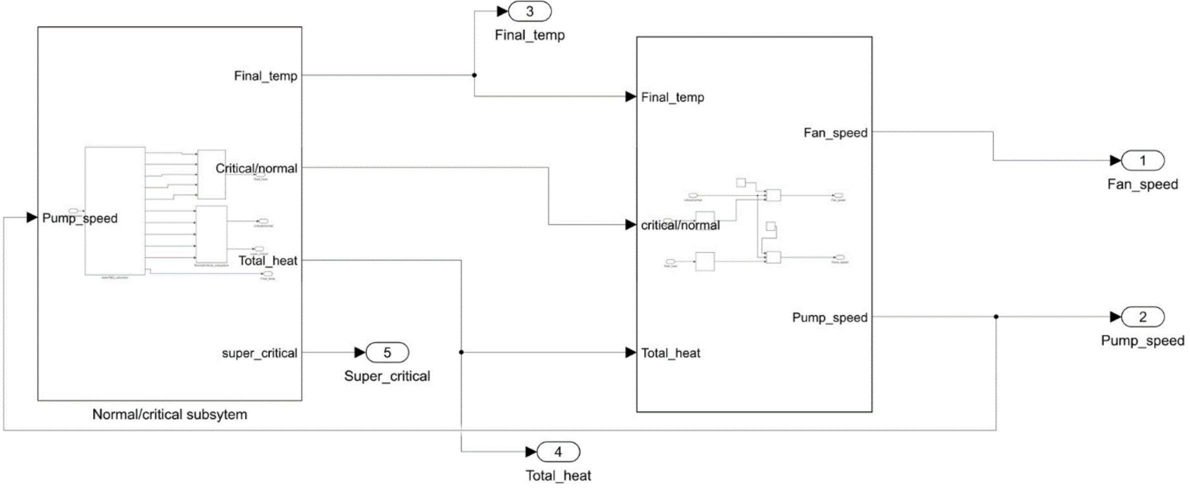


Figure 2State identification Subsystem

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II. Delta-T & Delta-Q Calculator Subsystem:

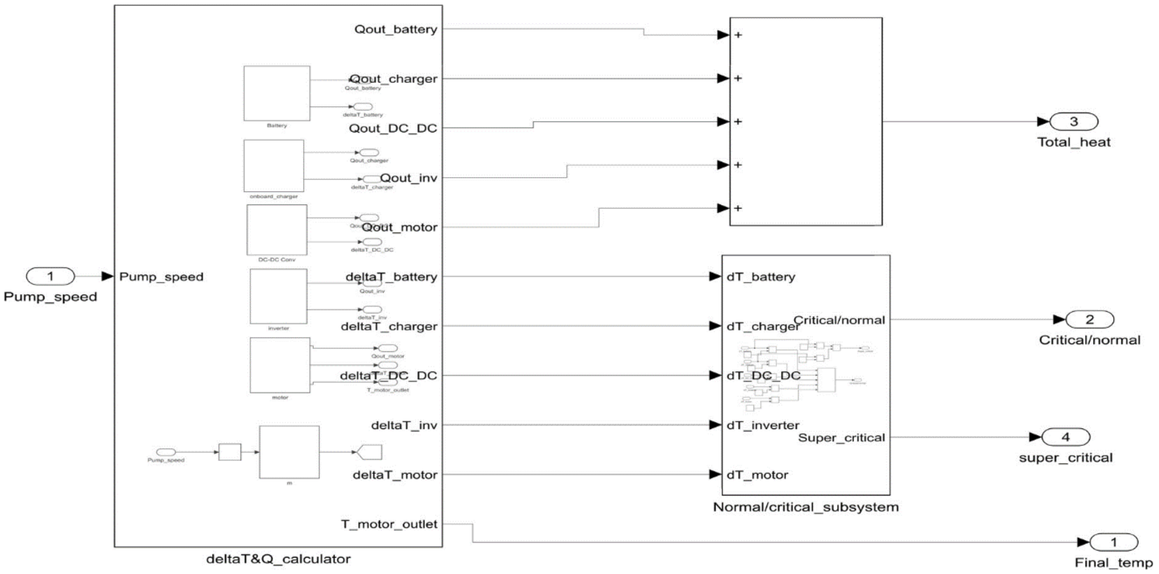

Figure 3Delta-T & Delta-Q Calculator Subsystem.

Figure 3Delta-T & Delta-Q Calculator Subsystem.

V.MODEL VERIFICATION

TESTING:
In Simulink, the Signal Builder block is a valuable tool for creating and managing input signals to verify and validate models. It allows you to define and generate input signals, making it particularly useful for model verification and testing. Here's how to use the Signal Builder block in Simulink for this purpose:

I.STEPS INVOLVED

1.1. **Open Simulink Model**: Start by opening the Simulink model you want to verify or test. If you don'thave a model yet, create one or import an existing one.

1.2. **Insert Signal Builder Block**:
1.2.1. In Simulink, navigate to the Simulink Library Browser.
1.2.2. Expand the "Simulink" block set.
1.2.3. Find the "Sources" category and locate the "Signal Builder" block.
1.2.4. Drag and drop the Signal Builder block into your Simulink model.

1.3. **Configure the Signal Builder Block**:
1.3.1. Double-click on the Signal Builder block to open its configuration dialog.
1.3.2. Define the signal names and values: You can specify the names of the signals and theirassociated data points. Each signal can be composed of multiple data points to create complex input profiles.
1.3.3. Define the time vector: Set the time vector to specify when each data point in the signalsoccurs.

1.4. **Define Signals and Data Points**:
1.4.1. In the Signal Builder block dialog, define the signals you want to use for your verification.
1.4.2. For each signal, define its data points by specifying values at specific time instances. You candefine linear ramps, step changes, or more complex waveforms.

1.5. **Save or Load Signal Builder Data**:
1.5.1. You can save and load Signal Builder data using the "Save" and "Load" buttons in the configuration dialog. This helps reuse signals in different models or share them with teammembers.

1.6. **Connect Signal Builder to the Model**:
1.6.1. Connect the output of the Signal Builder block to the input of the subsystem or block youwant to verify.

1.7. **Simulation Configuration**:
1.7.1. Configure your simulation settings, such as the simulation time, solver options, and anyother necessary settings for your specific model.

1.8. Run the Simulation:

1.8.1. Start the simulation to see how your model responds to the input signals generated by the Signal Builder. You can observe the system's behaviour and verify whether it meets your requirements.

1.9. Analyse Results:

1.9.1. After the simulation, you can analyse the results to determine if your model behaves as expected. Use Simulink's plotting and analysis tools to evaluate system performance.

1.10. Iterate and Refine:

1.10.1. You find any discrepancies or issues, make necessary adjustments to your model and repeat the verification process until your model meets the desired criteria.

In this model verification, the Signal builder is inserted in Simulink after importing the test cases file in it. The test case file is generally in Excel format.

II.TEST CASE DATA

Table 5: Test case Data

k	Tpump_ou	Tbat_out	Tcha_out	TDC_out	Tinv_out	Tmot_out	Fan_spee	dt_battery
1	10	15	20	25	30	35	0	5
2	10	16	18	25	32	40	1	4
3	20	25	65	68	70	75	2	5
4	10	40	45	45	50	60	2	30
5	10	16	18	25	32	40	1	4
6	30	40	50	55	65	68	1	10
7	20	25	28	30	36	60	1	5
8	30	32	38	52	70	80	2	2
9	30	35	40	60	65	75	2	5
10	30	62	70	75	78	80	2	32

VI.Results and Discussion

In this section, the generated outputs are compared with subsystem outputs

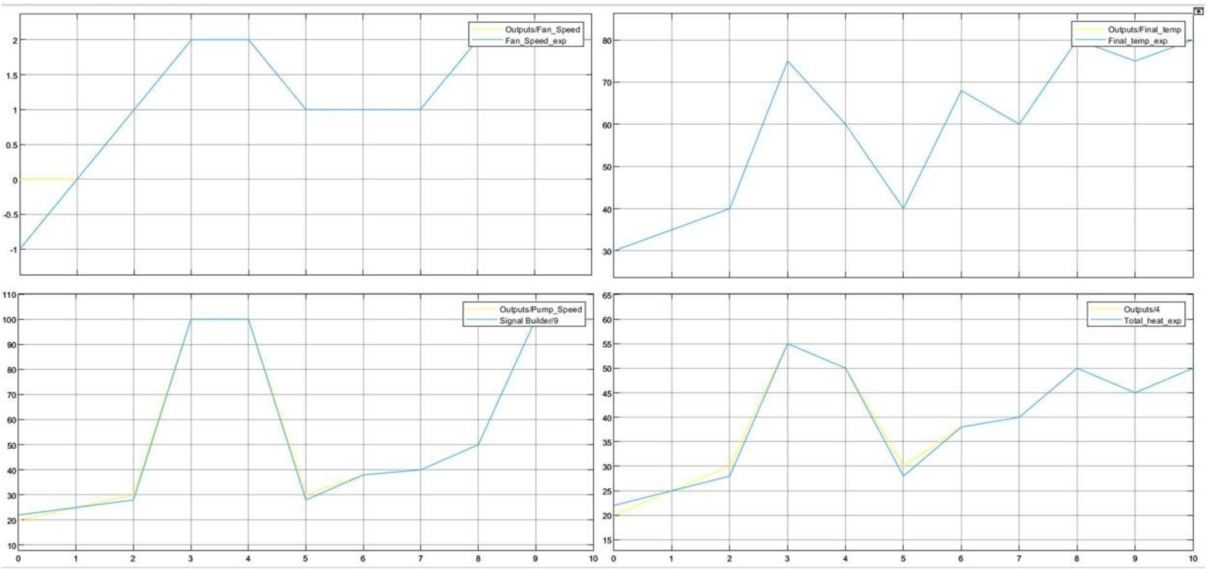

Fig.4. Signal Builder Outputs compared with subsystem outputs

If both graphs are superimposed then our model generates the expected output otherwise modify the logic till got expected output.

VII.CONCLUSIONS

A. Powertrain Model Conclusion:

This project mainly focuses on Requirements and model development. All Requirements are listed in one file before model development and those requirements are approved by Domain Expert. After getting all Requirements proceed to model development. Model development using MATLAB Simulink and control libraries.

B. FUTURE SCOPE

Validating the generated Simulink model of an engine cooling system with actual vehicle data is the project's next task. Real-time data from a vehicle's components may be gathered while it is being driven normally in order to validate the model. It is important to test and calibrate the model using all of the gathered data. It is necessary to collect a comparable set of data. Components for cooling in order to confirm that the suggested method can identify an issue with a component.

List of abbreviations

EV: Electric Vehicle.
ICE: Internal Combustion Engine.
AC: Air Conditioning.
DC: Direct Current.
Tin: Temperature at the inlet.
Tout: Temperature at the outlet.
M: mass flow rate of coolant.
Cp = specific heat capacity.
Delta-T: Temperature Difference.
Delta-Q: Amount of heat that is given to the system.
C: Celsius.

Declarations

Availability of data and materials

The corresponding author may provide the datasets used and/or analysed for this study upon reasonable request, and the principal researchers may grant access to particular data.

Competing interests

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Authors' contributions

A V N S D N TEJA was responsible for the concept, data gathering, investigation, methodology, and original draft writing. Process, supervision, and conceptualization were completed by P. Manjunath. **Dr. Smt.** G. Prasanthi carried out the conceptualization, data collecting, investigation, writing revision, and editing. The completed work was read and approved by all writers.

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