Thermal Loss Minimization in an EV Inverter

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***Abstract*-There are certain requisites for electric vehicle (EV) propulsion systems such as switching frequency, cost as well as power density, are becoming more demanding, whereas high reliability requires to be ensured for maximizing life-cycle of the vehicle. Since, most power inverter failure mechanisms are linked to extensive semi-conductor junction temperatures, incorporating a thermal control technique is suitable. This report proposes a material (Dopped paraffin) whose melting point is 120◦C and it is to be pasted between PCB (Printed circuit board) and semiconductors' junction of EV inverter for maintaining the semiconductor junction temperature lower to extend the EV's life cycle.**

***Index Terms*-Electric Vehicle, Semiconductors, Life-Cycle, Paraffin, Radar.**

I. INTRODUCTION

One of the significant causes of anthropogenic greenhouse gas emissions is transportation. Let's take road transport; it is responsible for 27% of the total emission in major European countries, making it a huge contributor amongst each sector [1]. According to the meta-analysis undertaken in there is almost universal agreement that a move to electro-mobility would be needed to satisfy the Paris Agreement goals. [2]. For this purpose, a thorough comparison of CO2 emissions produced by battery-powered electric vehicles (EV) vs internal combustion engine (gasoline and diesel) vehicles has been done. [3]. A life-cycle evaluation was conducted, which included emissions from fuel extraction, refining, power generation, raw material extraction, vehicle manufacture, geographical differences (electrical mix, driving distances, etc.), maintenance, and the end-of-life phase..According to the authors of [3,] the longer the EV's travelled distance, the lower the CO2 emissions (note that battery production penalises EVs in terms of emissions), making research focused on improving dependability and maximising the life-cycle of EVs particularly vital. EVs would outperform gasoline and diesel vehicles in Europe in terms of emissions over a range of 76,545 km and 109,415 km, respectively.

However, for end users to accept battery-powered EVs, features must be comparable to those found in internal combustion engine vehicles. As a result, both electric machines (power density of 5.7 kW/L, overall efficiency of 93 %, and cost of 4.7 $/kW) and power electronics (power density of 13.4 kW/L, overall efficiency of 97%, and cost of 3.3 $/kW) have set lofty technological goals. [4]. Surface mounted or internal "Permanent Magnet Synchronous Machines" (PMSM) are extensively utilized where high power density as well as efficiency are needed. [5–8]. Current PMSM technology advancements put emphasis on multi-phase setups. [9,10], high speed electric machines(HSEM) [11–13], and with that in-wheel direct drive solutions [14,15]. For this, wide band-gap semiconductor technologies are under the scope of study for their entry in PMSM drive power inverters [16,17]for the below given reasons:

1. HSEM and in–wheel multi-pole direct drive solutions are cause of high electrical stator frequencies. And these effects brings regulation issues which are needed to be addressed [13,18,19], these can be improved and worked on by introducing power electronics technologies which function at high switching frequencies with manageable power losses[20].
2. Cost lowering trends requires sharing the high temperature cooling loop of the electric machine (at 105 ◦C) with power electronics [21,22], or taking use of the air cooling technologies that adopt convenient power converter placement to take benefit of circulating the air at the time of EV motion [23]. Thus, the use and deploy of power semiconductor technologies which have the capacity to withstand higher junction temperatures are needed [20].

Power converter dependability may be threatened as a result of such demanding operating conditions. According to [24],Thermal concerns are responsible for around 60% of power semiconductor failures. Furthermore, a 10°C increase in a power semiconductor's operation mean temperature can double its failure ratio [25]; As a result, particular attention to inverter thermal management is required. Mismatches in the coefficients of thermal expansion of the materials that make up power modules cause severe thermo-mechanical wear during thermal or power cycling, resulting in such failures. [26].

To avoid extremely high junction temperatures, operation point-dependent predetermined current and/or switching frequency derating techniques are extensively employed in the traction industry. However, in many circumstances, such derating numbers are cautious, reducing the drive's functioning limitations unnecessarily [27]. As a result, active heat management systems are being researched to improve vehicle performance. An electric drive's several levels (drivers, modulation, and control) can all be used to actively reduce power losses[28].In this paper, control approaches for active PWM strategy enhancement (bringing variation between different space vector sequences , the continuous and discontinuous) are given [29]. The common switching frequency hysteresis regulators also can be deployed [29]. Even if hysteresis regulators are widely employed in industry for their ease of use, their specific use has several disadvantages, such as the fact that they do not negate steady state mistakes. So, much superior approaches are described in the literature. As an example to give, the authors in [27,30] show a current (torque) and switching frequency limit for traction drives that takes into account electro-thermal restrictions and real-time temperature assessment. Such limits are modified to accurately monitor a specific temperature constraint by integrating not solely hysteresis as well as discrete regulators. Just like that, an algorithm based on model predictive controller for active thermal management is proposed [31].

II. PARAFFINS

Paraffins are high molecule mass which are made up of straight hydrocarbon chains. The melting temperature of paraffin is proportional to the amount of carbon atoms in the material structure, with melting values ranging from 6 to 80 degrees Celsius for alkanes comprising 12-40 C-atoms. These are referred to as "pure paraffins," and they are not to be confused with paraffin waxes. Paraffin waxes are made up of a mixture of hydrocarbon molecules with different carbon numbers, which have lower “melting points and latent heats” than pure paraffins. Paraffin waxes are commonly consider as a low-grade PCM.

Paraffin waxes, are used because of their potential as phase change materials (PCM). Paraffin wax is

- non-corrosive,
- cost effective,
- predictable,
- safe and dependable,

They are chemically inert, have a low vapour content in the melt, and show less volume change during melting.

There are some disadvantages of using paraffine waxes, such as congruent melting and self nucleating properties, paraffin waxes are difficult to use in practical applications due to inconsequential properties like as leakage, low thermal conductivity, and limited thermal stability. All of these negative impacts, however, can be avoided simply altering the wax and storage system. The storage system can be adjusted in a variety of ways, including direct wax inclusion into the polymer and wax encapsulation via microencapsulation or macroencapsulation.

For specific applications and temperature ranges, paraffins make a good PCM option. Paraffins have a high thermal storage capacity and have been shown to freeze without the need for supercooling. Chemical stability over numerous heating and freezing cycles, high heat of fusion, compatibility with almost all materials, and non-reactivity with most encapsulating materials are all advantages of paraffins.

III. SEMICONDUCTOR

The electrical conductivity of a semiconductor material is somewhere between that of a conductor, such as metallic copper, and that of an insulator, such as glass. As the temperature rises, its resistivity decreases, whereas metals have the reverse effect. By injecting impurities ("doping") into the crystal structure, you can change its conducting qualities in advantageous ways. When two separate doped regions appear in the same crystal, they produce a semiconductor junction. The behavior of charge carriers such as electrons, ions, and electron holes at these junctions is what drives diodes, transistors, and most modern electronics. Semiconductors include silicon, germanium, gallium arsenide, and elements on the "metalloid staircase" of the periodic table. Gallium arsenide is utilised in laser diodes, solar cells, microwave-frequency integrated circuits, and other applications. Most electronic circuits contain silicon.

Semiconductor devices can have a range of advantages, such as the capacity to transmit current more easily in one direction than the other, variable resistance, and light or heat sensitivity. Because the electrical characteristics of a semiconductor material may be altered by doping and the application of electrical fields or light, devices made of semiconductors can be used for amplification, switching, and energy conversion.

To increase the conductivity of silicon, a small quantity of pentavalent (antimony, phosphorus, or arsenic) or trivalent (boron, gallium, indium) atoms (on the order of 1 in 108) are added. This process is known as doping, and the semiconductors that arise are known as doped or extrinsic semiconductors. In addition to doping, increasing the temperature of a semiconductor can improve its conductivity. This is in contrast to the behaviour of metals, which sees conductivity decrease as temperature rises.

Quantum physics is used to describe the movement of charge carriers in a crystal lattice in today's knowledge of semiconductor characteristics. Doping substantially increases the amount of charge carriers in a crystal. When there are free holes in a doped semiconductor, it is called "p-type," and when there are free electrons, it is called "n-type." Semiconductor materials used in electrical devices are doped under precise conditions to control the concentration and distribution of p- and n-type dopants. In a single semiconductor device crystal, there can be many p- and n-type areas; the p–n junctions that connect these regions are what provide the useful electrical behavior. To swiftly determine whether a semiconductor sample is p-type or n-type, a hot-point probe can be employed.

Several features of semiconductor materials were observed between the mid-nineteenth and early-twentieth centuries. The cat's-whisker detector, a crude semiconductor diode utilized in early radio receivers, was invented in 1904 and was the first practical use of semiconductors in electronics. The transistor was invented in 1947 as a consequence of developments in quantum physics, In 1958, the integrated circuit was introduced, then in 1959, the MOSFET (metal–oxide–semiconductor field-effect transistor).

PROPERTIES

- VARIABLE ELECTRICAL CONDUCTIVITY

Since current needs the flow of electrons, semiconductors are poor conductors in their natural state as their valence bands are completely occupied, preventing new electrons from passing through. Doping and gating are two methods for making semiconducting materials behave like conductors. N-type and p-type proteins are the results of these modifications. These terms allude to either an abundance or a scarcity of electrons. A current would run throughout the material if there were an equal number of electrons.

- HETEROJUNCTIONS

When two different doped semiconducting materials are combined, heterojunctions are created. A setup might include p-doped and n-doped germanium, for example. Electrons and holes are exchanged across semiconducting materials with different doping levels as a result of this. In comparison to p-doped germanium, n-doped germanium would have more electrons and holes. Recombination, which causes migrating electrons from the n-type to come into touch with migrating holes from the p-type, continues the transfer until equilibrium is attained. A thin strip of immobile ions formed as a result of this action, producing an electric field that crossed the junction.

- EXITED ELECTRONS

A variation in electric potential causes a semiconducting material to lose thermal equilibrium and enter a non-equilibrium state. This brings electrons and holes into the system, where they interact through a process known as ambipolar diffusion. When a semiconducting material's thermal equilibrium is disrupted, the quantity of holes and electrons fluctuates. Photons or a temperature difference that can enter the system and create electrons as well as holes, can cause such disruptions. Generation and recombination are the procedures which make and destroy electrons and holes, respectively.

- LIGHT EMISSIONS

Excited electrons under some semiconductors could relax instead of producing heat by radiating light. Light-emitting diodes (LEDs) and fluorescent quantum dots are made from these semiconductors.

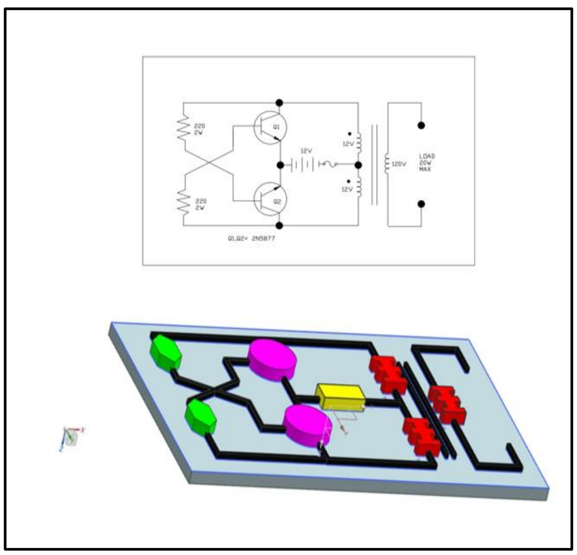
- HIGH THERMAL CONDUCTIVITY

'High thermal conductivity' semiconductors could be used to dissipate heat and improve electronic thermal management.

- THERMAL ENERGY CONVERSION

Due to their high thermoelectric figures of merit and large thermoelectric power factors, semiconductors are helpful in thermoelectric generators and coolers.

IV.PROPOSED MODEL



EVs are generally operate at low speeds having high torque, such as when climbing a hill, or in urban driving conditions with congested traffic, intersections, and traffic signals. These operating conditions are crucial because power losses are concentrated in a few power semiconductors at very low speeds, resulting in high junction temperatures.

As per study, Maximum Junction Temperature during the High load is 120◦C at maximum mechanical speed.

When this proposed material is applied between PCB (Printed circuit board) and semiconductors' junction of EV inverter and during load condition, semiconductors' junction temperature reaches at 120◦C then this material will be melted for keeping the temperature of semiconductor junction lower and eventually extend the EV life cycle.

V. CONCLUSION

In this study we discussed about the different properties of semiconductor and Paraffin(dopped) and how semiconductor can be saved by the use paraffin by applying this PCM between PCB (Printed circuit board) and semiconductors' junction of EV inverter and during load condition, semiconductors' junction temperature reaches at 120◦C then this material will be melted for keeping the temperature of semiconductor junction low enough as well as consequently extend the EV life cycle.

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