Asymmetrical Inductance to Support Long Cables in Low-Power Motor Drives

High capacitive turn-on current often overload IGBTs in low-power inverter applications that use long shielded cables. A simple workaround can reduce losses and electromagnetic interference and ensure more reliable performance. **Michael Frisch, Head of Product Marketing, Vincotech, Unterhaching/Munich, Germany**

Capacity and current for charging are independent of the output current. In low-power inverter applications, the additional losses for this capacitive load account for a significant share of overall power dissipation.

The additional dissipated energy is thus calculated according to equation 1:

$$E = ½ C*U^2 \quad (1)$$

The IGBT has to charge the capacity before it is able to turn on completely. The voltage drop between the DC voltage and capacitor voltage is dissipated in the switch. The losses are also proportional to the switching frequency and DC voltage. The problem with a long cable is perhaps most pronounced in low-power applications with 700 V DC and a PWM frequency of 16 kHz.

Countermeasure 1 - increase active current rating

A simple countermeasure is to increase the inverter IGBTs' current rating. A better cooling system would be necessary because of the increased losses, so selecting an inverter with a higher rating for applications with long cables is a simple solution, but certainly not the best economically speaking. The higher dissipation is a disadvantage and EMI increases with the high turn-on current, which compounds the EMI filter circuit's complexity.

Countermeasure 2 - add an output filter

A sine wave output filter is one way of reducing turn-on losses in the inverter. This kind of filter would rule out any increase in turn-on current, which in turn would reduce losses and EMI in the inverter. However, placing sine wave filters in the output would easily double the cost, so this is too expensive for most low-power applications.

Countermeasure 3 - add a small output inductor

Another approach would be to use low inductance in the output to achieve the required voltage drop with reactive power, the idea being to smooth out the slope of the output turn-on voltage and thus the cable capacitor's charging current. An inductor with just 2 µH would not add much to the inverter's cost. Unfortunately, this won't work. Once the inductor has charged the parasitic capacity of the cable, it will continue driving the current $I = I_{(motor)} + I_{(charge)}$. This would increase voltage at the output, alternating with increased current, which would culminate in heavy undamped oscillation.

Countermeasure 4 - use asymmetrical input inductance

Adding inductance to the DC input would work. A small snubber capacitor with a diode would have to be connected to prevent resonance with the output capacitance and voltage overshooting at turn-off (see Figure 2).

Although the IGBT turns on, the current is limited by the inductor. The inductor current includes the cable capacitance charging current. The current decreases once the output capacitance is charged. The stored energy in the inductor flows through the diode into the transient capacitor and is dissipated by a resistor.

Inverter with asymmetrical input inductance

Let's see what such an inverter could look like. The dimensions of the additional components would depend on cable capacitance.

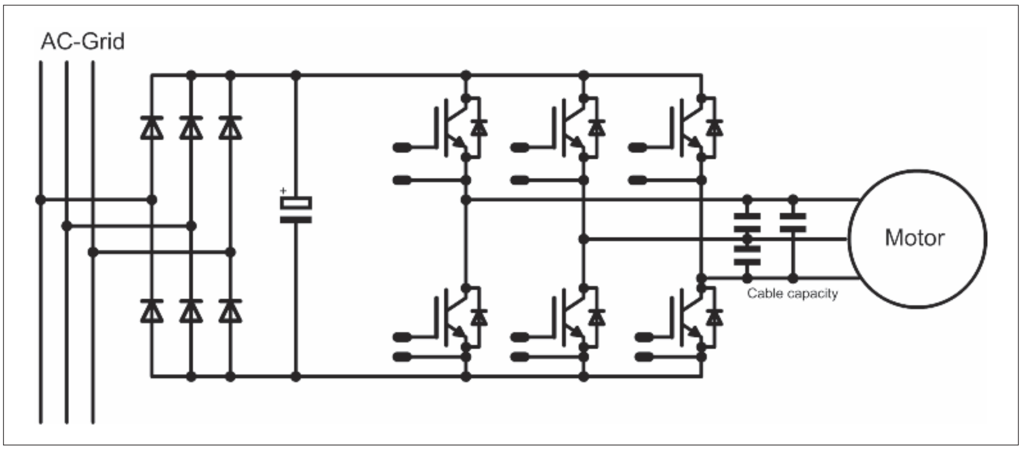

Figure 1: An inverter circuit with a capacitive load generated by a long motor cable

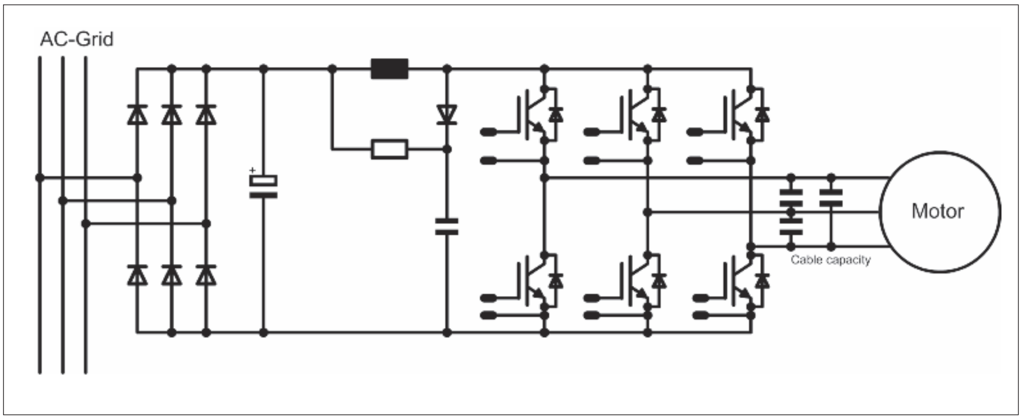

Figure 2: An inverter with a snubber circuit to reduce turn-on losses in the IGBT

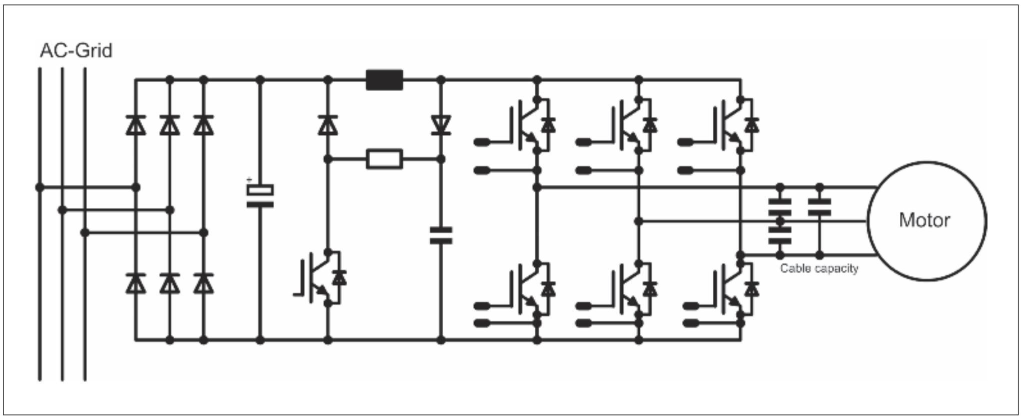

Figure 3: An inverter with snubber circuit where the brake resistor serves to dissipate parasitic energy

Energy according to equation 2

$E = ½\, C*\Delta U^2 = ½\, L*\Delta I^2)$ (2)

is transferred into the transient capacitor, and the majority of it is dissipated by a resistor according to the following example and equation 3:

- Long cable (100 m) with 5 nF output capacitance
- Transient capacitor: 2 µF
- DC inductance: 2 µH
- DC voltage VDC=600 V
- f_{PWM} = 16 kHz
- Output power: 2 kW to 4 kW
- I_{Out}(max) = 10 A

$E = ½\, C*U^2 = ½ * 5\ nF * (600\ V)^2$
$= 0.9\ mWs$ (3)

The voltage increase in the transient capacitor is less than 60V. The resistor then has to dissipate at turn-on

$P_{ON} = 16\ kHz * 0.9\ mWs = 14\ W$ (4)

and at turn-off

$P_{OFF} = f_{PWM} * ½\, I^2 * L$, $P_{OFF} = 16\ kHz * ½ * (10\ A)^2 * 2\ µH = 1.6\ W$ (5)

and in total

$P = P_{ON} + P_{OFF} = 15.6\ W$ (6)

The IGBT losses of 15.6W are transferred into the resistor. The inductor will also reduce the main DC capacitor's pulse load. And EMI is reduced because of the limited turn-on current.

Required components are 1 transient diode, 1 inductor (2 µH / 4 A), 1 DC capacitor (2 µF / 1000 V), and 1 resistor (100 Ω-200 Ω / 20 W).

Use of a brake resistor

In applications with a brake chopper, the brake resistor could be used to dissipate energy stored in the transient capacitor (see Figure 3). Required components are 1 transient diode, 1 inductor (2 µH / 4 A), and 1 DC capacitor (2 µF / 1000 V). The brake resistor serves to dissipate stored energy.

Benefits are reduced power dissipation in the IGBTs and in particular -15.6 W (reduced rating), reduced pulse load in the main DC capacitor resulting in a lower value, reduced peak current at turn-on resulting in a lighter workload for the EMI filter. The brake resistor also serves to dissipate transient energy at no extra cost.

Stored energy can be regenerated for applications demanding highest efficiency.

Conclusion

The combination of asymmetrical input inductance and a brake resistor that dissipates stored energy is the perfect solution to the problem with long cables in low-power inverter applications. The DC capacitor's reduced pulse load and the improved EMC more than compensates for the additional outlay. This new approach minimizes expenses, particularly for applications with a brake chopper where the brake resistor can be used to this end.