

Forced air cooled Heat sink design for Sic 1kV and 3.3kV power module using Multi-objective optimization

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ABSTRACT

Power electronics converters are making significant progress in making power conversion and distribution systems more efficient, reliable, power dense, and so on, partly by improving thermal management. This advancement in power electronics introduces new challenges for mitigating high power losses from power switches such as IGBTs, MOSFETs, etc. Air-cooled heat sinks are less expensive, lighter, and easier to install than liquid-cooled heat sinks, making them an excellent choice for high-risk applications such as shipboard applications. For this application, increasing the converter's power density is also an important consideration when choosing or designing the thermal management solution; the optimal design of the heat sink must be pursued to evaluate the benefits of the power throughput of the converter. This paper employs a genetic algorithm (NSGA-II) that performs multi-objective optimization of a forced air-cooled fin heat sink. The Pareto optimal front is shown, which maximizes power loss mitigation capability while minimizing heat sink volume and mass. The heat sink design is also validated using Finite Element Analysis (FEA).

I. INTRODUCTION

Power devices are critical and, to a large extent, ubiquitous for efficiently converting electricity. Despite their high energy conversion efficiencies, power modules always generate heat. These elements are unavoidable. Due to switching and conduction losses, a concentrated heat flux density occurs around the device and along the entire thermal path from the chip to the coolant. The efficiency of power devices suffers due to this heat flux, and devices and packages suffer from

thermally induced reliability issues. Power module packaging faces unprecedented thermal challenges as the market shifts from Si-based to SiC-based devices. SiC devices can be manufactured in much smaller sizes than Si devices for the same voltage and current specifications, allowing for more compact power module designs. The thermal resistance, on the other hand, increases quadratically as the die size shrinks. As a result, heat dissipation and cooling must be carefully considered when designing power module packing for SiC devices. [1].

A. Background and motivation

Earlier thermal advancements in a typical power module packaging focused primarily on steady-state thermal resistance. This method does not accurately reflect the transient thermal behavior of switching power modules. With rapid power pulses, SiC devices are expected to have highly concentrated heat flux densities. Improving thermal capacity and reducing thermal resistance are required to limit the peak temperature rises by these rapid pulses. Future power module

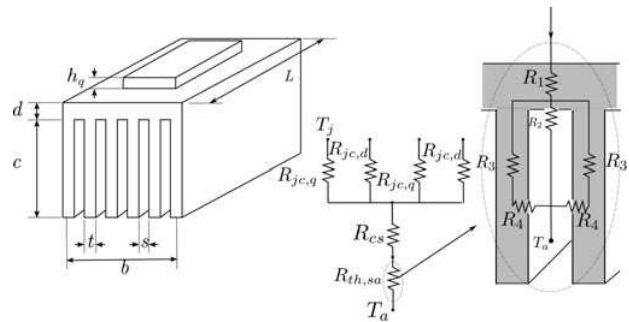


Fig. 1: Heat sink dimensions and equivalent thermal resistances. [2]

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bundles should consider the thermal issues brought on by using SiC devices [3].

Compared to silicon-based power semiconductor devices, wide bandgap power semiconductor devices developed in recent years have lower losses and a higher junction temperature capability; this makes air-cooled finned heat sinks an ideal candidate for high-power density applications. Heat sink optimization primarily focuses on reducing thermal resistance to increase the power density and reliability of the system [4]. The power density of the heat sinks is primarily around 100 W/cm², which can be improved to 1 kW/cm² by optimally choosing the materials and controlling all the factors listed in the next section II [5]. The system's power density is defined as the system's power transfer capability or rated power divided by converter volume. Although converter topology impacts system power density, the authors focus on optimizing for general device thermal losses and mitigating them. The power density of the heat sink combined with the cooling system's fan is limited by the fan's power consumption, the material's thermal conductivity, the thickness of the fins, and the number of fins. To evaluate the power density of the heat sinks, the [6] employs the cooling system performance index (CSPI), also called volumetric thermal conductivity. Although the CSPI is an excellent metric to evaluate power density in [7], no sophisticated algorithm is employed to evaluate large sets of data to evaluate and converge to a global solution. The authors expand the study to include fan selection and fin dimensions and use multi-objective optimization to narrow down the final solutions. The paper also illustrates a methodology called VPP [8] to assess trade-offs between five design space variables and five design space constraints, as shown in the next section II.

B. Research problem and objectives

The standard power module packaging based on DBC and wire bonds has a limited thermal resistance of unit area value, typically ranging from 0.3 to 0.4 K · cm²/W [9], assuming a 70-kVA inverter application, even with the most cutting-edge cooling strategies, such as directly cooled cold plates with pin fin structures. This value must be lower than 0.2 K · cm²/W to meet the study's [10] predicted future power module performance and cost goals. This can only be done using cutting-edge techniques, like double-sided cooling. The thermal management criteria listed below should be considered for future SiC packaging. Reducing or eliminating several package layers in the thermal route is preferable to minimize thermal resistance. Heat must be dissipated from the top side of the die to achieve a shallow degree of thermal resistance for a module. As a result, changes in the interconnection method to a larger area joint may be required. The use of advanced materials at the interfaces of the package's layers would allow for a reduction in thermal impedance. For instance, thermal conductivity joints and carbon-based composites can be used to substitute the materials used in the die attach and heat spreaders, respectively. Advanced cooling techniques such as

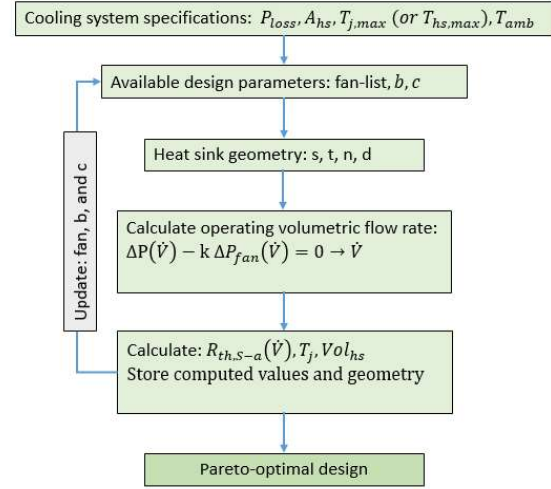


Fig. 2: Cooling system optimization fitness check for NSGA-II [2]

directed jet impingement, spray cooling, and microchannels must be implemented to improve heat removal capacity.

C. Brief overview of methodology and contributions

To address the issues that SiC devices present, novel methods for power module packaging are required. The virtual prototyping method can be used to design and optimize power module packaging. A virtual prototyping process includes modeling, simulating, and testing a design before creating a physical prototype. It enables the development of more efficient and cost-effective power module packaging. Virtual prototyping can improve the reliability and thermal efficiency of a forced air-cooled heat sink for SiC MOSFET modules. A forced air-cooled heat sink is commonly used to cool power module packaging. However, several heat sink design parameters must be optimized for optimal heat dissipation. The virtual prototyping method can aid in determining the best heat sink design by modeling various design parameters and simulating their performance. This significantly reduces the time and cost associated with actual prototyping and testing. Furthermore, virtual modeling can provide insights into the transient thermal. A promising strategy for overcoming these challenges is to use virtual prototyping techniques to develop and improve forced air-cooled heat sinks for SiC power modules. Because of its ability to reduce development time and cost and quickly evaluate a wide range of design options, virtual prototyping, which involves simulating and optimizing the performance of a design using computer models, has become increasingly popular in engineering design and optimization. Virtual prototyping can simulate the thermal performance of different heat sink designs, evaluate the impact of design parameters such as fin geometry, and optimize designs for maximum heat dissipation while minimizing pressure drop and other

design constraints in the case of heat sink design for SiC power modules. Virtual prototyping can also evaluate how well heat sink designs perform under different operating conditions, such as changing coolant flow rates or ambient temperatures. Several studies have already proven the use of virtual modeling for heat sink design. Zhang et al., for example, used virtual modeling in conjunction with a genetic algorithm optimization technique to improve the design of a heat sink for a SiC power module. They discovered that their optimized design had a 30% lower thermal impedance compared to a baseline design. Wang et al. used virtual prototyping to improve the design of a heat sink for a SiC power module, focusing on the impact of fin geometry on thermal efficiency. They discovered that decreasing the fin pitch and increasing the fin height significantly improved heat dissipation. Virtual prototyping was intended to investigate further the application of forced air-cooled heat sink design for SiC power modules in this investigation. The following objectives have been prioritized: Establish a virtual prototyping procedure for the forced air-cooled heat sink design for SiC power modules, including selecting appropriate modeling models and tools. Virtual prototyping will be used to improve the design of a heat sink for 1kV and 3.3kV SiC power units to reduce thermal resistance to less than 0.2 Kcm²/W. Determine how well the improved designs perform under different operating conditions, such as varying coolant flow rates and ambient temperatures. Examine how the improved designs respond to important design factors like fin geometry and coolant flow rate. The findings of this research will not only aid in creating SiC power module heat sink designs that are more efficient and effective, but they will also highlight the potential of virtual prototyping techniques for engineering design and optimization. Virtual prototyping techniques can help reduce the time required to develop new products and technologies, reduce costs, and improve engineered systems' overall performance and dependability.

II. VIRTUAL PROTOTYPING

Virtual prototyping (VPP) is a process that evaluates design space variables and trade space variables. NSGA-II runs the optimization described in [11]. Many attempts, including teaching-learning algorithms, have been made [12] to improve the finned cooled heat sink performance. Nevertheless, the standard comparison of the maximum possible power flow is needed and is shown in this paper. Each power switch module has a heat sink (or heat sink section). For simplicity, this study considers air-cooled, parallel plates heat sinks under forced convection like those of Fig. 1. Nevertheless, the methodology is extensible to different configurations, in Fig. 4 shows the details of the fan mass flow rate for the DC fans used for a section of these heat-sink packages, Fig. 3 shows the sample fans' relative sizes, Fig. 6 shows a sample heat sink design after it was built, Fig. 5 shows the 5th order poly-fit of the Fans cure listed in Table. I.

Virtual prototyping (VPP) has become an essential part of the design process for power electronics and heat sinks. It allows for evaluating design space and trade space variables,



Fig. 3: Cooling fans [13]

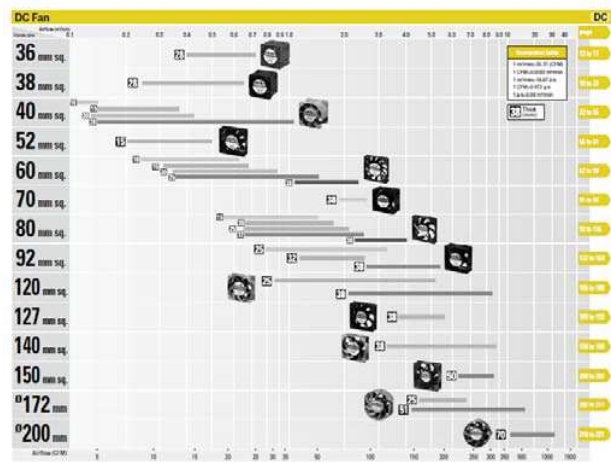


Fig. 4: Fan Mass flow rate vs pressure [13]

enabling designers to optimize their designs efficiently. This study combines VPP for power electronics and VPP for heat sink design for 1kV and 3.3kV SiC mosfet using the CSPI context and NSGA 2-based optimization.

A. Heat Sink Design:

Each power switch module is associated with a heat sink or a heat sink section. This study focuses on air-cooled, parallel plate heat sinks under forced convection, similar to the ones shown in Figure 1 following a methodology similar to that of [7]. In spite of the simplicity of the geometry, this methodology can be applied to different heat sink configurations. In Figure 1, b , L , d , c , t , and n denote the width, length, base plate thickness, fin height, fin thickness, and channel width, respectively. For a given fan and heat sink dimensions, the operating volumetric flow rate $\dot{V}$ is determined by the intersection of the fan curve, available from the manufacturer, and the system (heat sink) curve, which represents the ΔP versus $\dot{V}$ relationship. The pressure drop in the cooling system includes the pressure drop in the air duct connecting the fan to the heat sink, the pressure drop along the heat sink, and that associated with entry and exit effects—a thermal equivalent network approach, as presented in Figure 1, is used to represent the different heat transfer mechanisms. The junction-to-case resistance, R_{jc} , and the case-to-sink resistance, R_{cs} , are inputs from the manufacturer's data. The sink-to-air resistance, $R_{th,sa}$, is calculated

from the equivalent circuit shown in Figure 1 (right), where R_1 corresponds to a conduction resistance across the base, R_2 represents the convection resistance between the air and the horizontal portion of the channel formed by the fins, and R_3 and R_4 are used to represent the heat transfer through the fins (a combination of conduction and convection). The conduction resistances are evaluated from $R_{cond} = d/(kA)$, where d represents the thickness of the layer where conduction is taking place, k is the thermal conductivity of the solid material, and A is the cross-sectional area perpendicular to the heat flux. The convective resistances, $R_{cnv} = 1/(hA)$, are evaluated with the convective heat transfer coefficient, h , obtained from Nusselt number correlations. Since the flow is externally driven, it is convenient to express the flow speed u in terms of the total volumetric flow rate, $u = \dot{V}/(nA)$, where n accounts for the n flow passages formed by the fins. The correlations for friction factor and Nusselt number for forced and mixed convection and different flow regimes are expressed in terms of the Reynolds number, $Re_{D_h} = (uD_h)/\nu$, where u represents the flow speed, ν represents the kinematic viscosity, and D_h represents the hydraulic diameter, given by $D_h = (4A)/p$. Here, A represents the channel's cross-sectional area, and p represents its perimeter. When the flow is laminar, $Re_{D_h} < 2300$, we use $f = C/Re_{D_h}$. C depends on the aspect ratio, with $C=96$ for $(c/s > 8)$. For the combined entry problem, where velocity and thermal boundary layers develop simultaneously, we use Equation 1:

$$Nu_{D_h} = \frac{3.657(\tanh(2.264Gz_{D_h}^{-1/3} + 1.7Gz_{D_h}^{-2/3}))^{-1}}{\tanh(2.432Pr^{1/6}Gz_{D_h}^{-1/6})} + \frac{(0.0499Gz_{D_h}^{-1}) \tanh Gz_{D_h}^{-1}}{\tanh(2.432Pr^{1/6}Gz_{D_h}^{-1/6})} \quad (1)$$

Equation 1 is recommended by Baehr and Stephan for constant surface temperature, combined entry length, and fluids with $Pr \gtrsim 0.1$ with properties evaluated at mean film temperature. Gz_{D_h} represents the Grashof number. In the turbulent regime, we employ Petukhov's correlation,

$$f = (0.790 \ln Re_{D_h} - 1.64)^{-2} \quad (2)$$

which is recommended for $3000 \lesssim Re_{D_h} \lesssim 5 \times 10^6$. For the Nusselt number, we rely on Gnielinski's correlation,

$$Nu_{D_h} = \frac{(f/8)(Re_{D_h} - 1000)Pr}{1 + 12.7(f/8)^{1/2}(Pr^{2/3} - 1)}, \quad (3)$$

which is recommended for $0.5 \lesssim Pr \lesssim 2000$ and $3000 \lesssim Re_{D_h} \lesssim 5 \times 10^6$.

Once the Darcy friction factor is obtained, according to the flow regime, the pressure drop experienced by the coolant as it flows through the passages can be obtained from,

$$\Delta p = \frac{1}{2} \rho u^2 \left[K_c + K_e + f \frac{L}{D_h} \right] \quad (4)$$

Where K_c and K_e are loss coefficients associated with contraction and expansion at the entrance and exit of the

channels. The thermal resistance of the finned heat sink is illustrated in Fig. 1 can now be obtained, as the convective heat transfer coefficients can be obtained from the Nusselt number according to the flow regime (Eqs. 1 or 3), as $h = (Nu_{D_h} \kappa_f)/D_h$, where κ_f represents the coolant thermal conductivity. Refer to [7], for a very similar and detailed approach.

B. Fan Details:

Fans are essential to the heat sink design as they facilitate heat dissipation. Fig. 4 shows the details of the fan mass flow rate for the DC fans used for a section of these heat-sink packages. Fig. 3 shows the relative sizes of the sample fans used in this study. Table. I lists the 5th-order poly-fit of the fans' curves used in this study.

The table lists the specifications of five other DC fans used in this study. A unique name identifies each fan, and its dimensions are given by height (H), length (L), and width (W) in millimeters. The following two columns provide information on the mass airflow rate and the maximum pressure that each fan can generate.

The last six columns of the table list the coefficients of a 5th-order polynomial fit of the fan curve, which is used to model the fan's performance. The polynomial fit is represented by the equation $y = ax^5 + bx^4 + cx^3 + dx^2 + ex + f$, where y is the mass airflow rate in cubic meters per minute and x is the pressure in pascals. The coefficients x^5 , x^4 , x^3 , x^2 , x^1 , and c represent the corresponding polynomial fit coefficients. These coefficients are used to calculate the mass airflow rate at different pressure levels. The fan details are important because the performance of the heat sink is directly related to the mass airflow rate generated by the fan. The size and shape of the fan can also affect the heat dissipation efficiency. Therefore, selecting the appropriate fan is crucial for designing an efficient heat sink for power electronics. The polynomial fit of the fan curve allows for accurate modeling of the fan's performance and helps to optimize the heat sink design parameters.

NSGA-II runs the optimization described in [11]. This method allows for evaluating multiple objectives, and the Pareto front can be used to determine the optimal design.

C. CSPI:

The CSPI is used to optimize the heat sink and power electronics design. This context considers the following parameters: copper as number ID 4 and aluminum as number ID 1 for material properties, sink to ambient resistance (Fig. 11), analytically recorded junction temperature at the power module (Fig. 13), thermal density of the heat sink (Fig. 12), and calculated volume of the heat sink (Fig. 14). CSPI stands for "Cooling System Performance Index," a numerical value used to evaluate a cooling system's overall thermal performance. It considers several factors, including the thermal resistance of the components, the airflow rate, and the heat sink design. In the context of heat sink design, CSPI can be used to compare different heat sink designs and select the

TABLE I: List of 5 fan volumes and fan curves for NSGA-II

Fan data	Name	H (mm)	L (mm)	W (mm)	Mas Air Flow (m ³ /min)	Max Pressure (Pa)	x5	x4	x3	x2	x1	c
1	'36x36x289HV'	36	36	28	0.72	1400	54228.6	-104599.0	68807.8	-17517.3	228.8	851.3
2	'36x36x289GX'	36	36	28	0.69	838	104147.2	-187355.9	114248.1	-26469.1	630.6	827.7
3	'38x38x28 9GA J001'	38	38	28	0.57	720	123485.8	-217700.6	131452.8	-30789.6	1064.4	769.0
4	'38x38x289GAK001'	38	38	28	0.6	800	183734.2	-323378.1	199100.1	-50355.9	3571.1	691.8
5	'40x40x289GAJ01'	40	40	28	0.67	535	91227.5	-166416.5	104041.0	-25101.2	1038.6	509.2

one that provides the best thermal performance. It enables designers to quickly assess the effectiveness of various heat sink configurations and optimize design parameters for maximum cooling performance. CSPI is frequently used in VPP (Virtual Product Prototyping) simulations to evaluate heat sink designs. VPP entails creating a computer model of the heat sink and its surrounding components, simulating the system's thermal performance, and optimizing the design based on the result. Using CSPI in VPP simulations offers several advantages for heat sink design: It enables rapid prototyping and testing of various heat sink designs, reducing the time and cost of physical prototyping. It provides a quantitative measure of a cooling system's thermal performance, allowing for objectively comparing different designs. Can identify potential hot spots in the system and allow for targeted design improvements to optimize cooling performance. Allows the evaluation of the effect of various parameters such as airflow rate, heat sink material, and fin density on the system's thermal performance. Assists in determining the trade-offs between cooling performance and other design considerations such as size, weight, and cost. In summary, CSPI is a useful tool for assessing the thermal performance of heat sink designs and can be used in conjunction with VPP simulations to optimize design parameters for maximum cooling efficiency.

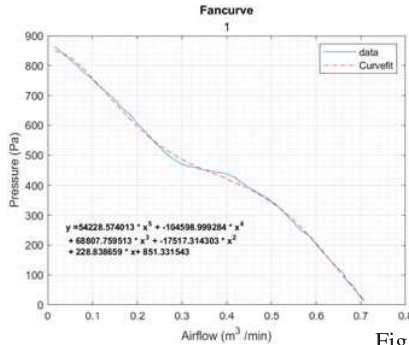


Fig. 5: Fan Fit Curve



Fig. 6: Sample heat sink design [7]

D. Gene Distribution: Fitness Function

Fig. 7 shows the gene distribution for the final population set using NSGA-II optimization. This distribution includes the following parameters: 1-Number of fins, 2-Fan ID, 3-Device

loss, 4-Device ID, 5-Aspect ratio(g) where $b/n = g * t + (g - 1)s$, and 6-Heat sink material.

The fitness function (F) used in the NSGA-II algorithm combines the objectives to be optimized. For the heat sink design problem, the fitness function can be defined as:

$$F = [f_1, f_2, \dots, f_k]$$

Where f_1 to f_k are the objectives to be optimized. The objectives can be defined as minimizing or maximizing a particular performance metric, such as minimizing the thermal resistance or maximizing the fin efficiency. The NSGA-II algorithm then uses this fitness function to evaluate the performance of each design and identify the best-performing designs. The fitness function used in this problem combines several objectives to be optimized. These objectives include minimizing the power density, minimizing the heat sink volume, minimizing the fan's power consumption, and maximizing the heat sink performance. The fitness function is defined as:

$$F = [f_1, f_2, f_3, f_4]$$

Where f_1 represents the inverse of the power density, f_2 represents the inverse of the heat sink volume, f_3 represents the inverse of the power consumption of the fan, and f_4 represents the heat sink performance, as measured by the ratio of the thermal resistance of the heat sink to its volume.

The power density (ρ) is computed using the power losses of the device ($P_{l,dev}$) and the power consumed by the fan ($P_{l,fans}$):

$$\rho = (P_{l,dev} + P_{l,fans}) / vol_{HS}$$

The inverse of the power density (α) is then computed as:

$$\alpha = \frac{1}{\rho}$$

In the context of the GOSET toolbox, NC stands for the number of chromosomes, which is the number of candidate solutions in a genetic algorithm population. CS stands for the crossover strategy, which refers to the method used to combine genetic material from different chromosomes to create new offspring for the next generation. Fitness function is defined as:

$$f = \epsilon \times [1 \ 1 \ 1 \ 1] \times \frac{CS - NC}{NC}$$

Where ϵ is a vector of weights used to balance the different objectives,

The heat sink performance index ($CSPI$) is computed as

$$CSPI = \frac{1}{R_{SA} \times vol_{HS} \times 1000}$$

Where R_{SA} is the thermal resistance of the heat sink, and vol_{HS} is the heat sink volume.

The fitness function is then defined as:

$$\mathbf{f} = \left[\frac{1}{\alpha} \frac{1}{vol_{HS}} \frac{1}{power_{fan}} CSPI \right]$$

Where α is the inverse of power density, vol_{HS} is the heat sink volume, $power_{fan}$ is the power consumed by the fan, and $CSPI$ is the coefficient of performance of the heat sink.

E. CFD Validation:

Fig. 8 shows the CFD validation using COMSOL of a few of the heat sink designs. This particular aspect of the validation effort targeted the understanding of the effect of heat sink geometry (fin number and total width) on the temperature field, as well as the impact of localization of the heat source.

Combining VPP for power electronics and VPP for heat sink design using the $CSPI$ context and NSGA 2-based optimization provides an efficient and effective design optimization method. The results of this study can be used to develop more efficient and reliable power electronics and heat sink designs for high-voltage applications.

III. OPTIMIZATION RESULTS

In this study, optimizing the $CSPI$ to create workable designs is essential. Using various materials, mass, sink-to-ambient resistance, junction temperature, thermal density, and heat sink volume, the authors of this study investigated the optimization of $CSPI$. Analytical computations, simulations, and genetic algorithms generated the results.

A comparison of copper and aluminum material attributes is shown in Fig. 10, with copper having a greater $CSPI$ than aluminum. This highlights how the heat sink's performance can be significantly impacted by the material that is selected. Similar designs are seen in Fig. 9, where smaller designs have a greater $CSPI$ than larger designs. This shows that a smaller, more compact design may more efficiently dissipate heat than a more extensive, bulkier form.

The change in the sink to ambient resistance is shown in Fig. 11, with a lower resistance leading to a greater $CSPI$.

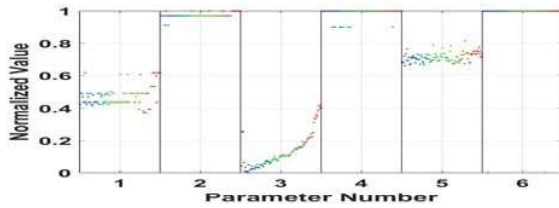


Fig. 7: Gene Design Space

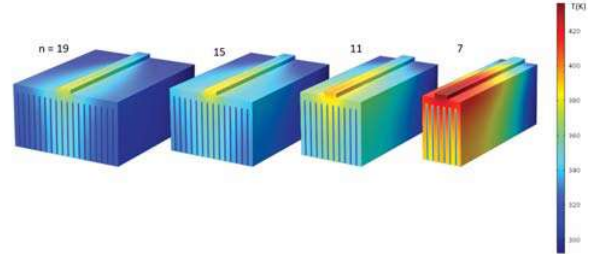


Fig. 8: Selected CFD cases of heat sink [2]

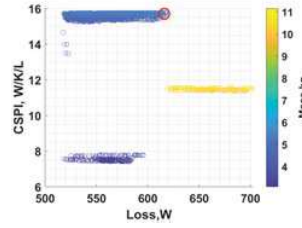


Fig. 9: Mass

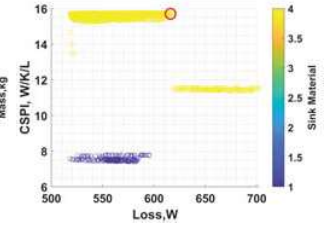


Fig. 10: Material

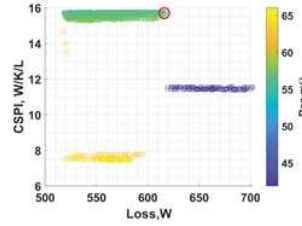


Fig. 11: Rsa

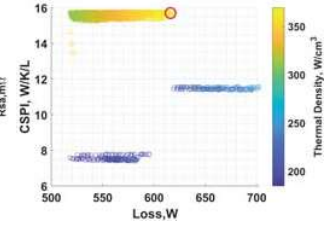


Fig. 12: Thermal Density

This suggests that lowering the resistance between the heat sink and surrounding air can significantly boost the heat sink's performance. The junction temperature at the power module is shown in Fig. 13, with a lower temperature resulting in a larger $CSPI$. This highlights the need to maintain a low power module temperature to enhance the efficiency of the heat sink. The thermal density of the heat sink is indicated in Fig. 12, with a higher thermal density translating into a higher $CSPI$. This shows that raising the heat sink's thermal density may enhance the heat sink's capacity to dissipate heat. The computed volume of the heat sink is shown in Fig. 14, with a lower volume resulting in a greater $CSPI$. This is consistent with the findings in Fig. 9, which show that a smaller, more compact design may dissipate heat more efficiently than a more significant, bulkier design. Based on the results from Figs. 10-14, the authors identified the most optimal heat sink designs shown by the red circles in the figures. These designs were chosen for further analysis and validation.

The final population set's gene distribution using NSGA-II optimization is shown in Fig. 7. A multi-objective opti-

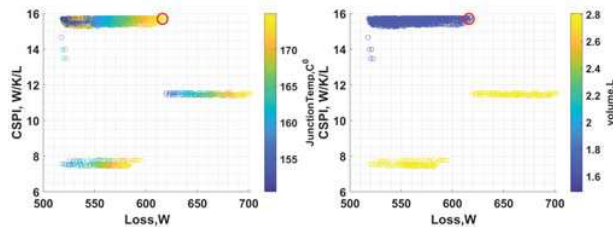


Fig. 13: Mass

Fig. 14: Material

mization algorithm that may simultaneously maximize several objectives is called NSGA-II. The objectives in this instance were the fin count, fan ID, device loss, device ID, aspect ratio, and heat sink material. The aspect ratio is expressed as $b/n = g*t + (g-1)s$, where g is the number of fins, t is the thickness of each fin, s is the distance between each fin, and b and n are the width and length of each fin base, respectively. The authors determined the best combinations of these design parameters using NSGA-II to provide the maximum CSPI.

Fig. 8 shows the CFD validation using COMSOL of a few of the heat sink designs. CFD (Computational Fluid Dynamics) is a simulation tool that can analyze fluid flow and heat transfer. In this case, CFD was used to simulate the heat transfer in the heat sink designs identified by NSGA-II. The results showed good agreement with the analytical calculations, validating the effectiveness of the VPP.

IV. CONCLUSION AND FUTURE WORK

This article introduces a new VPP framework cooling system optimization algorithm. The algorithm helps design and optimize electronic device cooling systems. The algorithm begins by understanding the device geometry, heat dissipation, and limiting temperatures. It then performs a design exploration covering various heat sink geometries matched to multiple fans from a fan database. The algorithm finds the best combination of heat sink geometry and fan selection for each case by calculating the operating flow rate, pressure drops, heat transfer coefficients, thermal resistances, heat sink volume, and junction temperatures. Finally, the fan selection is based on the cell's optimal power density. The proposed algorithm has several advantages over traditional methods for designing cooling systems. For starters, it enables a more thorough design space exploration, resulting in better-optimized designs. Second, it can create cooling systems for various devices, making it a valuable tool for designers of electronic devices. Finally, genetic algorithms enable the discovery of optimal solutions that would have been considered using something other than traditional design methods.

REFERENCES

- [1] H. Lee, V. Smet, and R. Tummala, "A review of sic power module packaging technologies: Challenges, advances, and emerging issues," *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 8, no. 1, pp. 239–255, 2019.
- [2] R. Siddaiah, M. Vygoder, R. M. Cuzner, J. C. Ordonez, and M. B. Chagas, "Virtual prototyping process for assessment of medium voltage grid-connected solid state transformer implementations," in *2021 IEEE Energy Conversion Congress and Exposition (ECCE)*. IEEE, 2021, pp. 1156–1163.
- [3] H. Zhang and L. M. Tolbert, "Efficiency impact of silicon carbide power electronics for modern wind turbine full scale frequency converter," *IEEE Transactions on Industrial Electronics*, vol. 58, no. 1, pp. 21–28, 2010.
- [4] T. Wu, Z. Wang, B. Ozpineci, M. Chinthavali, and S. Campbell, "Automated Heatsink Optimization for Air-Cooled Power Semiconductor Modules," *IEEE Transactions on Power Electronics*, vol. 34, no. 6, pp. 5027–5031, 2019.
- [5] F. Wang, Z. Zhang, T. Ericksen, R. Raju, R. Burgos, and D. Boroyevich, "Advances in power conversion and drives for shipboard systems," *Proceedings of the IEEE*, vol. 103, no. 12, pp. 2285–2311, 2015.
- [6] U. Drofenik and J. W. Kolar, "Thermal power density barriers of converter systems," in *5th International Conference on Integrated Power Electronics Systems*. VDE, 2008, pp. 1–5.
- [7] U. Drofenik, A. Stupar, S. Member, and J. W. Kolar, "Analysis of Theoretical Limits of Forced-Air Cooling Using Advanced Composite Materials with High Thermal Conductivities," vol. 1, no. 4, pp. 528–535, 2011.
- [8] R. Siddaiah, W. J. Koebel, and R. M. Cuzner, "Virtual prototyping of mv & hv modular multilevel power converter using evolutionary optimization based on ρ & η ," in *2020 IEEE Energy Conversion Congress and Exposition (ECCE)*. IEEE, 2020, pp. 3532–3539.
- [9] C. Peng, W. Zhu, P. Ke, R. Li, X. Dai, and L. Wang, "Investigation of vehicle-oriented double-sided cooling power module with bga technology," *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 10, no. 5, pp. 6171–6179, 2022.
- [10] H. H. Sathler, L. Nagano, B. Cougo, F. Costa, and D. Labrousse, "Impact of multilevel converters on emc filter weight of a 70 kva power drive system for more electrical aircraft," in *CIPS 2020; 11th International Conference on Integrated Power Electronics Systems*. VDE, 2020, pp. 1–8.
- [11] S. D. Sudhoff, *Power magnetic devices: a multi-objective design approach*. John Wiley & Sons, 2014.
- [12] R. Rao and G. Waghmare, "Multi-objective design optimization of a plate-fin heat sink using a teaching-learning-based optimization algorithm," *Applied Thermal Engineering*, vol. 76, pp. 521–529, 2015.
- [13] sanyodenki. Cooling Fab. (2021, June 30). [Online]. Available: <https://www.sanyodenki.com/archive/SanAceE>