Alihan Kale, Yunus Tosun, Hüseyin Oğuz

IGBT Thermal Analysis and Heatsink Selection — Forced Air Cooling Selection

Power Loss Calculation and Thermal Analysis

Methodology and Data Source

To ensure the operational reliability of the DC motor drive, a detailed thermal analysis was conducted for the main switching element. The **IXGH24N60C4D1 IGBT**, manufactured by IXYS Corporation, was selected for this design. All electrical and thermal characteristics used in the calculations below were extracted directly from the official IXYS component datasheet. You can check the Github repository part for datasheet documentation.

Total Power Dissipation (P_{total})

The total power dissipation is defined as the sum of steady-state conduction losses and dynamic switching losses under the revised load condition of 12 A.

a. Conduction Losses (P_{cond})

Based on the "Output Characteristics" graph provided in the datasheet, the Collector-Emitter voltage (V_{CE}) at a collector current of 12 A and elevated junction temperature is conservatively identified as 2.2 V.

$$P_{cond} = V_{CE} \times I_{load} \approx 2.2 \text{ V} \times 12 \text{ A} = 26.4 \text{ W}$$

b. Switching Loss (P_{sw})

Switching energy losses (E_{on} and E_{off}) were referenced from the datasheet's "Dependence of Energy Loss on Collector Current" graph. According to the relation regarding switching loss is as follows:

$$P_{sw} = (E_{on} + E_{off}) \times f_{sw}$$

Where $f_{sw} = 2\ kHz$.

For I_C = 12 A and standard temperature at 25°C given in the datasheet:

Turn-on Energy (E_{on}) $\approx 0.40\ mJ$

Turn-off Energy (E_{off}) $\approx 0.30\ mJ$

Total Energy (E_{tot}) $\approx 0.70\ mJ$

$$P_{sw} = E_{tot} \times f_{sw} = 0.70 \times 10^{-3} \text{ J} \times 2000 \text{ Hz} = 1.4\ W$$

c. Total Power Loss

$$P_{total} = P_{cond} + P_{sw} = 26.4\,W + 1.4\,W = 27.8\,W$$

Heatsink Selection and Cooling Strategy

To maintain the IGBT junction temperature (T_j)below a safe design limit of 110°C in a 30°C ambient environment (T_{amb}), the maximum allowable thermal resistance for the heatsink ($R_{\theta SA}$) is calculated using the thermal equivalent circuit model:

Junction-to-Case ($R_{\theta JC}$): 0.66 °C/W (from Datasheet)

Case-to-Sink ($R_{\theta CS}$)**:** 1.0 °C/W (Estimated for thermal pad/insulator)

$$R_{\theta SA} \leq \frac{T_{J,max} - T_{amb}}{P_{loss}} - \left(R_{\theta JC} + R_{\theta CS}\right)$$

$$R_{\theta SA} \leq \frac{110°C - 30°C}{27.8\ W} - (0.66 + 1.0)$$

$$R_{\theta SA} \leq 2.88 - 1.6 \approx 1.22°C/W$$

The calculation demonstrates that a heatsink with a thermal resistance of 1.22 °C/W or lower is required. Standard passive aluminum heatsinks typically found in the laboratory inventory range between 10–15 °C/W, which is insufficient for dissipating 27.8 W of heat.

Consequently, an Active Cooling Solution is mandatory. A high-performance heatsink equipped with a forced-air cooling fan (such as a CPU cooler) must be implemented to ensure the junction temperature remains within the Safe Operating Area (SOA).

Since the thermal analysis mandated a thermal resistance lower than 1.22 °C/W, relying solely on passive convection was deemed insufficient. Consequently, an active cooling solution was designed. The required airflow (CFM) was calculated to ensure the IGBT junction temperature remains within the Safe Operating Area (SOA) even under worst-case power dissipation ($P_{total} = 27.8\,W$).

a. Required Airflow Calculation

The necessary airflow in Cubic Feet per Minute (CFM) is determined using the standard heat transfer equation. This calculation assumes a permissible air temperature rise (ΔT_{air}) of 10°C as the cooling air passes through the heatsink fins.

The fundamental formula for the required airflow is:

$$CFM_{req} \approx 1.76 \cdot \frac{P_{tot}(\mathrm{W})}{\Delta T(°\mathrm{C})} \times \eta_{safety}$$

Note: The constant 3.16 *applies when ΔT is expressed in* $°F$.
For ΔT in $°C$, *the equivalent constant is approximately* 1.76.

An allowable air temperature rise of ΔT = 10 °C ΔT = 10°C was selected as a practical design target for forced-air cooling; a safety factor was applied to account for pressure drop and non-ideal airflow.

In this design, a safety factor (η_{safety}) of 3 was applied to account for pressure drops across the heatsink fins, air leakage, and non-ideal heat transfer efficiency.

Substituting the design values ($P_{total} = 27.8\ W$ and $\Delta T_{air} = 10$°C):

$$CFM_{req} = \frac{1.76 \times 27.8}{10} \times 3 \approx 14.7 \text{ CFM}$$

b. Fan Selection and Specifications

To meet the calculated requirement of 14.7 CFM, a high-speed 12V DC fan was selected and implemented into the hardware design. The specifications of the selected fan are as follows:

Dimensions: 60 x 60 x 10 mm

Rated Voltage: 12 V DC

Current Rating: 0.21 A

Power Consumption: 2.52 W

Rotational Speed: 4700 RPM

The selected fan provides a rated airflow of 23.5 CFM. Comparing this to our calculated requirement:

$$CFM_{fan}(25) > CFM_{req}(14.7)$$

Conclusion: The datasheet-verified airflow of 23.5 CFM is significantly higher than the minimum requirement of 14.7 CFM. This surplus airflow ensures effective heat dissipation and guarantees that the IGBT operates safely below the thermal limit, even under continuous full-load conditions.