Cut domestic energy with speed control

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Demand is growing for appliances such as washing machines, refrigerators and air-conditioning units to help improve domestic energy efficiency. Moving from conventional fixed-speed motors to variable-speed operation could save as much as 30 percent of energy consumed, but appliance vendors must deliver this increased efficiency at little or no extra cost to end-users. Several solutions have emerged to ease the digital design aspects of such a project, but designers also need integrated modules and associated design tools to ease design of the power stage.

Component vendors seek to reduce the cost of the variable-speed controller, which is the most expensive part of the system, by easing design and reducing build complexity. For example, several digital signal controller platforms have emerged, combining DSP and RISC processors with integrated motor-control peripherals including pulse-width modulator modules. These provide a programmable platform capable of hosting a third-party or in-house motor control algorithm.

Alternative solutions are available that implement the motor control algorithm directly in hardware, which eliminates software development and integration challenges and also speeds up algorithm execution to enhance torque and speed control. The iMOTION is one example; the integrated design platform provides a menu-driven configuration tool through which

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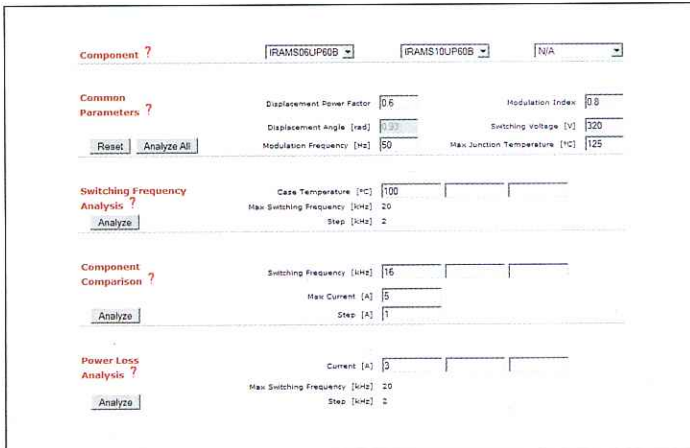

Figure 1: The iSine tool uses the appropriate models for the selected module to generate a series of performance curves describing IPM behavior under the application conditions entered by the user.

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an engineer can quickly enter system parameters to complete the design.

Whichever solution is preferred, the digital control challenges can now be solved quite quickly, even by engineers who are not experienced motion-control designers. However, the other major hurdle is to design and integrate the power stage. Configuring a suitable inverter, gate driver and associated protection circuitry requires considerable power electronic design skills.

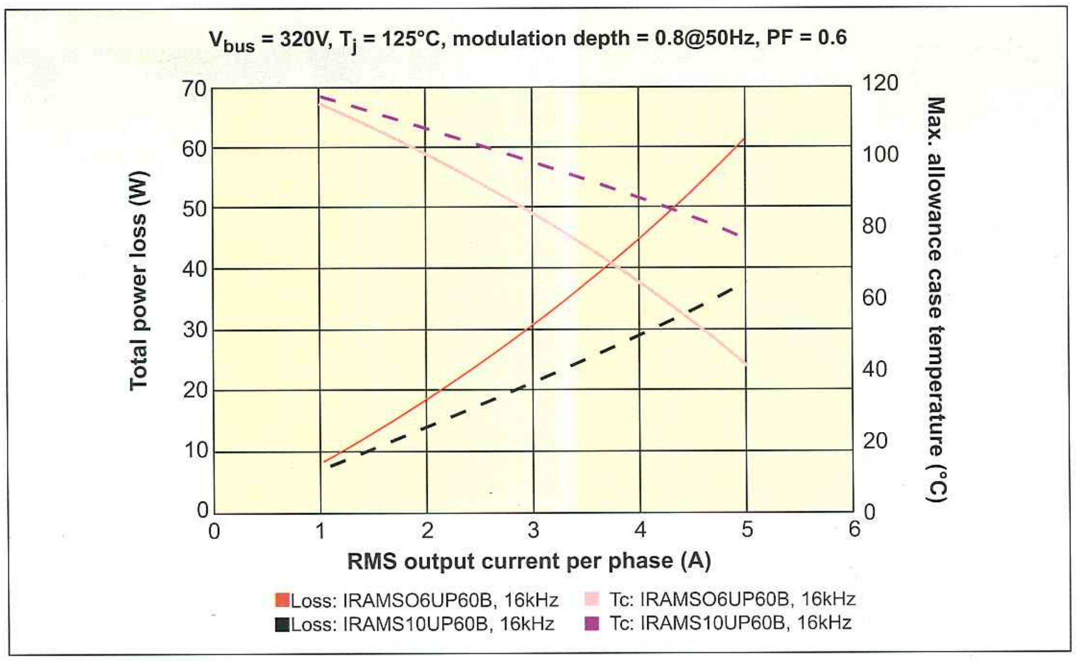

Figure 2: Results show both the power loss of the inverter and the maximum heat-sink temperature for the app.

Integrated power modules

An integrated power module (IPM) eases design and delivers additional benefits such as reduced component count and increased reliability.

The IPM absorbs much of the engineering effort associated with power electronic design for motion control applications. For example, gate impedances are preoptimized for lower EMI noise and power loss, and bootstrap diodes and resistors are also integrated to drive high-side IGBTs. Driver layout challenges are addressed to minimize losses due to parasitic effect and to maximize thermal performance, and protection against overcurrent and overtemperature is also built-in. The engineer simply has to choose the right IPM for the intended application.

However, even this can be a daunting task. The performance of the IPM in a system depends on many application-related parameters, such as the switching frequency, modulation index and module case temperature. Data sheets provide some guidance but usually relate to standard operating conditions. Designers need extra help to predict performance in a specific application, including choosing the right module, matching selectable parameters including the switching frequency and sizing the heat sink to maintain the junction temperature within manufacturer-specified limits under worst-case operating conditions.

To choose the right IPM, the designer needs to collect information about the application. Consider a washing machine controller intended for operation at up to $3A_{rms}$ phase current and 16kHz switching frequency with a DC bus voltage of 320V. If enhanced reliability is an intended selling point for the end product, the specified maximum junction temperature may be set well within the module vendor's recommended limit, say 125°C.

The IR IRAM family of IPMs is available in a number of current ratings, including 6A and 10A modules, either of which is suitable for this application. However, because the power losses will be different for each module under the given operating conditions, the heat sink necessary to maintain junction temperature under 125°C will also be different. Calculating the required heat-sink thermal resistance (R_{th}) requires complex knowledge of IPM thermal and electrical behavior to identify conduction and switching losses and predict the junction temperature based on these data. Although modeling steady-state conditions is relatively straightforward, the power losses in practice are not constant. In operation, the junction temperature will fluctuate beyond the steady-state average because power losses vary at a fundamental frequency equivalent to the modulation frequency of the inverter. Another important aspect is mutual heating, since the multiple heat sources within the IPM share the same paths from case to ambient. This effect must be taken into account if the model of the IPM is to be accurate.

Detailed models of IPMs power modules can be a great benefit when identifying and selecting appropriate modules. IR's iSine software tool, for example, incorporates electrical and thermal models for currently available IRAM-series modules. This tool is published online to help engineers optimize module selection and determine the required heat-sink rating.

The iSine tool uses the appropriate models for the selected module to generate a series of performance curves describing IPM behavior under the application conditions entered by the user. Users can also change parameters such as switching frequency, power factor and modulation index to obtain performance curves customized for the application. **Figure 1** shows the iSine user interface, with menu-style entry of application parameters and part number selection. When the user selects the part, iSine uses the associated model for loss and thermal calculation, and provides three analysis tools to help the user choose the optimal IPM.

- Switching frequency analysis to calculate the maximum motor current under different switching frequencies;
- Power-loss analysis to produce power loss vs. switching frequency curves for up to three IRAM-series parts;
- Component comparison, which produces power loss and case temperature curves for heat sink selection.

Considering the design example earlier, iSine can be used to calculate the R_{th}. **Figure 2** presents the Component Comparison analysis result from iSine, showing both the power loss of the inverter and the maximum heat sink temperature for this application.

At $3A_{rms}$, the power losses are 31W for the 6A module and 21W for the 10A module. The maximum allowable case temperature is 84°C and 99°C for the 6A and 10A modules, respectively. The R_{th} can be calculated as $R_{th\,(S-A)} = (TC-TA)/P-R_{th\,(C-S)}$.

The calculations indicate that the smaller IPM will require a larger heat sink. Therefore, the final choice should be made based on minimizing total system cost and size, including both the IPM and heat sink.

The same method can be used to select an IPM for an air-conditioner app. These typically combine a 400Vdc bus and PFC front-end. The switching frequency will be lower than a washer application to limit EMI noise. If the application requires $10A_{rms}$ current at 6kHz switching frequency, iSine can show the trade-offs between 16A and 20A IPMs.

This tool can also be used to analyze the effect of modulation index, switching frequency, heat sink temperature and power factor on the current rating of the power module. This information can help engineers define suitable system parameters for an optimal solution. One important design parameter is the switching frequency. In this case, iSine can be used to investigate the maximum motor current and power losses of IPM at different switching frequency. Selecting up to three parts in each type of analysis shows that power loss increases and maximum current decreases with increasing switching frequency.

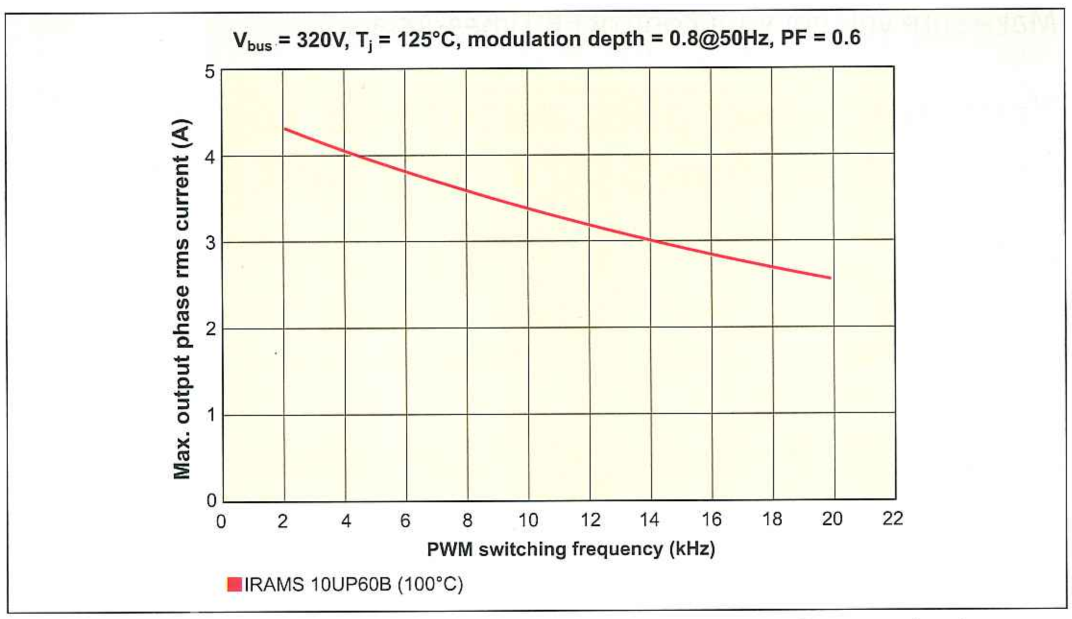

Figure 3: iSine can be used to investigate the maximum motor current and power losses of IPM at switching frequencies.