

Thermal Management at Charging Stations

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Abstract:

The need for effective EV charging stations has grown as a result of the electric cars' (EVs') explosive rise. By efficiently dissipating heat from the charging apparatus, the thermal management system keeps its constituent parts operating within safe bounds. A variety of cooling methods are investigated, including liquid, air, and PCM, and their efficacy is assessed using simulations. The study looks at heat flow, finds important hot spots, and suggests ways to improve cooling techniques using programs like Solid Works for design and Ansys for thermal analysis. The project's findings will help create a reliable, scalable, and energy-efficient thermal management system that will improve EV charging stations' longevity, performance, and safety. A battery thermal management system based on a charging station heat pump system is presented to improve battery charging efficiency during high-power direct current charging. Through the charging station heat pump system, the system supplies coolant at the proper temperature. It makes it possible to charge the battery at the ideal temperature, increasing charging efficiency and cutting down on charging time. The suggested system's temperature characteristics and charging time, as well as the original battery thermal management system based on the electric vehicle heat pump system, are examined under five distinct temperature conditions using numerical simulation software to model and analyze the two system models. In this paper we will discuss. Thermal management at charging stations.

Keywords: Thermal Management, Charging Stations, EV Charging, Energy-Efficient, Battery, Temperature Differential, Megawatt Charging Stations, Cooling, Electricity Transfer.

Introduction:

The resistance to heat transfer from the electronics' core (junction) to their external packaging (case), which is represented by parts like Insulated Gate Bipolar Transistors (IGBTs), increases as power electronics manage higher loads. Due to this increase in resistance, the thermal management solution must work harder to dissipate the same amount of power while using a smaller thermal budget, which is the temperature differential between the ambient air and the electronics package.

Therefore, the need for more effective thermal management solutions grows as the infrastructure develops and the demand for faster charging increases. [1]

In order to manage the heat produced during the quick charging operations, high-power EV charging stations, such as those found in Megawatt Charging Stations (MCS), need sophisticated thermal management. To maintain operational integrity and safety, these stations must effectively control the surrounding temperature and cool the charging hardware.

Usually, stationary charging stations have liquid cooling systems to efficiently control the heat. These systems are particularly important in regions with high ambient temperatures, where cooling demands are much higher. They work by circulating a coolant to absorb and dissipate heat from the chargers. [2]

Advanced Thermal Management in High-Power EV Charging Stations

Megawatt Charging Systems (MCS) and other high-power EV charging stations need advanced thermal management to handle the significant heat produced during quick charging operations. In order to maintain operational integrity and safety, these stations must simultaneously control the surrounding temperature and cool the charging hardware.

Cooling the Charging Hardware

The capacity of high-power charging stations to effectively dissipate heat produced during the charging process is the foundation of thermal management. This is essential to preserving the longevity and integrity of the car's battery as well as the charging station. A liquid cooling mechanism is used in the majority of high-power charging systems. In order to absorb heat and subsequently release it from the charging components and the car, these systems use a coolant that circulates via the charging cables and connectors.

Ambient Temperature Management

High-power charging stations must control the surrounding temperature in addition to cooling the hardware. This is particularly crucial in areas with high ambient temperatures because the heat from the outside might make the temperature issues related to quick charging worse. Effective control of the ambient air temperature is necessary to avoid equipment overheating and to guarantee that safety regulations are fulfilled. For enclosed charging stations, this is frequently accomplished by combining ventilation, shaded station designs, and occasionally air conditioning. [3]

Integrating Cooling Systems

The development and sustainability of electric vehicles in heavy-duty and commercial applications depend on the installation of effective thermal management systems in off-highway vehicle battery charging, MCS for commercial trucks, and high-power EV charging stations. These technologies maximize the battery's lifespan and the overall efficacy of electric vehicle technology by ensuring that the infrastructure and vehicles run securely, dependably, and efficiently.

Pumps, radiators, and thermal sensors are some of the parts that go into integrating cooling systems in EV charging stations. Together, these parts create a feedback loop that modifies cooling intensity in response to heat load measurements made during charging sessions. In order to maintain ideal operating temperatures and increase efficiency and lower energy consumption, advanced systems can dynamically modify cooling flows based on real-time data.

Benefits of Effective Thermal Management

Protecting equipment is only one aspect of efficient thermal management in EV charging stations. It has a crucial part in:

- By keeping the ideal temperatures for electricity transfer, you can increase the charging speed.
- By avoiding temperature extremes, you can extend the life of the car's battery and the charging station.
- Guaranteeing the station's dependability, which is essential for user trust and the wider uptake of electric vehicles. [4]

Thermal management options for EV charging stations

After you comprehend your obstacles, waste heat loads, and surroundings, you may start thinking about your options:

Sealed Enclosure Cooling: ACT's enclosure cooling solutions use circulating air cooling to efficiently remove heat from the charging station's interior. Since they are off-the-shelf and reasonably priced, these are typically the first choice. In contrast to a conventional fan filter combo, ACT's Enclosure Cooling Product Line includes NEMA-rated seals to protect the cabinet from water, dust, and other contaminants while simultaneously cooling the inside. Numerous product SKUs with different cooling capabilities and above-ambient vs air conditioning choices are available. Please utilize our online calculator to determine the optimum product match for your application, and get in touch if you need further engineering assistance. Don't worry if the calculator doesn't have an option; you can still solve your EV station thermal targets with a bespoke method.

Another air-cooled product is the Loop Thermosyphon, which places the evaporator at the source component or components to provide a direct cooling method and, in the end, reduce thermal resistance between the power electronics casing and the air. Due to its orientation dependence (requiring the liquid to return by gravity), this is one of the hidden gems of thermal management alternatives. It is not appropriate for the

majority of applications, and the loop operation to improve capacity is not frequently taken into consideration. This is a perfect fit for this business because EV charging stations may usually find the air-cooled condenser at the top of the cabinet. It provides the maximum capacity above ambient air-cooled EV charging station alternatives because to its large capacity (shown > 50kW air cooled heat rejection), flexible packaging options, and exceptionally low thermal resistance (< 0.005 W/C). The excellent dependability and low energy consumption (totally passive operation) are even more significant than thermal performance, making it a cost-effective choice when taking installation and lifetime ownership costs into account.

Liquid Cooling: Switching from passive air cooling to active liquid cooling is the next sensible step in your cooling strategy. This enables a higher EV station power density (waste heat), but it also necessitates higher energy consumption and pump maintenance. Low freezing point water mixes, such as EGW, are rather well understood and have high heat transfer capabilities. When combining water with medium-to-high voltage applications, they do present certain safety risks; nevertheless, risk is frequently reduced by careful implementation and separating the liquid loops from the power electronics.

Two-Phase Pumped Cooling Systems: Two-phase liquid cooling systems effectively remove heat from electronic components by using the latent heat of vaporization. Primarily based on refrigerant, P2P provides comparable cooling capabilities to single phase water solutions, but because it relies on boiling effects rather than fluid velocity (fractional pump power required), it has a better degree of intrinsic safety and uses less energy. Although this technology is more emerging than mainstream, P2P is gaining traction in high power density racks like data centers and Power Electronics systems like EV charging stations. [5]

Review of Literature:

Although electric vehicles (EVs) have been around since the mid-19th century, they've only recently gained popularity. The need to reduce greenhouse gas (GHG) emissions is one of the main factors behind this popularity. In addition to this, new technologies, ease of use, subsidies and tax rebates from governments, increased customer awareness, and the availability of a wide range of models have given rise to the popularity of EVs [6]

The increasing demand for traditional energy sources has led to a number of unfavorable environmental effects. As a result of resource depletion and excessive CO₂ emissions, the greenhouse effect and unintended global warming occur. The Paris Agreement controlled the planet's temperature and decreased CO₂ emissions (Saerbeck et al., 2020). To lessen these issues, clean energy resources and associated technologies have been developed. Approximately 25% of greenhouse gas emissions originate from the transportation sector, despite the fact that technological developments have greatly decreased these emissions. [7]

Objectives:

- To Study the Thermal Management at Charging Stations
- To Explain Charging technology for electric vehicles
- To Study the requirements of Electric Vehicle Thermal Management

Research Methodology:

The study is exploratory in nature. The data used for preparing this paper are secondary in nature which is collected from the various published resources. The data derived for preparing this research paper has been extracted from various elite journals and relevant websites.

Result and Discussion:

Electric vehicles (EVs) drastically reduce pollution and their impact on the environment by using batteries to power their motors rather than fossil fuels. EVs do away with combustion by using electricity to charge the battery, providing advantages like:

- Improved energy efficiency
- Pollution-free operation

- Lower environmental footprint

Notwithstanding these benefits, there are still issues with charging infrastructure, especially the requirement for quick, widely dispersed charging stations. Heat generation rises with charging rates, requiring sophisticated cooling methods to preserve effectiveness and security. [8]



Figure 1: Charging technology for electric vehicles

Charging technology for electric vehicles

As illustrated in Figure 2, this section offers details on various EV charging levels, charging methods, and charging schemes in addition to a few international standards to take into account when setting up an EVCS.

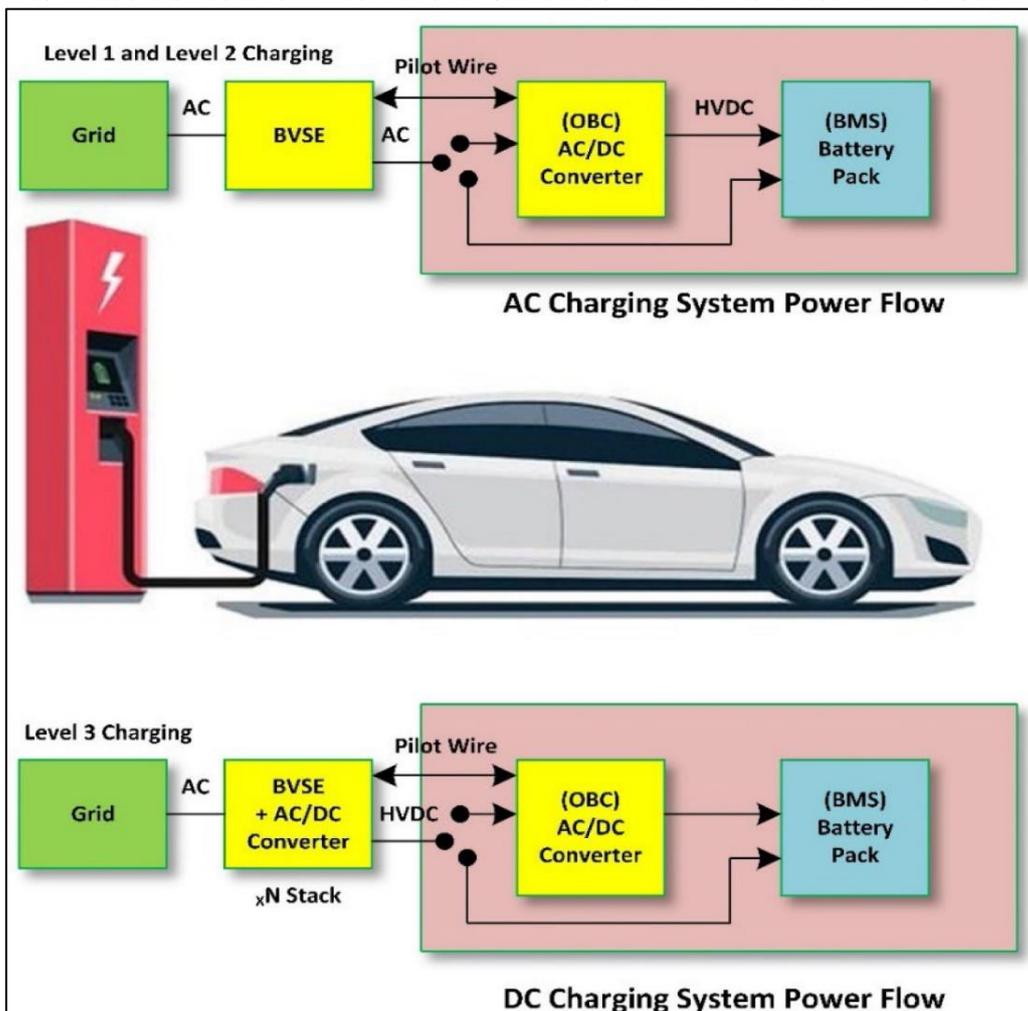


Figure 2: Modes of charging at different levels.

Electric Vehicle Thermal Management Requirements:

1. Cabin Thermal Management Requirements

The environment that a driver experiences while traveling is provided by the vehicle's cabin. Existing research shows that harsh driving conditions can lead to driver tiredness and cognitive impairment, underscoring the significance of cabin temperature control in the automobile sector. Controlling a number of variables, such as temperature, humidity, and airflow, is necessary to maintain levels within the intended comfort range and provide the best possible thermal comfort in the cabin. It is important to remember that, as Table 1 illustrates, the cabin's thermal management requirements may change from summer to winter.

Table 1. Cabin thermal management requirements

Seasons	Cabin Temperature (°C)	Relative Humidity (%)	Airflow Rate (m/s)	Fresh Air Volume (m ³ /h)	Thermal Load (kW)
Summer	24~28	40~65	0.3~0.4	20~25	3.0~9.3
Winter	18~20	>30	0.2~0.3	15~20	1.5~6.0

The steady-state heat transfer method, quasi-steady-state heat transfer method, and unsteady-state heat transfer method are the three categories into which recent studies have divided cabin thermal load calculation techniques. The steady-state heat transfer approach is frequently employed for thermal load estimate in current investigations because of the complicated nature of cabin thermal load, which involves multiple elements, as illustrated in Figure 3. Models that have been specially constructed or pre-designed using multiphysics field simulation software, such as MATLAB SimDriveline, MATLAB/Simulink, AME Sim, and Dymola/Modelica, are used to streamline the modeling process of the electric vehicle cabin and increase the speed and accuracy of thermal simulation. [9]

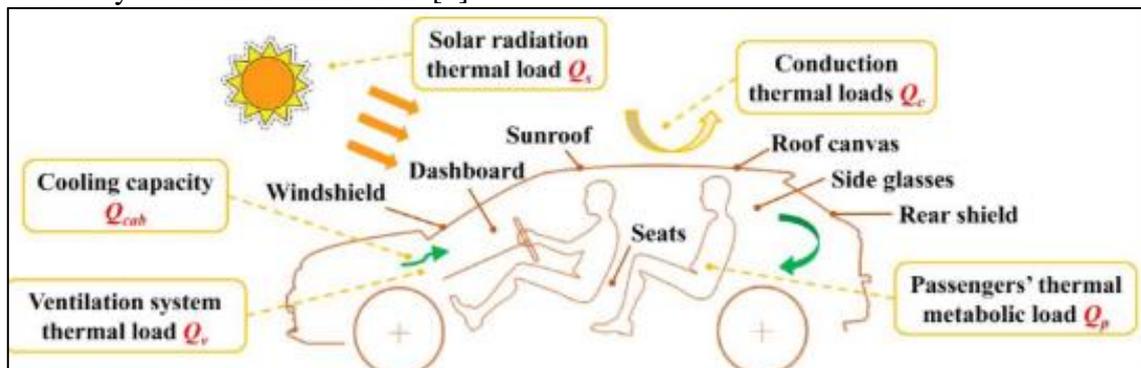


Figure 3. Cabin thermal loads.

2. Power Battery Thermal Management Requirements

Due to its many advantages over other rechargeable technologies, including high energy density, low self-discharge rates, extended cycle life, and light weight, Li-ion batteries are thought to be the best power source for electric cars. Li-ion batteries may theoretically operate in the temperature range of $-10\text{ }^{\circ}\text{C}$ and $50\text{ }^{\circ}\text{C}$, according to studies. Nevertheless, studies have shown that the battery experiences a process of capacity degradation at low temperatures, and aging is exacerbated at temperatures higher than $50\text{ }^{\circ}\text{C}$. High operating temperatures can affect safety, internal electrochemical processes, battery life, and charge/discharge efficiency. The positive feedback loop for battery thermal runaway and the subsequent chain reactions during thermal runaway are depicted in Figure 4. In order to maximize performance and guarantee safety, the literature currently in publication indicates that optimal battery thermal management necessitates keeping the battery temperature within the advised operating temperature range, which is normally between $15\text{ }^{\circ}\text{C}$ and $35\text{ }^{\circ}\text{C}$. Thermal inconsistency must be taken into account while packing batteries, and there should be no more than a $5\text{ }^{\circ}\text{C}$ temperature differential between battery cells in a pack.

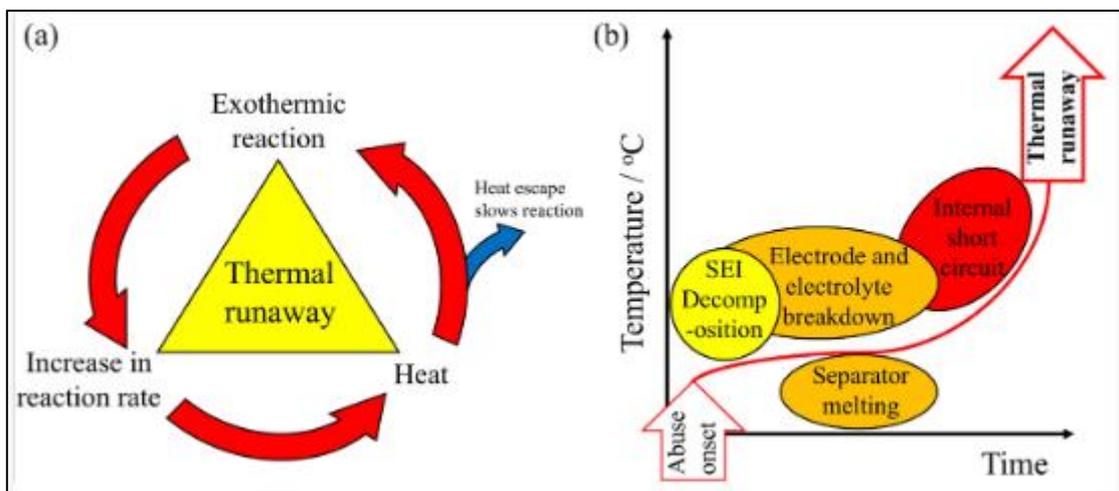


Figure 4: (a) Battery thermal runaway positive feedback loop; (b) chain responses during thermal runaway

A number of heat-generating models, such as the electrochemical-thermal model, the electro-thermal model, and data-driven models based on intelligent algorithms, have been developed to precisely explain the thermal characteristics of batteries. The internal cell structure, component thermal properties, and the electrochemical reaction mechanism are the main topics of the electrochemical-thermal model. This model represents the current, voltage, heat production, and heat transfer processes that occur in the cell during electrochemical reactions, including the diffusion migration of lithium ions and variations in electrolyte concentration. It is based on the kinetics and thermodynamics of electrochemical reactions. The single particle (SP) model and the pseudo-two-dimensional (P2D) model are the most often utilized electrochemical-thermal models. However, the inclusion of several coupled partial differential equations (PDEs) necessitates the simplification of the models from an engineering standpoint. [10]

3. Electric Motor Thermal Management Requirements

Motors need to have more power density, torque density, and speed in order to satisfy the growing demand for electric vehicles. This raises the temperature and loss density significantly, which can result in short circuits, magnet demagnetization, and other problems. Electric motor performance metrics, such as power density, longevity, and driving range on a single charge, will rapidly decline if the motor is not adequately cooled. High temperatures have the potential to demagnetize the magnets incorporated into the rotor of permanent magnet motors. As seen in Figure 5, the motor is a major contributor to the energy production of electric vehicles and produces a significant quantity of heat when in use. Permanent magnet synchronous motors, switching reluctance motors, and AC induction motors are the most widely used electric vehicle motors. The power required for thermal management varies according to the size of the electric vehicle motor, which can range from 2.5 to 6 kW, 6 to 10 kW, and 10 to 15 kW.

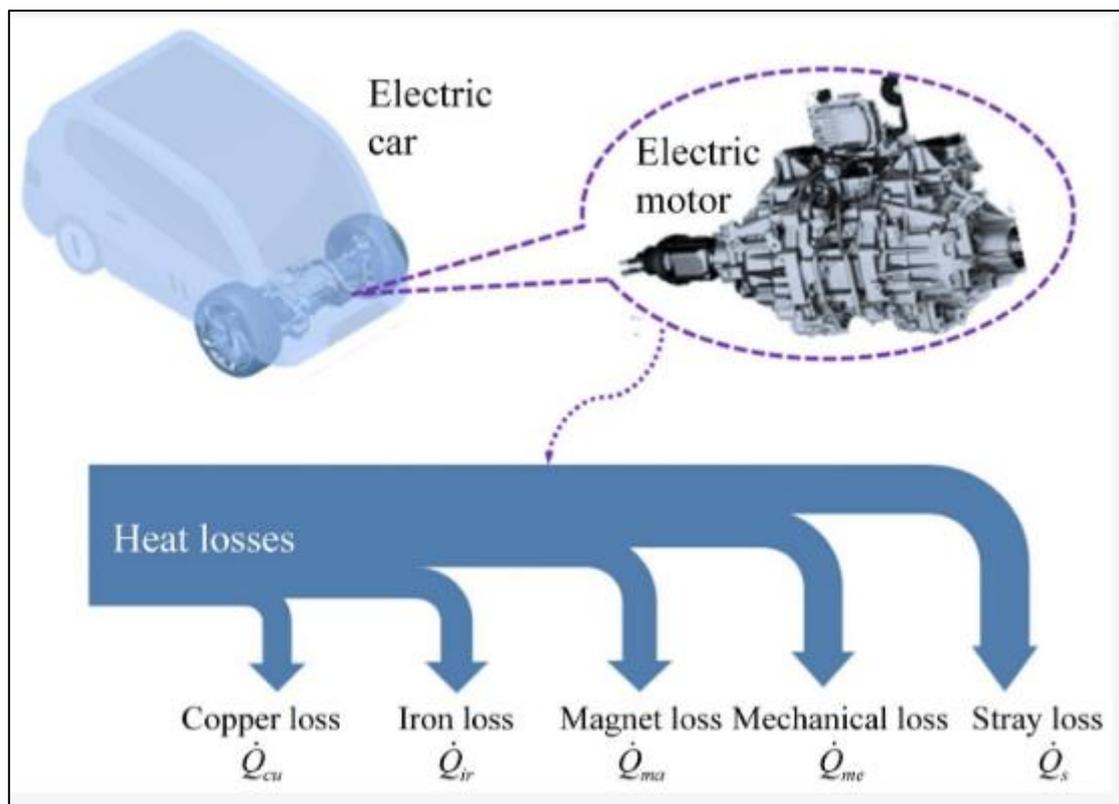


Figure 5: Electric motor heat generation.

A number of theoretical modeling techniques have been put out to support academic efforts to meet electric motor thermal management criteria. The finite element method (FEM), lumped-parameter thermal network (LPTM) method, and computational fluid dynamics (CFD) method are the main theoretical modeling techniques. Details like heat flow, temperature, and pressure distribution in the motor domain under specified boundary conditions are provided by the FEM and CFD methodologies. On the other hand, the LPTM approach can estimate the thermal nodes' temperature quickly but with less precision. [11-12]

CONCLUSION:

Thermal management at EV charging stations is crucial for fast charging, as high-power levels generate significant heat that must be controlled to prevent component damage, maintain charging efficiency, and ensure safety. Systems use methods like liquid cooling, air cooling, and cooling fins to dissipate heat from the charger and the vehicle's battery pack. Without proper management, chargers can overheat, leading to failure and a shorter lifespan. In an EV, the thermal management system for controlling the temperatures of various vehicle components is very complex: It cools and heats the battery and motors efficiently, keeping components at their optimal operating temperatures.

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