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Review of Li- Ion Battery Thermal Management Methods and Mitigating Techniques: 2/3 W Electric Vehicle for Tropical Climatic Condition

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Abstract: The quantum of transient heat generated and subsequent transient temperature is interdependent non linear functionality with several boundary conditions affecting the lithium ion battery pack performance with transient heat conduction under tangible operating and ambient temperature has a substantial short and long term impact on the electrical performance, life, reliability and safety of lithium-ion batteries.

In the tropical condition, the variation in ambient temperature of lithium ion battery pack for 2/3 wheeler is comparatively high and varies from + 25°C to +55°C because of higher atmospheric temperature as well as the batteries having less thermal evacuation system and ventilation because of lack of space and other constraints, thus exerting constantly higher but variable thermal stress like temperature gradients, thermal expansion or contraction and thermal shocks causes irreparable aging and degradation effect.

It is essential to quantify the transient heat generation and temperature distribution of a battery cell, module, and pack during different operating conditions with methodologies for its proficient management and mitigating techniques.

The demand for thermal management is multi prong to maintain the temperature of batteries within the safe operating temperature range zone and the non-uniform temperature distribution must remain within the range of the reference limit for the purpose of preventing the occurring of thermal runaway for favorable working performance.

The objective of thermal management is to device suitable monitoring and measurement, designing the suitable thermal path to expel heat generated and suitable mechanism for prevention of breakdown.

In this paper, the comparative transient temperature distributions across two identical battery packs(48V24Ah (15S4P) series-parallel connected lithium-ion Ferro phosphate cell), one without any thermal management system and other with thermal management system are studied under various charging and discharging currents with various ambient temperature range, similar to tropical region for checking the effectiveness of designed thermal management system of the battery pack.

Keywords: Lithium ion battery, Battery thermal management system, electric vehicle, heat dissipation.

I. INTRODUCTION

Tropical climate or mega thermal climate is located around the equator with latitudes ranging from 25^0 south to 24^0 degrees north is a major climate groups with almost 40% of global surface with 40% of global population which falls on high monthly average temperatures of 18°C or higher with high levels of precipitation.[1,2]

The countries in this range are fast developing and are also experiencing higher demand for portable and stationery energy storage systems for their communication, renewable energy and mobility growth. Mobility growth starts with basic two wheelers are for personal transportation where as three wheelers are for small last mile connectivity as well as point to point transportation.

The demand for Lithium ion batteries which is the main driver for electric vehicle propulsion is expected to be 213 GWh in 2020 and rise to 794 GWh in 2025[3].

Lithium ion batteries for electric vehicle are most suitable because of several advantages like high energy density and long cycle life over other technology batteries but temperature raise in cell as well as battery pack poses several challenges. While low temperature affects the performance, life and reliability but higher or abnormal temperature may cause explosion or fire and raises severe safety concern.

A sample survey of commercially available models reveals that the voltage range of a 2/3 wheeler battery electric vehicle hovers from 12V till 72V with ampere hour ranges between 12Ah till 200Ah with capacity of 2- 10KW for 3 Wheeler and 1-6KWH for 2 wheelers. Because of several manufacturers in the segment, wide variety of battery pack is used with only constraint is the battery should be light weighted and should occupy least space.

Several studies, research and development on various aspects of raise in temperature inside a cell or battery packs and several management and mitigation techniques are proposed and thus a suitable thermal management system is an absolute necessity to control the monitor and control the operating temperature and protect lithium ion batteries in battery packs for electric vehicles in case of any abnormalities from optimized parameters. Thermal management is a challenging topic for batteries in electric vehicles. The operational temperature range of electrical components, such as the battery, inverters and drive motors in electric vehicle are relatively small and its performance degrades drastically with fluctuation in temperature, compared to conventional propulsion systems which uses different thermal management methodologies and their components are more thermal stable and more robust towards temperature fluctuation. Thermal management is also safety pertinent because of the possible and unexpected derating effects which lead to reduced acceleration capabilities, as well as possible thermal events and pack runaway/venting.

Electrochemical batteries, first invented by Alessandro Volta in 1800, now become the necessities in today's life. Electrochemical batteries classified into primary and secondary batteries. Primary batteries are which cannot be recharged, which is due to the irreversible electrochemical reactions occurring in the batteries. Zinc–carbon batteries are one of the examples of primary batteries.

Secondary batteries, which are also called rechargeable batteries due to reversible electrochemical reactions that occur in the batteries. Although primary batteries still hold the major part of the commercial battery market, there are challenges associated with the use of primary batteries, including the generation of large amounts of unrecyclable materials, and the toxic components in the batteries that post environmental concerns.

The development of secondary batteries rose rapidly in last few decades, including the development of nickel–metal hydride batteries, Lead Acid Batteries and lithium-ion batteries etc. Among these secondary batteries, lithium-ion batteries, which exhibit high energy density and excellent working performance, are leading the current secondary batteries usages which has high energy density (up to 705 Wh/L) and power density (up to 10,000 W/L) exhibit high capacity and great working performance. As rechargeable batteries, lithium-ion batteries serve as energy storage and power sources in numerous applications.

The first commercial lithium-ion batteries, introduced by Sony Corporation in 1991, led a revolution of the energy storage market. A common lithium-ion battery consists of lithium compound-based cathode, carbon-based anode, electrolyte and separator. In general, the cathode materials are coated on an aluminum foil and the anode materials are coated on a copper foil, respectively. The aluminum and copper serve as the current collectors. A piece of porous polymer separator that is immersed in electrolyte and sandwiched between the anode and cathode prevents the shorting of the two electrodes.

Lithium ion batteries are used as power sources to various electronic products, electric vehicles, and energy storage systems as well as in military and aerospace applications. One of the major limitations of lithium-ion batteries is operating temperature, which significantly impacts on the performance of lithium-ion batteries and also limits the application of lithium-ion batteries. Moreover, different ambient temperature results different and adverse effects. Accurate measurement of temperature inside lithium ion batteries and understanding the temperature effects are important for the proper battery management.

Most of the temperature effects are related to chemical reactions occurring in the batteries and also materials used in the batteries and battery pack. Regarding chemical reactions, the relationship between the rate of chemical reactions and reaction temperature follows Arrhenius equation, and temperature variation can lead to the change of electrochemical reaction rate in batteries. Besides chemical reactions, the ionic conductivities of electrodes and electrolytes are also affected by temperature.

Generally, the acceptable operating temperature region for lithium-ion batteries is −20°C~ +60°C and optimal ambient temperature range for lithium-ion batteries is 15°C~ 35°C. Once the temperature is out of these comfortable regions, lithium-ion batteries starts degrading fast with increased risk of facing safety problems that include fire and explosion.

In general, impacts from temperature can be divided into two categories: low temperature effects and high temperature effects. Low temperature effects mostly take place in high-latitude country areas, such as Russia, Canada and Greenland Island and it affect the performance and life of lithium-ion batteries, especially for those used in Electric Vehicles. At these low operating temperatures, lithium-ion batteries will show slow chemical-reaction activity and charge-transfer velocity, which leads to the decrease of ionic conductivity in the electrolytes and lithium-ion diffusivity within the electrodes. Such decrease will result in the reduction of energy and power capability, and sometimes even performance failure.

As compare to the low temperature effects that are mostly limited to the low temperature application environments, the high temperature effects happen in a much broad range of application environments, including not only high temperature environments but also on low temperature environments. The environmental temperature plays a critical role in low temperature effects, while most of time high temperature effects are attributed to the high internal temperature of lithium-ion batteries during operation rather than the environmental temperature. The high internal temperature is caused by heat generation inside the lithium-ion batteries, which happens at high current state, including operations with fast charging rate and fast discharging rate. The high temperature effects will also lead to the performance degradation of the batteries, including the loss of capacity and power. If the temperature is out of control, thermal runaway will be triggered, which may lead to self-ignition and even explosion in some cases.

Proper management of the operating temperature of lithium-ion batteries plays important role in performance and safe operation of the batteries. One of the approaches to provide suitable working conditions for lithium-ion batteries by adding thermal monitoring, heat dissipation and control mechanism referred to as battery thermal management system (BTMS) which serves both the purpose of keeping the maximum/minimum temperature of batteries within the operating temperature range limit and maintaining the non-uniform temperature distribution within the range of the reference limit for prevention of performance loss and thermal runaway.

The phenomenon of non-uniform temperature distribution is related to the battery pack geometric, packing material feature, charge/discharge rate, ambient temperature and heat dissipation rate. For a battery, the battery's surface area to volume ratio has a significant effect on the non-uniform temperature distribution. Different locations of current collecting points/terminals and the ratio of the battery's length and width distinctly affect the uneven distribution of temperature. An appropriate battery geometry design can produce a uniform temperature through parameters such as the length to width ratio, location of current collecting points/terminals, and the ratio of volume and surface area. In a lithium-ion battery pack, the position of the cell may cause huge differences in the cooling effect and little output and performance, which may lead to variable non uniform temperature distribution. Less temperature uniformity results in the rapid decay of the cycle life of the battery pack. Even worse, the non-uniform temperature distribution may aggravate the unbalanced discharging phenomenon and decreases the available energy for the battery packs. A combination of an appropriate heat dissipation strategy, the pack's structure, and the rate of charge/discharge is required to design a suitable BTMS which also involves multi objective optimization algorithm for design optimization with objective of simplified and accurate design and efficient models under variable parameters for design. Designing a BTMS for a specific battery pack, the following parametric analysis is to be carried out like how much heat must be removed from the pack, what are the allowable maximum and difference in temperature, which kind of heat transfer pattern is needed, is active cooling required, etc.

II. REVIEW ON HEAT GENERATION IN A LITHIUM ION BATTERY PACK

Degradation in lithium ion (Li-ion) battery cells is the consequence of a complex interaction of congregational of different physical and chemical mechanism taken place either in storage or in use. The quantifiable effects of degradation mechanisms on the cell can be summarized in terms of three degradation modes- loss of lithium inventory, loss of active positive electrode material and loss of active negative electrode material.

The different degradation modes are assumed to have unique and measurable effects on the open circuit voltage (OCV) of lithium ion cells and electrodes. The rate of degradation and degradation itself is also interlinked with heat generation inside cell as well as battery packs.

Heat is either generated inside cell and gets accumulated due to technically non feasible or inefficient heat dissipation methodologies which build up inside the pack and creates cascading effect leading towards thermal runaway and explosion/ fire. Heat generation measurement itself is a complicated process as the surface measured temperature can only describe the trends of core temperature changes rather than the real time changes because the heat conduction between the heat source and battery surface is not instantaneous.

The heat generation within the lithium ion batteries at any ambient temperature is associated with charge transfer and chemical reactions during both charging and discharging cycle in the reversible or entropic heat originates from the reversible entropy change during electrochemical reactions and the irreversible process like active polarization process, ohmic heating process, heating due to mixing and enthalpy change.

The heat generation triggers lithium ion battery aging and subsequently thermal runway because of exothermic reactions and the uncontrolled heat generation triggers more heat that exceeds the heat endurance of the batteries causing fire and exploration.

The degradation of components at higher temperature leading towards thermal runaway inside a lithium ion cell starts overlapped sequential phenomenon of solid electrolyte interface decomposition, self discharge of cathode, negative active material and electrolyte reaction, positive active material and electrolyte reaction, electrolyte decomposition, negative active material and binder reaction, etc.

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Unlike to low rate of charge/ discharge, lithium ion battery generates more heat during the high current charge and discharge process. Due to inefficient or technically impossible accumulated heat dissipation in certain areas of the lithium ion battery pack leads to nonuniformity temperature distribution results indifferent performance, self-discharging rate, state-of-health, and state-of-life of each individual cell in the battery pack. Research shows that 10^0C to 15^0C temperature gradient across the battery pack causes a 30% to 50% degradation of the cells which leads towards a well-designed thermal management system development becomes important to maintain each cell temperature within the optimal range and keep the temperature uniform across the battery pack.

The heat generations within the lithium ion batteries are governed by law of thermodynamics and was studied extensively by several researchers, pioneered by Bernardi et al(1970) onwards, long before invention of lithium ion batteries and is having few similarities with other electrochemical energy storage and was extensively studied[4-7].

The thermal process and electric process inside a working lithium ion battery are often coupled together. For example, the heat generation inside the lithium ion battery is correlated with the internal resistance. The increase of the internal temperature can lead to the drop of the battery resistance, and in turn affect the heat generation. The change of resistance will also affect the battery power. Therefore, several researches paid attention to the establishment of thermal-electric models that consider the interactions between thermal and electrical processes.

In lithium ion cell, all components like current collectors, separator, and electrodes has different in heat generation behavior with different thermal conductivities and the temperature profile inside the cell is non homogeneous which complicates further due to different placement pattern and different heat dissipation methodologies.

In order to achieve an effective battery thermal management system, absolute needs is to have elementary understanding and information from which area, how much of heat generated inside the lithium ion battery pack and where the pack is operating at what duty cycle and what are the objectives to be achieved with this battery pack etc.

The best objective for a battery thermal management system is to achieve the best possible heat transportation and dissipation to maintain the operating and ambient temperature in permissible range.

It is also evident that thermal management is ambient temperature dependent and different battery thermal management system may required at different climatic conditions.

Afzal, et al. [2018], investigated the effect of spacing between the battery cells on thermal performance of li-ion battery cells, using finite volume approach, assuming heat generation within the battery cell is assumed to be uniform subjected to flow of laminar and incompressible coolant (air).

Alaoui, chakib. [2013] computationally designed & evaluated Peltier effect heat pump based BTMS & experimental validated on a 60ah lfp 60ah prismatic & pouch type Li - ion cell measured under different rates & ambient temperature cell.

Al-zareer, et al.[2017] proposed a unique battery cooling system with the evaporating pool based cooling concept based on 3d electrochemical thermal model, using liquid propane by boiling it to convert into vapour which can be used in all direction and to understand how to attain the battery pack thermal performance within the optimum recommended operation range, and achieve a similar and even better performance than the commonly used air and liquid based systems.

Arora, et al.[2019], experimentally investigated the relationship of heat generation rates with cell capacity and thickness for developing a scalable battery TMS and arrived that heat generation rate for lithium ion cells depends on discharge rate, ambient temperature , DOD and cell electrode thickness.

Chen, et al.[2020] develop a simple method of constructing a symmetrical air-cooled system with uneven cell-spacing distribution to improve the cooling performance using computational & experimental method and found that it has better performance than asymmetrical system and developed 5 different arrangement to compare symmetrical & asymmetrical arrangement.

Chen, et al.[2018] computationally developed flow resistance network model to calculate the airflow rates of the cooling channels cooling efficiency of parallel air-cooled battery BTMS with U-type flow improved through optimizing the structure of the system and the numerical results shows that temperature and temperature difference among the battery cells reduction can't be effective through arranging the angles of the plenums, while optimizing the widths of the inlet and the outlet improve the cooling efficiency of the BTMS.

Chen, et al.[2019], studied the improvement in cooling efficiency of the air-cooled BTMS through designing the flow pattern of the system using CFD method to calculate the flow field and the temperature field of the BTMS.

De vita, et al.[2017] presented a computational modeling approach to characterize the internal temperature distribution within a Li-ion battery pack using entropy-based and irreversible-based heat generation in mathematical calculations.

Huo, et al.[2015] designed a mini-channel cold plate-based battery thermal management system to cool a rectangular li-ion battery using a three-dimensional thermal model of the cooling system and the effects of number of channels, flow direction, inlet mass flow rate and ambient temperature on temperature rise and distribution of the battery during the discharge process were investigated and the simulation results shall be useful for the design of mini-channel cold plate-based battery thermal management system.

Iora, et al.[2019], presented a general quasi-steady backward-looking model for energy consumption estimation of electric vehicles used to assess the effect of ambient temperature on energy consumption and range, considering various reference driving cycles and the results were supported and validated using data available from an experimental campaign where, Nissan leaf was driven to depletion across a broad range of winter ambient temperatures.

Jarrett, et al.[2014] determined the influence of different operating conditions on the optimum cooling plate designed and modeled parametrically and assessed using CFD and found that the distribution of heat generated by the battery cell is main focus to design coolant plate with simulation done by defining the boundary conditions.

Jiaqiang, et al.[2017]. Analyze the influence of four parameters(channel height h, width l, channel number m and the coolant flow rate v) affecting the system heat dissipation on the cooling effect of a liquid-cooled BTMS and proved that channel number effect is most obvious, effect of coolant flow rate is followed & channel height has minimum effect for the cooling.

Jouhara, et al.[2020], experimentally investigated the performance of a heat pipe based thermal management technique for prismatic lto batteries and demonstrated that heat mat technology can improve battery performance and longevity by reducing the degradation and ageing process and cell imbalances, that result from high cell temperatures and module/pack-level temperature non-uniformity.

Kantharaj, et al.[2019] reviewed and summarized the sources and origins of heat generation in Lithium-ion batteries, highlights recent advances in thermal characterization and modeling of Lithium-ion batteries with an emphasis on the multi-scale aspect of battery systems: from the micro scale electrode components to the macro scale battery packs. Both heat generation and thermal properties and emphasized that thermal runaway must be thoroughly investigated using different combined experimental-computational techniques with varying cathode chemistry. Computational efforts must be directed toward developing simulations of electrode microstructures.

Kim, et al.[2019] reviewed the heat generation phenomena and critical thermal issues of lithium-ion batteries for various battery thermal management system and categorized them according to thermal cycle options.

Kong, et al.[2020] proposed a coupled composite phase change material and liquid cooling thermal management system and their simulation results showed that the coupled system with suitable design exhibited good thermal performance at an ambient temperature of 30 °C, which kept the maximum surface temperature and the temperature difference of the battery pack at 41.1°C and 4°C at the end of 3C discharge.

Lan, et al.[2016] developed a novel design of BTMS based on aluminum mini channel tubes and applied it on a single prismatic li-ion cell under different discharge rates.

Li, et al.[2014] designed a sandwiched cooling structure using copper metal foam saturated with phase change materials and their thermal efficiency were experimentally evaluated and compared with two control cases: a cooling mode with pure phase change materials and an air-cooling mode. Their results showed that the thermal management with air natural convection cannot fulfill the safety demand of the Li-ion battery.

Lin, et al.[2015] developed a passive thermal management system for $LiFePO_4$ battery modules using phase change material (PCM) as the heat dissipation source to control battery temperature rise and their experiments on warm-keeping performance show that the passive TMS can effectively keep the battery within its optimum operating temperature for a long time during cold weather uses.

Liu, et al.[2014]. Carried out a series of experiments on a power- type lithium manganese oxide/graphite battery implemented under different conditions using lumped battery heat transfer model and arrived that the total heat determined are by influencing parameters like environmental temperature, aging effect, SOC & operation current (charge/ discharge current) etc and arrived that due to its simplicity, the temperature variation estimation method is suitable for real time applications.

Liu, et al.[2019] investigated the performance implications caused by various factors like single cell performance, uneven currents in parallel strings due to cell-to-cell variations, thermal gradients and/or cell interconnects by simulating six parallel connected batteries based on a thermally coupled single particle model with the solid electrolyte inter phase growth degradation mechanism modeled. Their experimentally validated simulations show that cells closest to the load points of a pack experience higher currents than cells further away due to uneven over potentials caused by the interconnects.

Lu, et al.[2019] established two different thermal conditions, namely constant temperature condition and near-adiabatic condition to explore charging/discharging characteristics and heat generation behaviors of the lithium-ion battery with Li cathode.

Lyu, et al.[2019] experimentally investigate the performance on an advanced battery thermal management system and developed battery thermal management system is a combination of thermoelectric cooling, forced air cooling, and liquid cooling.

Ma, et al.[2018] reviewed the effects of temperature to Lithium-ion batteries at both low and high temperature ranges and the current approaches in monitoring the internal temperature of lithium-ion batteries via both contact and contactless processes were discussed.

Ma, et al. [2018] reviewed that thermal challenges exist in the applications of Lithium-ion batteries due to the temperature-dependent performance. High temperature effect the accelerates the aging, shorten life & leads thermal run away due to exothermic reaction in LIBs where as low temperature effect the ionic conductivity & increase in charge transfer resistance. They opinioned that at present the temperature in most models are assumed to be uniform, while in reality the distribution of temperature in batteries is inhomogeneous.

Maures, et al.[2019] proposed a calendar ageing model featuring time and temperature dependence of a lithium-ion battery and the ageing procedure is done at a high state of charge (SOC) of 95% and the tested temperatures range from −20°C to 55°C.

Mohammadian, et al.[2015] computationally analyzed special kind of aluminum pin fin heat sink whose heights of pin fins increase linearly through the width of the channel in air flow direction and effects of pin fins arrangements, discharge rates, inlet air flow velocities, and inlet air temperatures on the battery were investigated by 3d transient thermal analysis of an air-cooled module.

Mohammadia et al.[2017] studied three-dimensional transient thermal analysis of an air-cooled module was carried out to investigate cumulative effects of using pin fin heat sink and porous metal foam on thermal management of a Li-ion battery pack under different test cases.

Nazari, et al.[2017] studied and determined the different sources of heat generation which are significant and which sources of heat generation are negligible at different Li-ion battery pack design and operating conditions.

Panchal, et al.[2017] presented a comparative study of the temperature and velocity distributions within the mini channel cold plates placed in a prismatic lithium-ion battery cell and their study was conducted both experimentally and numerically using the RANS models in ANSYS fluent.

Qian, et al.[2016] investigated the thermal performance of lithium-ion battery pack using liquid cooling method based on mini-channel cold-plate and established the three-dimensional numerical model. The results showed that the mini-channel cold-plate thermal management system provided good cooling efficiency in controlling the battery temperature at 5C discharge.

Rao, et al.[2013] their experimental result showed that the maximum temperature could be controlled below 50°C when the heat generation rate was lower than 50 W. Coupled with the desired temperature difference, the heat generation rate should not exceed 30 W. They also investigated using paraffin/ copper foams also.

Rizk, et al.[2018] proposed a three-dimensional transient model, predicting the thermal behavior of a 60 ah prismatic Li-ion battery during charge/discharge cycles under natural convection and used an experimental test bench to charge and discharge the battery at different current rates in order to track its thermal behavior using thermocouples and heat flux sensors.

Shang, et al.[2018] mathematical derivation and numerical analyzed a liquid cooling system for lithium-ion battery with changing contact surface is determined by the width of cooling plate. Evaluation of cooling performance and the consumption of pump power is determined and its results show that increasing inlet mass flow can effectively limit the maximum temperature, but cannot improve temperature uniformity significantly.

Shen, et al.[2020] solve the thermal management problem of a 55 ah Li Ion battery by designing a mini channel cold plate–based liquid cooling method using numerical simulation method and the performance of the BTMS are parametrically studied by using different configurations, flow rates, and inlet coolant temperatures.

Shen, et al.[2020]carried out computational analysis and proposed a refrigerant based BTMS and accesses its thermal behavior and system energy and exergy efficiency based and established a mathematical simulation model for refrigerant-based BTMS, and its performance was analyzed under different stressful conditions based on AMESim in the background of vehicle system.

Sun, et al.[2014] .used analytical design of experiments (DOE) approach done using optimal Latin-hypercube technique then correlated with battery pack thermal model and a morphing model for temperature uniformity across the battery pack, individual lithium-ion pouch cell, and the cooling efficiency of the battery pack.

Wang, et al.[2016] experimentally studied a phase change material/oscillating heat pipe (PCM/OHP)-based BTMS and its influencing factors, including temperature variations under different heating powers, battery surrogate terminal direction and OHP placement, were discussed.

Wang, et al.[2019] carried out quantitative measurements and simulations of heat release. A thermal condition monitoring system was built by them to obtain the temperature of a lithium-ion battery under electrical heating conditions and the results were validated using two independent simulation methods and showed that the heat generated by the battery increases with the decrease of the discharge resistance.

Wei, et al. [2020], used CFD & COMOSOL software with experimental validation for design and development of a reciprocating cooling strategy combined with a flat heat pipe which overcomes the drawbacks of unidirectional cooling because of temperature gradient. They proved their strategy to have several advantages over unidirectional cooling methodologies.

Wiriyasart, et al.[2019], computational analyzed that the maximum temperature has significant effect on energy storage, durability, life cycle & efficiency of the battery module 444 cylindrical (18650) Li ion cells and for cooling a appropriate range of coolant – nano fluids & water is used and a 28.65% reduction in max temp was observed.

Xi, et al.[2020] proposed analyzed and optimized with computational fluid dynamics method, a novel Z-shaped battery pack structure.

Xia, et al.[2017] reviewed the heat generation phenomena and critical thermal issues of lithium-ion batteries and categorized various according to thermal cycle options and opinioned that future BTMS will be developed to integrate several option like the direct two-phase refrigerant cooling with the PCM, heat pipe and thermoelectric systems.

Yang, et al.[2015] developed a thermal model to investigate the variations of the cell temperature in a cylindrical battery packs (10 x 6). The effects of the longitudinal and transverse spacing on the cooling performances of are discussed for both aligned and staggered cell arrangements.

Yang, et al.[2019] reviewed thermal physical parameter for different type of cells, heat generation & dissipation model, air, liquid & PCM based coolant, battery heating strategies, system evaluation criteria as delta temp., energy density or volume ratio of pack, cooling effectiveness of BTMS, energy consumption & thermal runaway risk etc with existing commercially available car models. They concluded that it is indispensable to establish criteria to evaluate battery thermal management systems.

Yuksel, et al.[2015] characterized the effect of regional temperature differences on battery electric vehicle (BEV) efficiency, range, and use-phase power plant CO_2 emissions in the U.S.A and find that the efficiency varies with ambient temperature due to battery efficiency and cabin climate control with finding that annual energy consumption of BEVS can increase by an average of 15% in the upper mid west or in the southwest compared to the pacific coast due to temperature differences.

Zhang, et al.[2020] experimented on a tafel-lae895 100 ah ternary lithium ion batteries the discharging at different rates to study the surface temperature increasing characteristics of the battery where heat pipes with high thermal conductivity were used to accelerate dissipating heat on the surface of the battery & found that the heat pipe was sufficient to keep the battery temperature within the desired range with a mid level discharge rate.

Zhang, et al.[2020] carried exergy analysis of an electric vehicle heat pump air conditioning system (HPACS) with battery thermal management system by studying the exergy loss of each component and found that performance of the HPACS is better than that of the positive temperature coefficient (PTC) heater in cabin heating mode.

Zhao, et al.[2019] numerically studied and analyzing the effectiveness of cooling channels to reduce thermal non-uniformity in lithium-ion battery packs of electric vehicles with particular approach towards zero or near-zero thermal non-uniformity in lithium-ion battery packs and their performance and viability are evaluated through numerical simulations. The battery packs cooled by liquid flowing in serpentine channels are used to illustrate the proposed approaches.

Zhao, et al.[2015] reviewed a number of useful battery temperature control strategies from the aspects of both internal electrode modification and external thermal management in the hope of paving the way for the development of more reliable, robust, long-lived li-ion battery systems.

Literature review provides qualitative knowledge on the generation of heat and its effect on lithium ion battery pack. It is also revealed that ambient temperature affects the performance of a lithium ion battery pack. Several methods and designs with experimental as well as simulation validation were carried out for determining, mitigating the heat generated inside the battery packs. Literature also provide in depth knowledge and learning of the effects of design variance in making a battery pack.

However it is silent and found that no research work is found to be carried out for quantifying the thermal effects and its mitigation methodology for lithium ion battery pack for 2/3 wheeler for tropical region. Absence on a standard for lithium ion battery pack for 2/3 wheeler is also not observed, which makes different researchers, manufacturer, assemblers of lithium ion battery manufacturer to adopt different plan and process leading to wide variance in performance.

From simplicity point of view, air cooling methodologies can best suited for 2/3 wheeler lithium ion battery packs, where the structure of an air cooling system is considerably simple and without a sealing problem and works on newton's law of cooling and three methods can be selected: increasing convective heat transfer, increasing heat transfer area, and increasing the temperature difference between batteries and the cooling medium $\phi = hA\Delta t$, where h is convective heat transfer coefficient, A is heat transfer area. Convective heat transfer coefficient is a key parameter to evaluate the ability of air cooling structure, which can be gained by empirical equation of Nusselt number and Reynolds number for experiment of air cooling structure.

Air cooling strategies can be further categorized as natural cooling (natural convection) and forced cooling (forced convection) where later is better efficient.

Two types of natural air cooling structures are the serial cooling structure and the parallel cooling structure. Because specific heat capacity of air is much lower than many other cooling mediums, the air cooling strategy can achieved low cost and simplest pack structure for low to moderate heat generation rates, when batteries working as high-rate charge/discharge and the heat generation rate is larger, the strategy unable control the battery temperature in an expect range.

III. DISCUSSION

In this paper, we addressed the problem and need of multi directional approach and development of different types of battery thermal management system with wide variance in material, methodologies and process for standardization. We identified definite gaps in development of battery thermal management system for specific climatic region like tropical region for a particular application like 2/3 wheeler battery electric vehicle. While 2/3 Wheeler battery electric vehicle counters several unique constraints, design challenges, service requirements, no research and development work is been carried out for addressing this segment, which itself is a considerable big in these regions.

The literature review indicates gap in industry adoptability of proposed battery thermal management systems by different researchers.

The existing standards, practices and technical writing offer a extensive variety of options for a battery thermal management system with different approaches and methodologies without considering the applicability into 2/3 wheeler battery electric vehicle as well as variance in ambient temperature especially in tropical regions. While every literature proves lower as well as higher temperature effects on lithium ion battery, which itself has several variance in construction and chemical composition, a set of battery thermal management system for a particular battery for a particular application at a particular climatic condition is still not worked.

The design of this application oriented, inventive yet well-functioning battery thermal management system requires detailed research, design and analysis, product development, stricter supervision and control, quality audit and continuous improvement of the whole process for its quantified advantages and its shortcoming is needed for wide adoptability of this lithium ion battery technology.

While different vehicle requires different voltage/ capacity combination with different sizing and constraint in space, the cell & other components inside the battery pack also differs widely, making wide variance in performance of the battery pack.

Wide industry wise conscience on standardization of voltage- capacity of the battery, its pack size, its control and communication techniques, its serviceability etc shall lead to a quick, focused and directional development of product.

Our contribution in this paper is to identify the need for research and development of lithium ion battery thermal management system for 2/3 wheeler battery electric vehicle for tropical region with reviews on available the technological and research gaps.

Another contribution relies in the gaps in standardization which may lead towards development of standards of battery packs for its better performance, life and reliability.

From an experimental point of view, our contribution lies in the need for future development, short/ long term testing of standardized battery thermal management system for 2/3-wheeler battery electric vehicle.

In the tropical region different battery thermal management system like air cooled & or liquid cooling system can also be practiced for 2/3 wheeler Li ion battery packs to overcome the ambient temperature problem inside the battery pack because now a day no implementation done for better cooling in 1.5 kW & 2.0 kW swappable & or fixed battery pack for 2/3 wheeler electric vehicles.

IV. CONCLUSION

There are rarely thorough and common standards used to assess the performance of battery thermal management system till date. Most previous research was simply concerned about the maximum temperature and maximum temperature difference of batteries. Li ion Batteries' heat generation rates are complicated and closely related to their states.

The thermal issues of lithium-ion batteries are important. For the design of battery thermal management system, the focus should be on the cooling or heating capacity, the system complexity, energy consumption, reliability, and maintenance costs.

V. FUTURE WORK

Complexities in different methodologies, product types, approaches, service requirements, effect of ambient climatic condition leads to several possible product combinations whose development, adaptations, tests, and experiments which have been left for the future due to lack of time. Future work concerns to in design, development, depth analysis of particular mechanisms, new proposals to try different methods, or simply curiosity. Obviously, the use of other types of individual representations and different functionalities could be investigated since they have an important influence.

Specially, for 2-wheeler applications like Electric scooter & Electric Bike a vehicle integrated Li ion battery pack required to improve the air-based cooling by utilization of air flow surrounding the vehicle during running.

Liquid based battery thermal management system is also possible to implement, as small amount of power required to drive the cooling system which can be compensated by Regenerative power of vehicle.

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