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# 1-D SIMULATION STUDIES ON IMPACT OF HVAC SYSTEM LOAD ON ELECTRIC VEHICLE

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**ABSTRACT:** The HVAC system is a critical component for maintaining year-round thermal comfort and regulating the operating temperature of the High Voltage battery pack (HV battery) in electric vehicles (EVs). Serving as the sole energy source for EVs, batteries play a pivotal role in addressing global warming. However, the HVAC system has a significant impact on EV range, particularly in adverse weather conditions, as it consumes a substantial portion of the battery capacity, making it a primary energy consumer. To comprehensively design and understand the interactions between different HVAC components, 1D simulations are employed, proving effective for optimizing the entire system. The primary objective of this project is to analyse the auxiliary system load, specifically the HVAC system, in relation to battery sizing and range estimation. This analysis encompasses ambient loads, metabolic loads, radiation loads, and ventilation loads for EVs. Precise numerical calculations for air conditioning (AC) and heating loads are essential. Before delving into the HVAC system's impact, the project involves modelling powertrain components and subsystems of the EV, taking into account various drive cycles and forces acting on the vehicle. The investigation aims to discern how energy consumption fluctuates due to HVAC load and its repercussions on vehicle performance and battery lifespan. The entire process, including modelling, analysis, calculation, and result validation, will be executed using Matlab and Simulink software. The anticipated outcome of this project is to determine the optimal energy requirement, ensuring a high level of thermal comfort within the passenger cabin and enhancing the driving range for an electric vehicle across different city temperature scenarios.

**KEYWORDS:** HVAC simulation, HVAC 1-D Simulation, HVAC Analysis,

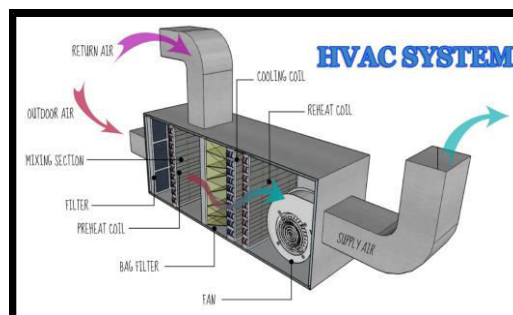
## I. INTRODUCTION

An electric vehicle (EV) operates on an electric motor rather than an internal-combustion engine, presenting a promising solution to address issues like pollution, global warming, and depleting natural resources. The concept of electric vehicles has gained significant traction in the past decade due to the increasing environmental impact of fuel-based vehicles. EVs offer low to zero carbon emissions, low noise, high efficiency, and flexibility in grid operation, making them a key player in achieving a sustainable transport sector. Green mobility and electric vehicles are now imperative to meet environmental targets for zero emissions. The architecture of electric vehicles must be adaptable for drivetrain electrification, ensuring sustainability for society. With fewer moving parts, EVs have lower running costs and are environmentally friendly, using minimal fossil fuels. Modern battery electric vehicles predominantly employ lithium-ion batteries for their longevity and energy retention capabilities. Despite advancements, challenges remain, such as thermal runaway issues in batteries, necessitating ongoing safety improvements. Electric vehicles encompass various modes of transport, including bikes, cars, rickshaws, and electric trains, which already operate globally on electricity.

The essential components of an all-electric car include a battery for auxiliary power, a charge port enabling external power connection, a DC/DC converter for voltage conversion, an on-board charger for AC-to-DC power conversion, a power electronics controller managing electrical flow, a thermal system for temperature regulation, a traction battery pack storing electricity, and an electric transmission transferring power to the wheels. Electric vehicles offer advantages such as cost savings on fuel, environmental friendliness with zero emissions, lower maintenance due to efficient electric motors, and improved performance.

Amidst a global shift towards alternative energy options, India is investing in electric mobility to address oil import burdens, pollution concerns, and international climate change commitments. The HVAC (Heating, Ventilation, and Air Conditioning) system plays a crucial role in achieving thermal comfort and indoor air quality for occupants. Classified as central or local systems, HVAC components include heating and cooling equipment, air distribution systems, and terminal units. The selection of HVAC systems depends on factors such as climate, building age, owner preferences,

budget, and architectural design. The HVAC system is indispensable in electric vehicles, regulating temperature for the high voltage battery pack. While contributing to environmental goals, the HVAC system also poses challenges, notably in reducing the electric vehicle's range due to significant energy consumption, especially in adverse weather conditions. Keywords in HVAC systems encompass central and local systems, heating, and air-conditioning systems. The major classification of HVAC systems involves central and decentralized or local systems, with criteria such as location and primary equipment influencing design decisions. Six main categories, including heating and cooling production, air handling processes, distribution systems, and terminal units, are identified for HVAC components and equipment. The classification also considers necessary processes like heating, cooling, and ventilation, along with additional processes like humidification and dehumidification. The detailed analysis and classification of components within each main category provide a comprehensive overview of HVAC systems.



**Figure 1.1 HVAC System**

A central HVAC system caters to one or more thermal zones, with major equipment situated outside these zones in a central location. Control points, such as thermostats for each zone, sub-classify the system based on the thermal energy medium. Primary equipment includes heating devices like steam and hot water boilers, air delivery units with fans, and refrigeration equipment for cooling. Space requirements influence system centralization, with facilities like equipment rooms, HVAC facilities, fan rooms, vertical shafts, and equipment access crucial for installation, maintenance, and performance. Air distribution involves ductwork for efficient conditioned air delivery, and all ductwork and piping should be insulated for energy savings. The piping system delivers refrigerants, hot water, and other substances, with insulation based on code criteria. In electric vehicles, advanced heat pumps, vaporized coolant, and efficient heating and cooling systems using high-voltage DC power ensure comfort. The 1D simulation method aids in understanding the intricate interactions of mechanical, electrical, and other components within complex systems, facilitating innovative designs and optimization across various industries. This simulation approach is particularly beneficial for system-level optimization, offering advantages in digital prototyping, reduced physical testing costs, and enhanced communication throughout the development cycle.

The collection of research papers explores various aspects of Heating, Ventilation, and Air Conditioning (HVAC) systems in electric vehicles (EVs). Kiran R. Kambly et al. [1] focus on developing a systems-level approach connecting HVAC technologies to vehicle performance metrics. Gokhan Sevilgen et al. [2] employ a detailed 1-D model to evaluate the thermal performance of refrigerants in HVAC systems. Dominik Dvorak et al. [3] introduce advancements in reducing computational costs in assessing vehicle cabin thermal comfort and energy flows. Tiantian Wang et al. [4] optimize numerical simulations of car compartment flow fields using simplified models, enhancing computational efficiency. Ivan Cvok et al. [5] propose a dynamic programming-based optimization algorithm for HVAC control variables to balance passenger comfort and system efficiency. Jannesari Ghomsheh et al. [6] present a novel HVAC system with a heat pump and phase change material to improve EV range. Other papers address topics like thermal challenges in transport electrification, energy consumption estimation models, heat pump applications, and the impact of air conditioning on EV range. The comprehensive overview encompasses studies on reducing energy consumption, enhancing vehicle performance, and optimizing HVAC systems for electric vehicles.

The problem at hand involves the evolving landscape of vehicles with the integration of automation and electrification, impacting their design and applications. Electric vehicles (EVs) face the challenge of determining driving range, crucial for fleet applications. To accurately size the battery, it's essential not only to estimate powertrain consumption but also auxiliary users like Heating, Ventilation, and Air Conditioning (HVAC). A variable HVAC model for electric powertrain vehicles was developed, factoring in vehicle size and weather scenarios. Integrated into a tool for autonomous and electric vehicle concept development, simulations of various concepts in different conditions

revealed significant battery resizing needs based on weather scenarios. Particularly in urban driving cycles, HVAC consumption's percentage can surpass that of the powertrain due to lower average speeds, emphasizing the importance of considering HVAC in the development of electric vehicles primarily used in cities.

The objectives include estimating thermal, ambient, metabolic, and ventilation loads, developing a fully functional HVAC model, estimating HVAC electric load, analyzing HVAC load in various ambient temperatures, and validating vehicle performance parameters such as energy consumption. The methodology involves an overview of TESLA thermal management systems and power electronics, BEV powertrain modeling for component sizing, and modeling of the BEV HVAC system. The latter includes a review of HVAC systems, loads acting on HVAC, numerical calculations for AC and heating loads, modeling, sizing, and estimating energy consumption due to HVAC, followed by results and discussions including HVAC model validation, energy consumption analysis, and State of Charge (SOC) variation concerning different ambient temperatures during vehicle operation.

## II. MODELLING

### Modelling of Powertrain and HVAC system:

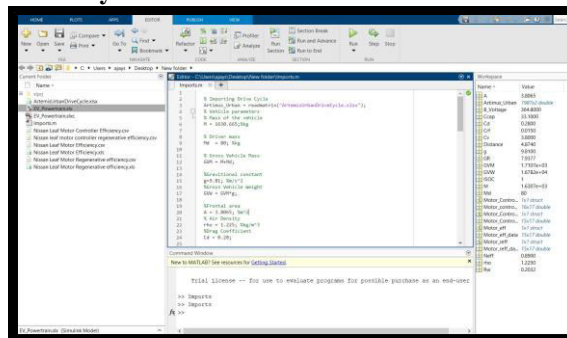


Figure 1.2 Matlab imports file for EV powertrain

Initially the specifications of the vehicle and the factors affecting are entered into Matlab. The data such as mass of vehicle, radius of wheel, drag constant etc. needed for the equations required for rendering the simulation are acquired from this Matlab file.

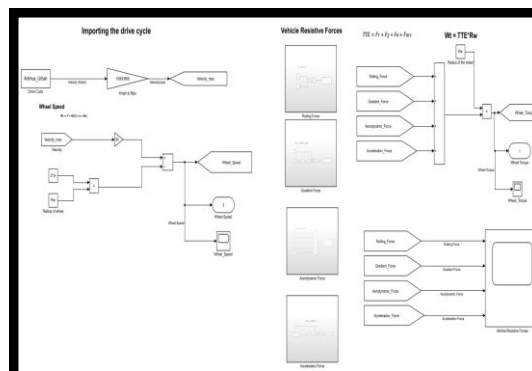


Figure 1.3 Drive cycle and vehicle resistive forces

Here the drive cycle is imported, which is typically represented by a series of data points which plots vehicle speed against time. Driving cycles are produced to assess the performance of vehicles in various ways, including fuel consumption and pollutant emissions. Then the major resistive forces that impact the performance of the vehicle are taken into consideration. These forces are rolling force, gradient force, aerodynamic force and acceleration force. From these forces the wheel torque is obtained.

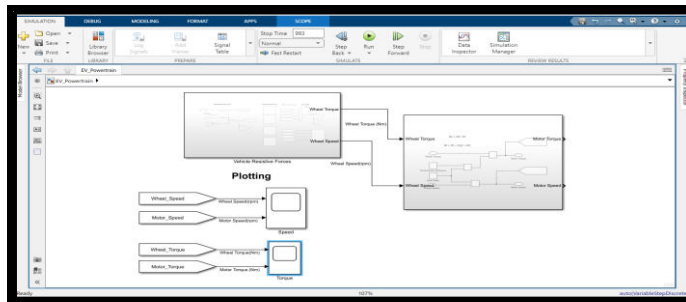


Figure 1.4 Plotting of output connections

The motor torque and motor speed is obtained from wheel torque and wheel speed respectively. They are calculated from the transmission efficiency and gear ratio of the vehicle. These are important factors in deciding the performance of the vehicle as they affect energy consumption and different variations of it.

These variations are taken at an average value of their variations to arrive at the suitable value taken in consideration during calculations which is necessary in obtaining power required for functioning of the powertrain of the electric vehicle.

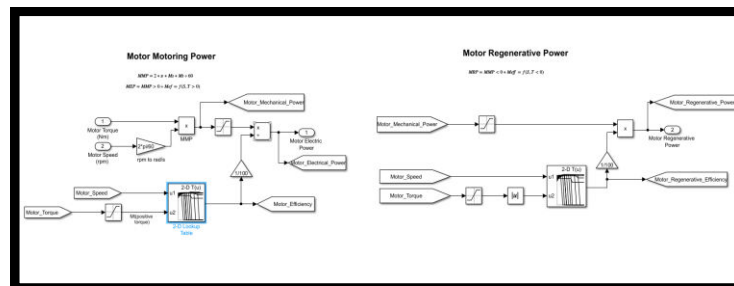


Figure 1.5 Motor motoring and regenerative power

Motor motoring power means the amount of mechanical energy output generated by the motor within a given timeframe. It has an impact on the car's acceleration, traction capacity. It is derived from motor torque and motor speed. Regenerative energy is the energy that returns to an inverter when a motor decelerates or a load descends. As soon as the motor overcomes the battery it inverts the current direction and starts feeding current into the battery.

Here the motor becomes a generator to produce regenerative power. A motor behaves as motor and as generator at the same time. In fact while a motor is 'motoring', that is doing mechanical work, it generates counter electromotive force (CEMF, also known as back EMF) acting as generator, although the CEMF is lower than the battery voltage so the motor acts as a load and absorbs current. In certain situations the CEMF may overcome the battery, in which case the generator component becomes dominant; the motor acts as a generator inverting the direction of its current and forcing it into the battery.

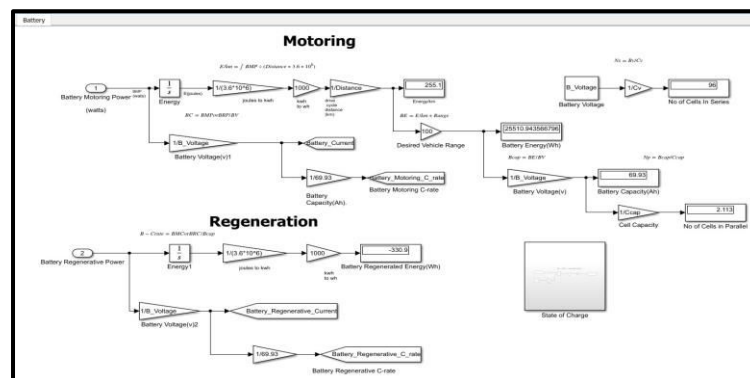


Figure 1.6 Battery C rate model

The battery C Rating is the measurement of current in which a battery is charged and discharged at. The capacity of a battery is commonly rated at 1C, meaning that a fully charged battery rated at 1Ah should provide 1A for one hour. State of charge (SoC) is the level of charge of an electric battery relative to its capacity.

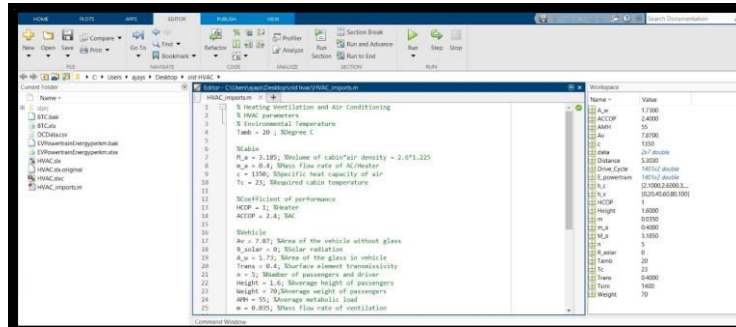


Figure 1.6 HVAC imports file

Here different parameters and constants for the vehicle impacting HVAC inside and surroundings are defined.

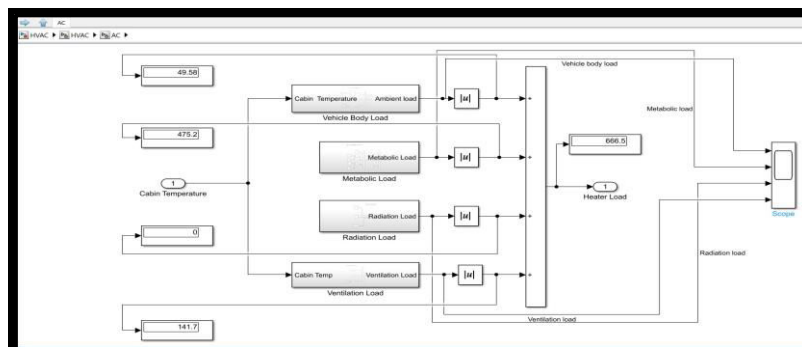


Figure 1.7 AC loads

The thermal dynamics within a vehicle cabin encompass four key loads. Firstly, the Metabolic Load results from the continuous heat and humidity generated by metabolic processes within the human body. This heat traverses through body tissues and ultimately dissipates into the cabin air, constituting the metabolic load. Secondly, the Ambient Load characterizes the thermal conditions transferred to the cabin air due to temperature variations between the external environment and the cabin air. The third component, Ventilation Load, involves the introduction of fresh air into the vehicle cabin to uphold passenger air quality. With passengers exhaling, CO2 concentration gradually rises, necessitating a consistent inflow of fresh air for comfort. Notably, the cabin pressure is typically maintained slightly higher than ambient pressure due to the influence of air conditioning and ventilation systems.

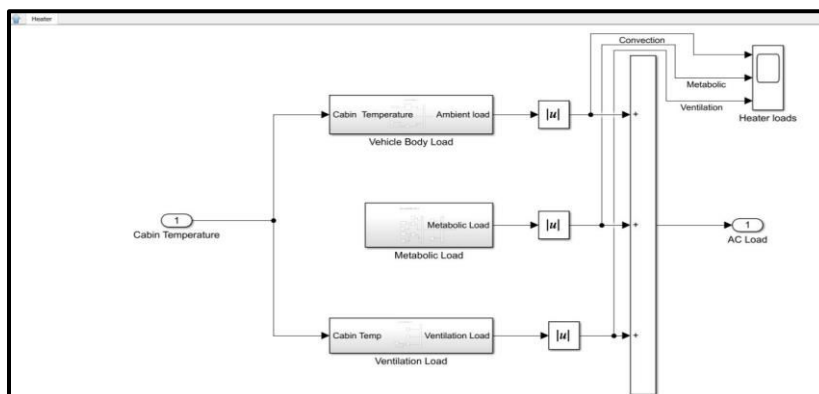


Figure 1.8 Heater loads

Similarly, the loads are calculated for the desired cabin temperature to determine total Heater loads. The heater is not affected by radiation loads. The heating load is the amount of heat energy that would need to be added to a space to maintain the temperature in an acceptable range. The heater and AC loads are compounded and calculated against other factors such as mass flow rate to match the required cabin temperature to the desired cabin temperature. Then these loads are considered against the coefficient of performance, which is the is a ratio of useful heating or cooling provided to work (energy) required of AC and heater to determine the power required by the HVAC system.

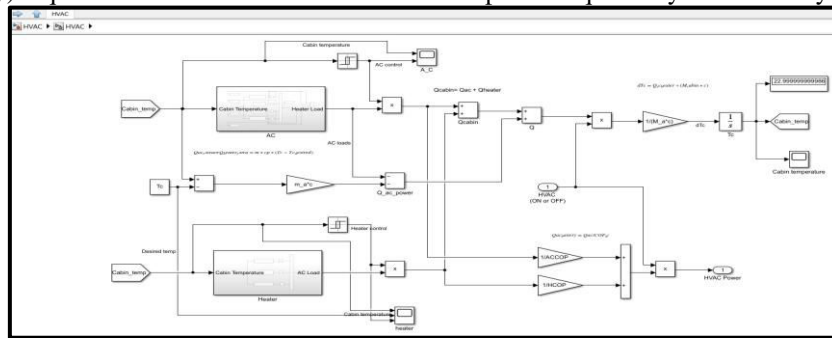


Figure 1.9 Connections of cabin temperature and loads

Here the HVAC battery energy and Electric vehicle powertrain energy is obtained as output. We can get the output by opening and closing the circuit (HVAC on and off). The HVAC system is connected to a DC-DC converter and the energy output is obtained. Then the data from the powertrain model is merged to obtain the electric HVAC load.

### III. RESULTS

We have understood about the functionality of HVAC system and in general thermal systems of an electric car by considering Tesla electric car for reference. We also gained knowledge regarding the components of HVAC systems and need for heat pump in electric cars. The functioning of components such as compressor, cabin condenser, cabin evaporator, liquid cooled condenser, chiller, radiator, pump, valves and various other components gives a wider insight into the working and inter-relation between the substituents and their impact on the performance of the electric vehicle. A detailed exposure & understanding of heat pump & non heat pump based thermal management systems for cabin & battery cooling & heating, motor & power electronics cooling, significance of energy savings using heat pump based system, HV components such as charging unit, power distribution, HV wiring connections, DC-DC converter & safety components which are part of latest electric vehicles is obtained and analysed with respect to various geographical and climatic conditions.

The vehicle resistive forces such as rolling force, aerodynamic force, gradient force and acceleration force impact the speed and performance of the vehicle. The force resisting the motion of a rolling body on a surface is known as rolling friction or rolling resistance. An aerodynamic force is a force exerted on a body by the air which the body is immersed, and is due to the relative motion between the body and the gas. The pressure-gradient force is the force that results when there is a difference in pressure across a surface. The acceleration force refers to the vehicle's resistance to speed variations. This force holds you back when you increase your speed and also moves you forward when you slow down. The average velocity of the vehicle is obtained from the standard drive cycle. Here the Artemis drive cycle is used. The velocity of vehicle and radius of the wheel is used to determine the wheel speed. The motor torque and wheel speed is obtained from wheel speed and wheel torque respectively. Torque is a crucial part of generating power from a car's engine, as it represents the load an engine can handle to generate a certain amount of power to rotate the engine on its axis.

Motoring and regenerative power are required to determine the energy consumed per unit distance in an electric vehicle and thus the variation of these powers results in significant changes to the performance of the vehicle. The AC and heater switches on and off alternatively as per required to maintain desired cabin temperature which is taken to be 23°C. Here, the heater control is 1 which means it's switched on and the temperature is below 23°C and so it's heated to reach the desired cabin temperature. Alternatively if the cabin temperature is higher than the desired then heater shuts off and AC switches on thus trying to reach desired cabin temperature.

When either the heater or air conditioning is switched off the control output is denoted as zero and meanwhile the other is switched on and the output is one. The controls keep switching on and off as demanded by the system through relays

to maintain the desired cabin temperature. Here the heater is switched on and AC is off so the output for heater is one while AC control output is zero.

#### IV. CONCLUSION

The car occupies the daily universe of our society; however, noise pollution, global warming gas emissions, and increased fuel consumption are constantly increasing. The electric vehicle is one of the recommended solutions by the reason of its zero emission. Heating and air-conditioning (HVAC) system is a part of the power system of the vehicle when the purpose is to provide complete thermal comfort for its occupants, however it requires far more energy than any other car accessory. Electric vehicles have a low-energy storage capacity, and HVAC may consume a substantial amount of the total energy stored, considerably reducing the vehicle range, which is one of the most important parameters for EV acceptability.

The significance of vehicle thermal management system is to improve the automotive thermal efficiency, as well as to achieve passenger comfort and long-lasting component reliability. In the same time, an efficient vehicle thermal management system can boost the automotive thermal efficiency which leads to higher miles per charge of electric vehicles (EVs) therefore, an optimised vehicle thermal management system is crucial for band EVs. In this study, the thermal load of HVAC on EV vehicle was determined and correlated to numerical calculation and test data of the vehicle. The determination of HVAC electric load helps in optimising and improving the performance of the vehicle as well as customizing the needs as per change in ambient temperatures.

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