Methods measure power electronics’ efficiency

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Validating the system efficiency of a power-electronics circuit is essential in evaluating the overall system performance, design optimization, and sizing of cooling systems. Figure 1 shows the conventional method of performing efficiency measurement. The power-electronics system operates at the rated output-power level, and, by measuring the input power and output power, you can calculate the system’s efficiency using the equation \( \eta = \left( \frac{P_{\text{OUT}}}{P_{\text{IN}}} \right) \times 100\% \), where \( P_{\text{OUT}} \) is output power and \( P_{\text{IN}} \) is input power. In other words, the measured input power is equal to the output power plus the power loss of the system.

However, measuring the efficiency of a high-power system that delivers power to loads such as motors, generators, or industrial-computer equipment requires a source that delivers the rated power. The infrastructure therefore should comprise a suitably rated source and an equivalent load that can support the rating of the power-electronics system you are evaluating. These requirements can drive up the facility’s infrastructure cost; for one-time design-validation measurements, this cost is difficult to justify.

This Design Idea describes alternative methods of measuring the efficiency of a high-power power-electronics system that simplifies the test-infrastructure requirement by eliminating the test load and using a source that must support only the loss of the power-electronics system. Figure 2 shows the proposed method, which eliminates the test load by shorting the output/load terminals. The system’s control algorithm maintains the required input- and output-current amplitude and frequency by developing circulating reactive power. IGBTs (insulated-gate bipolar transistors) and magnetic components dominate the system’s losses, which are functions of the amplitude and frequency of the input and output currents. The loss is also less sensitive to the power-factor and PWM (pulse-width-modulation) index.

To know the required input and output current, you must estimate the system’s power factor, the motor’s back EMF (electromotive force), and the system’s source voltage. This example uses a field-oriented control for both source- and load-side inverters, resulting in the following equations:

\[
I_{\text{ROUT}} = I_{\text{ROUT,RE}} + I_{\text{ROUT,IM}} = \frac{P_{\text{OUT}}}{\sqrt{3} V_{\text{BEMF}}} ;
\]
where $I_{\text{ROUT}}$ is the required output current, which comprises real current, $I_{\text{ROUT, RE}}$, and reactive current, $I_{\text{ROUT, IM}}$; $I_{\text{RIN}}$ is the required input current, which comprises the real current, $I_{\text{RIN, RE}}$, and the reactive current, $I_{\text{RIN, IM}}$; $P_{\text{RIN}}$ is the required input power; $P_{\text{OUT}}$ is the output power at the test condition; $V_{\text{BEMF}}$ is the motor’s back EMF; $V_{\text{GRID}}$ is the grid voltage; and $\eta_{E}$ is the estimated efficiency of the circuit.

By maintaining the input current to be $I_{\text{RIN}}$ and the output current to be $I_{\text{ROUT}}$, the measured input real power will be close to the power loss, $P_{\text{LOSS}}$, at the actual output-power level, $P_{\text{OUT}}$. Therefore, you can calculate the efficiency as follows: $\eta = \frac{P_{\text{OUT}}}{P_{\text{OUT}} + P_{\text{LOSS}}} \times 100\%$.

If the measured efficiency, which you calculate using this equation, does not quite match the estimated efficiency, $\eta_{E}$, update the second equation using the measured efficiency, $\eta$, and repeat the measurement until they are close. Calnetix has used this method to evaluate the efficiency of a 125-kW power-electronics system, compared the results with the conventional measurements, and found them to be closely matching.

Most high-power power-electronics systems have high efficiency, which means that the real current is much less than the reactive current. To reduce the required current from the grid, you can use the method in Figure 3, which uses another identical system to offset the input reactive current that the test system creates. By providing a path for circulating reactive power, the utility sources the lost power only, not the total power. In Figure 3, the input current of the second power-electronics circuit is $I_{\text{RIN}} = I_{\text{RIN, RE}} + jI_{\text{RIN, IM}}$. By setting the first circuit to have an input current of $I_{\text{RIN}} \approx I_{\text{RIN, RE}} - jI_{\text{RIN, IM}}$, the power from the source is only $P_{\text{SOURCE}} = I_{\text{RIN, RE}} \approx I_{\text{RIN, RE}} + I_{\text{RIN, RE}} + j(I_{\text{RIN, IM}} - I_{\text{RIN, IM}}) = 2I_{\text{RIN, RE}}$. The circuit uses the input current from the source only to overcome the power losses of the two circuits, thereby eliminating the need for a high-power infrastructure.