Power Electronics and Battery Cooling Methods

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The global promotion of electric vehicles (EVs) through various incentives has led to a significant increase in their sales. The prolonged charging duration remains a significant hindrance to the widespread adoption of these vehicles and the broader electrification of transportation. While DC-fast chargers have the potential to significantly reduce charging time, they also result in high power demands that the grid and hence may require local battery energy storage systems (BESS) for peak shaving applications. A high power demand also creates high losses and cooling methods play an important role in overall efficiency, sound pollution, system size, reliability, and lifetime of the system.

EV DC-fast charging battery energy storage system (BESS) EV charger topology

1. Power Electronics Cooling Methods

Regardless of which topology is selected, a DC-fast charger consists of a grid-connected power filter, AC/DC active front end stage, DC/DC stage, and isolation stage. Therefore, a power electronics system cooling consists of cooling the power semiconductors, power inductors [1] and transformers [2][3], and capacitors. In [4], a review of cooling strategies is made for EV traction inverters. In **Figure 1**, different methods are listed with the coolant material phase and the material.

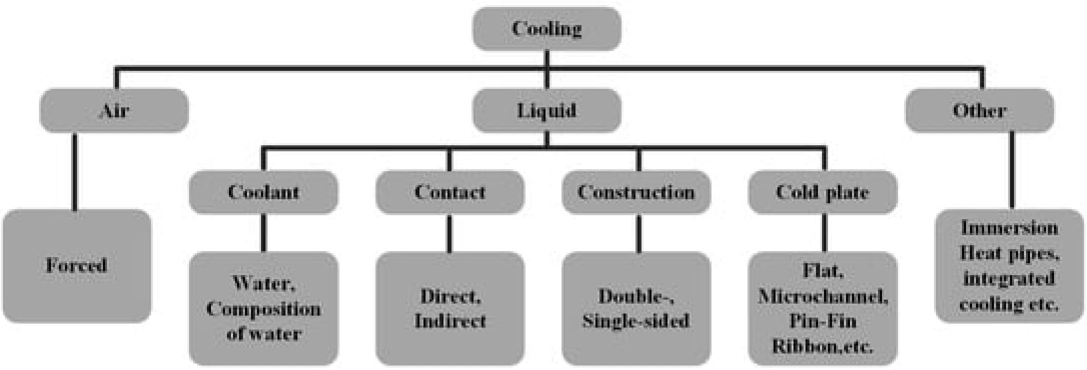

Figure 1. Different cooling methods for PE cooling [4].

In **Figure 2**, the cooling methods for a few industrial DC-fast charger systems are presented where the majority of the manufacturers are using liquid cooling methods with a few using forced air cooling. The advantages/disadvantages of air cooling and liquid cooling are presented in **Table 1**. As discussed in the introduction, the number of DC-fast charging stations will increase in the future and will be distributed. This means the chargers will be integrated into the urban areas and commercial areas ext, meaning the size of the overall system is important. Therefore, the manufacturers are choosing liquid cooling over force air cooling. Moreover, these charging systems are subject to environmental conditions where the IP rating becomes important. Liquid cooling allows the removal of heat from enclosed systems meaning a higher IP rating can be achieved. In addition, considering the high number of chargers integrated into public spaces, reducing sound pollution is essential. Finally, a higher efficiency results in lower operational cost and less heat generation meaning a lower junction temperature oscillation resulting in a higher reliability and longer lifetime.

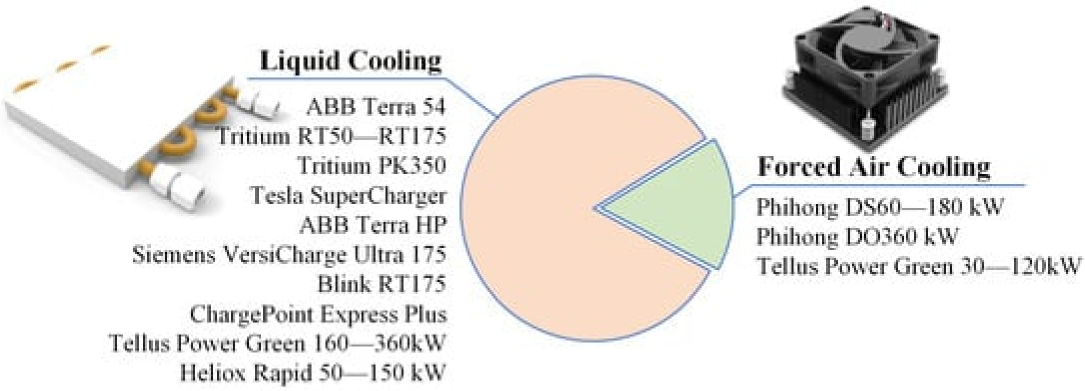

Figure 2. Type of cooling used in the commercially available industrial EV DC-fast charger systems.

Table 1. Comparison of air and liquid cooling methods.

	Advantages	Disadvantages
Air Cooling	• Low cost • Does not need additional equipment like heat-exchanger, pump,.. • Active control of fans allow control of junction temperature	• Performance depends on the environment. • Requires CFD analysis for complex systems. • Can be bulky for high-power applications. • Harder to achieve high IP ratings due to polluted air. • High operation noise. • Fan reliability effects the overall lifetime.
Liquid Cooling	• Higher efficiency • Heat removal from enclosed system is easier • Less space and lighter system • Low operation noise	• Requires CFD analysis for proper channel design • Required pumps, heat exchanger ext.

2. Stationary and EV Battery Cooling Methods

So far, the cooling methods for power electronics were the focus of the discussion. However, for a DC-fast charger with BESS, the cooling of batteries are just as important from the point of view of increased lifetime and reliability.

2.1. State-of-the-Art Cooling Methods for Local BESS and EV Batteries

Battery energy storage systems (BESS) are an important technology for renewable energy storage, as they allow excess energy to be stored and used when needed. However, one challenge with BESS is keeping the batteries at an optimal temperature to ensure their performance and longevity, particularly in challenging situations such as providing short-term power.

One of the most common methods for cooling BESS is air cooling, which uses fans or other mechanical devices to circulate air around the batteries and dissipate heat [5]. This method is relatively simple and inexpensive, but it can be less effective at cooling the batteries in high ambient temperatures or at high charge/discharge rates.

Another method for cooling BESS is liquid cooling, which uses a liquid coolant to transfer heat from the batteries to a heat exchanger [6]. This method is more effective at removing heat from the batteries, but it requires a more complex cooling system and can be more expensive to implement.

In **Figure 3**, different configurations for air and liquid cooling for thermal control are presented [7]. In **Table 2**, the advantages and disadvantages of both methods are listed.

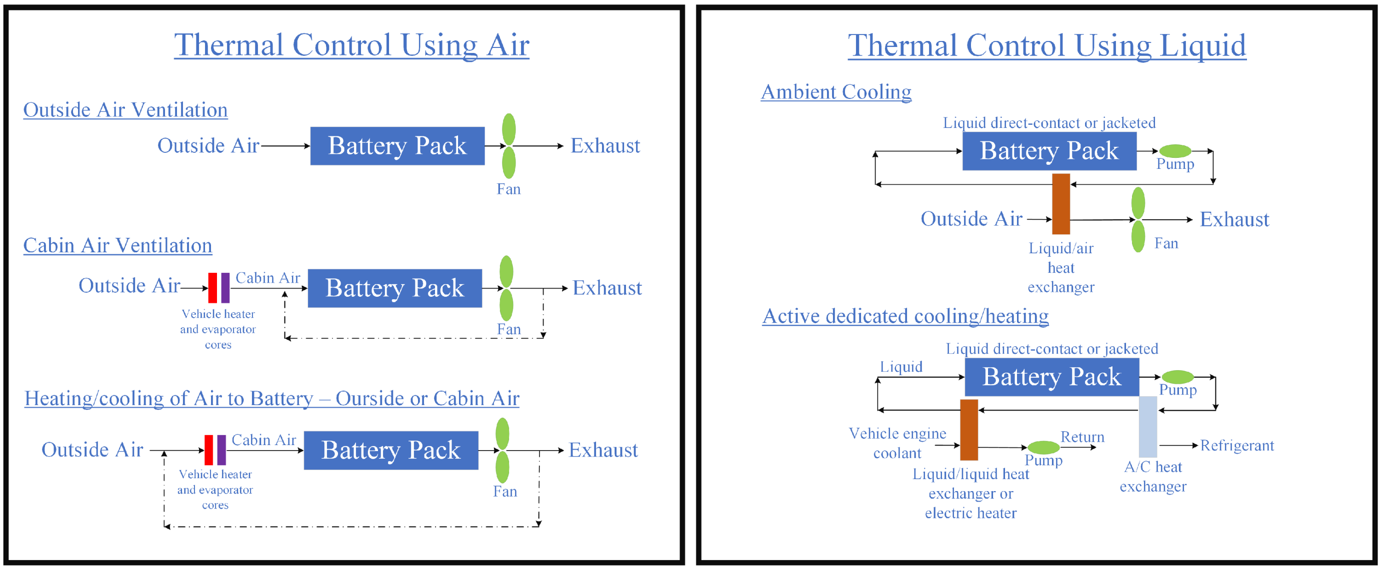

Figure 3. Different cooling methods for Battery Thermal Management.

Table 2. Advantages and Disadvantages of Using Air/Liquid for Thermal Control.

	Thermal Control Using Air	Thermal Control Using Liquid
Advantages	Waste heat released to air No separate cooling loop No leakage concern No electrical short-circuit due to leakage	Pack temperature is more uniform and thermally stable Good heat transfer capability Better thermal control Lower pumping power

	Thermal Control Using Air	Thermal Control Using Liquid
	Simple design and lower cost Easier to maintain	Lower volume Compact design
Disadvantages	Low heat transfer capability More temperature variation in the pack Might influence cabin temperature Potential of venting battery gas to cabin High blower power Blower fan noise	Additional components Higher weight Liquid conductivity can lead to isolation loss Leakage potential Higher maintenance Higher cost

erials that e [8]. PCM cooling can be more effective at maintaining a consistent temperature for the batteries, but it requires special PCM materials and can be challenging to implement in practice. A variation of this includes the use of phase change slurry (PCS), as a working fluid for cooling. This has the advantage of the requirement for smaller cooling circuits and associated pumps.

There are several different methods for cooling BESS, each with its own advantages and disadvantages. Air cooling is simple and inexpensive, but may not be effective at high temperatures or high charge/discharge rates. Liquid cooling is more effective, but requires a complex cooling system and can be expensive. PCM cooling can maintain a consistent temperature, but requires special materials and can be challenging to implement. Further research and development are needed to improve cooling methods for BESS and optimize their performance and longevity.

2.2. Smart Pre-Conditioning Methods for Battery Charging for Improved Lifetime

Pre-conditioning of battery systems typically includes the pre-heating or pre-cooling of the battery system such that the charge transfer can be maximized with minimal detrimental effects to the batteries in terms of aging and safety [9]. These types of methods can make use of both of the thermal management circuits of the battery and also include interaction with other thermal management subsystems (such as that of the climate system) [10]. These operations can be run prior to the charging process (provided that predictive information is available), or in parallel with the charging process. Typically the higher C-Rates experienced by the battery for fast charging can lead to phenomena such as lithium plating (resulting in the loss of active material within the battery) [11]. This is most prevalent at lower temperatures and lower SOCs. As such pre-warming of the cells is desirable before fast charging can occur. Additionally, the high C-Rates over sustained periods can lead to high cell temperatures. By managing a lower starting temperature, the shorter-term requirement on the cooling circuit can be minimized. An alternative approach has also been suggested wherein the coolant is rapidly exchanged during the charging process. This method allows for the pre-conditioning of the cooling, and the high demand on the vehicle-side heating/cooling is removed [12].

Several ongoing research areas exist for the pre-conditioning for battery charging for an improved lifetime. These include:

- The development of advanced algorithms and machine learning techniques for predicting and optimizing the charging process, in order to minimize stress on the battery and maximize its capacity and longevity [13].
- The development of improved understanding of the effects of different charging protocols, such as the constant current/constant voltage (CC/CV) charging, pulse charging, and others, on the performance and lifetime of the battery [14].
- Studying the interactions between different factors that affect battery charging, such as temperature, state of charge, and charging rate, in order to develop more sophisticated models and algorithms for optimizing the charging process [15].
- Testing and evaluating smart pre-conditioning in different battery chemistries and applications, such as lithium-ion batteries for electric vehicles, stationary energy storage systems, and portable electronic devices.
- Integrating smart pre-conditioning into commercial battery charging systems, in order to demonstrate its benefits and potential for real-world applications.

There is considerable potential for further research and development in the area of smart pre-conditioning for battery charging, and this remains an open area of ongoing research.

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