Efficiency of Motor Side Common Mode (CM) Filtering Techniques for PWM Inverters

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Abstract

In this paper several inverter output CM reduction filters are compared through experimental results. Filters with or without connection to ground and to the DC link are introduced. Quality criteria like leakage current and voltage drop on motor side, conducted emissions and leakage current on line side, power loss and inverter impact are used to compare all filters comprehensively.

1. Introduction

When using a PWM inverter to drive a motor there are several problems along with the gain of flexibility.

First the inverter is a source of differential mode (DM) disturbances. DM voltage is the voltage between two lines and has a rectangle shape at the output of the inverter. The steeper the slew rate of inverter output DM voltage and the longer the motor leads the higher is the potential for overvoltages at the motor because of reflections [1]. These overvoltages may destroy the motor insulation and are avoided easily with a motor line inductor or better a sineformer, [2] which will be used by default in this paper.

Common Mode (CM) disturbances appear because the sum of the inverter output voltages principally is not equal to zero, so that a CM current is driven over the parasitic capacitances of the motor and the leads back through the power supply to the DC link, which is the reference potential of the CM voltage [3], [1], [4], [5]. The analytical expression for the CM voltage is

\[ u_{CM} = \frac{u_{1M} + u_{2M} + u_{3M}}{3} \] (1)

where \( u_{1M}, u_{2M} \) and \( u_{3M} \) are the voltages between inverter output phases and inverter DC midpoint.

The CM voltage can have severe consequences for the System. A voltage between motor shaft and ground potential occurs, which leads to bearing currents and may destroy the motor bearings [6]. If the motor is grounded local with the building ground, the CM leakage current can create a large loop and is then a source of intensive radiated emissions [7]. Expensive shielded conduits normally must be used to avoid the radiation. Furthermore the CM leakage current uses the way back through the supply line to the DC link, which leads to conducted emissions and increased leakage currents on line side.

Conducted emissions are limited by the EN 61800-3 and leakage currents are limited by the residual current detector (RCD) which is used in the building.

2. Compared filters

In this investigation six filter topologies on the inverter output are compared with each other and in relation to a measurement without filter. An overview of the system and the placement of the filters is given in figure 2.

2.1. DM low pass LC filter

Standard DM filter, which consist of a three phase DM inductor \( L_{sin} \) and three DM capacitor \( C_{sin} \) connected between the phases to create a sinusoidal voltage waveform between the phases (sine former). With three phase 3UI cores the filter only has little influence on CM disturbances except the damping effect of the leakage inductance of the DM inductor.
2.2. galvanic isolating transformers

With an isolating transformer the CM path is interrupted, so that CM currents cannot flow, except over parasitic capacitances between the two windings [8].

2.3. CM inductor

CM inductors $L_{cm}$ have one magnetic core where all three phases are wound on. They offer inductive damping for CM current while affecting the DM currents only by their leakage inductance [9].

2.4. additional CM LC low pass with connection to ground

CM low pass LC filters consist of a CM inductor and a further capacitance $C_{PE}$ connected between DM LC filter capacitors star point and ground. The filter shortcuts the CM disturbances before they reach the motor line and the motor [10], [11].

2.5. CM LC low pass with connection to inverter DC link

CM LC low pass with connection to inverter DC link have a DC link connection over a capacitance $C_{Zk}$ from the DM LC filter capacitors star point. They do not use the ground to shortcut the CM disturbances. They directly offer CM currents a
path back to the DC link [12], [13], [14], [15].

![Image](image1.png)

**Fig. 6**: additional CM LC low pass with connection to inverter DC link

### 2.6. CM transformer

CM transformers are CM inductors with a fourth winding. The CM current is lead from the DM filter capacitors star point through the fourth winding to the DC link. The current in the fourth winding induces the CM voltage to the three phases so that the CM voltage in the motor leads is canceled. This is called voltage cancellation principle [13], [14], [15].

![Image](image2.png)

**Fig. 7**: additional CM transformer

### 3. Experimental results

To test the filter comparatively, an invariant drive configuration was built up. The 11kW inverter had an internal class A line filter. The switching frequency $f_s$ was set to 8kHz at 50Hz fundamental frequency. 50m 4G4 motor leads where used. The 15kW motor did not have isolated bearings, so that for estimating bearing currents the motor leakage current and the motor star point to ground voltage were measured which can be done for estimating the bearing currents [16]. All filter prototypes compared here were designed cost effective and as small as possible by the professional filter design department of BLOCK Transformatoren-Elektronik GmbH & Co. KG.

#### 3.1. motor star point to ground voltage

The measurement of the motor star point to ground voltage $u_{Y-PE}$ shows that the isolating transformer and the CM transformer offer best reduction, although it must be noticed that the isolating transformer only damps the low frequency components while the high frequencies are not damped due to the stray capacitances between the windings. The sine former and especially the CM inductor (CM_ind) boost the low frequency parts of $u_{Y-PE}$ which worsens the bearing problems. High frequency components are damped very good with a simple CM inductor. For damping of the lower frequencies, $L_{com}$ would have had to be uneconomically high to set the corner frequency low enough.

![Image](image3.png)

**Fig. 8**: motor star point to ground voltage comparison

#### 3.2. motor leakage current

It can be stated that the motor leakage currents are damped very good with all three CM low pass LC filters, whereas the CM transformer offers the best damping.
3.3. filter power loss

The power loss in all CM filters in comparison to the single sine former and especially the isolating transformer is significantly lower. The isolating transformer losses are high because it was built of laminated iron with a high material insertion. The sine former has higher losses because of the CM currents, which are not damped in contrast to the other filters.

3.4. inverter impact

The inverter output phase current is a degree for the inverter stress. Without filter there are very high inverter output peak currents due to recharging of motor and lead parasitic capacitances. With all filters the inverter stress could be reduced significantly.

3.5. line leakage current

CM currents emitted by the inverter output flow partly through the ground to the power line and back to the inverter. The line side leakage current is often monitored by residual current detectors (RCD), which could trigger because of the CM currents. It can be stated that the best damping effect could be reached by the CM transformer and the CM inductor with connection to the DC link. The CM inductor with connection to the ground in opposite increases the leakage current drastically because the ground is used for short circuiting CM disturbances.

3.6. conducted emissions on line side

To comply with EN61800-3 limits, line side filters are used. In this investigation it can be figured out that filtering on the inverter output lead to significant reduction of conducted emissions on line side. All CM filters provide a further reduction in comparison to a simple sine former up to 10MHz.
4. Conclusion

This paper categorizes and compares motor filters which reduce the CM emissions of PWM inverters. The CM transformer has shown to be the superior solution for a whole system improvement, including bearing currents, line side leakage currents and conducted emissions, power loss and inverter stress. It can also be stated that the CM transformer filter has been the filter with the smallest size.

Literature


