Asymmetrical inductance supporting long cable at low power motor drive applications

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1. Abstract

IGBT´s in low power inverter applications with long shielded cable are often overloaded with high capacitive turn-on current. A simple workaround will reduce losses, EMC and increase the reliability of the application.

2. Challenge of long cable

The capacity and the current for charging are independent from the output current. In low power inverter applications will the additional losses for this capacitive load reach a significant share of the total power dissipation.

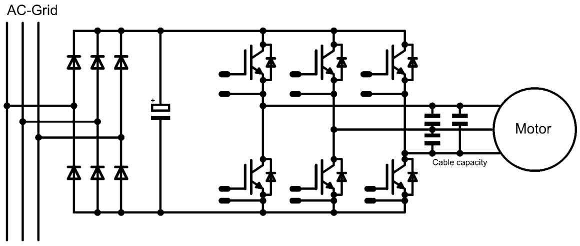


Figure 1: Inverter circuit with capacitive load caused by long motor cable

The additional dissipated energy is calculated with:

$$E = ½ C*U^2$$

The IGBT have to charge the capacity before it is able to turn on completely. The voltage drop between DC voltage and capacitor voltage is dissipated in the switch. The losses are also proportional with the switching frequency and with the DC-voltage. Low power applications with 700V DC voltage and 16kHz PWM frequency might be the typical application were the long cable problem hurt worst.

3. Counter Actions

3.1. Increased Current Rating of the Active Switches

A simple counteraction is the increase of the current rating of the inverter IGBT´s. Due to the increased losses is also a better cooling system required, this leads to a simple but not economical ideal solution, to select a higher rated inverter for the long cable application. The higher dissipation is a disadvantage but also will the high turn-on current cause increased EMC which might increase the effort for the EMC-filter.

3.2. Output Filter

A sine wave output filter is one possibility to reduce the turn on losses in the inverter. Such a filter will ensure that there are no increased turn-on currents. This reduces the losses and EMC in the inverter. But such sine wave filters in the output are easily doubling the cost and they are too expensive for most low power applications.

3.3. Small Output Inductor

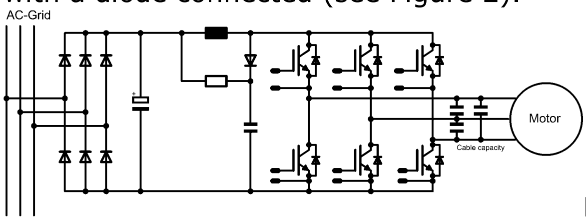
Another idea is a small inductance in the output to achieve the required voltage drop with reactive power. The idea is to smoothen the slope of the output turn-on voltage and with this the charging current of the cable capacitor. The inductor with just 2µH would have only very little impact in the inverter cost. Unfortunately does this idea not working. After charging the cable capacity, the inductor will force to continue the current according:

$$I = I(motor) + I(charge)$$

This will lead to increased voltage on the output alternating with increased current. This ends in a heavy not damped oscillation.

3.4. Asymmetrical Input Inductance

With this approach is the inductance added in the DC input. To avoid resonance with the output capacitance and voltage overshooting at turn-off is a small snubber capacitor with a diode connected (see Figure 2).



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igure 2: Inverter circuit with snubber circuit for turn-on loss reduction in the IGBT

The IGBT will turn on but the voltage drop is at the inductor. The inductor current is including the charging current of the cable capacitance. The current will decrease after the output capacitance is charged. The stored energy in the inductor will flow via diode into the transient capacitor and dissipated with a resistor.

4. Inverter Concept with Asymmetrical Input Inductance

Here a concept for an inverter using this approach. The dimension of the additional components is dependent on the cable capacitance: The energy $E = ½\ C*\Delta U^2 = ½\ L*\Delta I^2$ is transferred into the transient capacitor and the majority is dissipated with a resistor.

Example:

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

$E = ½\ C*U^2 = ½ * 5nF * (600V)^2 = 0{,}9mWs$

The voltage increase in the transient capacitor is less than 60V. The resistor has to dissipate:

Turn-on:

$P_{ON} = 16kHz * 0{,}9mWs = 14W$

Turn-off:

$P_{OFF} = f_{PWM} * ½\ I^2 * L$

$P_{OFF} = 16khz * ½ * (10A)^2 * 2\mu H$

$P_{OFF} = 1{,}6W$

Total:

$P = P_{ON} + P_{OFF} = 15{,}6W$

The IGBT losses of 15,6W are transferred into the resistor. The inductor will also reduce the pulse load of the main DC-capacitor, this allows a reduction its value so that some effort is compensated. Also EMC is reduced due to the limitation of the turn on current.

Effort / Required components:

- ⇨ 1x transient diode
- ⇨ 1x inductor (2µH / 4A)
- ⇨ 1x DC-capacitor (2µF / 1000V)
- ⇨ 1x Resistor (100Ω-200Ω / 20W)

5. Utilization of the brake resistor

In applications with brake chopper could the brake resistor be utilized to dissipate the stored energy in the transient capacitor (see Figure 3).

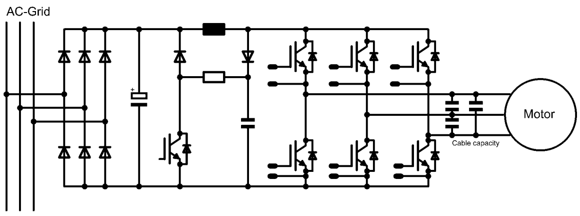

Figure 3: Inverter circuit with snubber circuit and utilization of the brake resistor for the dissipation of parasitic energy.

Effort / Required components:

- ⇨ 1x transient diode
- ⇨ 1x inductor (2µH / 4A)
- ⇨ 1x DC-capacitor (2µF / 1000V)
- ⇨ The brake resistor is used to dissipate the stored energy

Advantage:

- ⇨ Reduced Power dissipation in the IGBT´s: -15,6W (reduced rating)
- ⇨ Reduced pulse load in the main DC-capacitor leads to reduced value.
- ⇨ Reduced peak current at turn-on leads to EMC filter effort reduction.
- ⇨ The brake resistor is utilized also for dissipating the transient energy => no extra effort

6. High Efficient Applications

In applications with the goal of highest efficiency is a regeneration of the stored energy possible.

7. Conclusion

Asymmetrical input inductance in connection with the utilization of the break resistor for a dissipation of stored energy is a perfect solution for the long cable problem in low power inverter applications. The reduced pulse load of the DC capacitor and the advantage in EMC will over compensate the effort. The new approach is minimizing the expenses in particular for applications with brake chopper were a utilization of the brake resistor is possible.