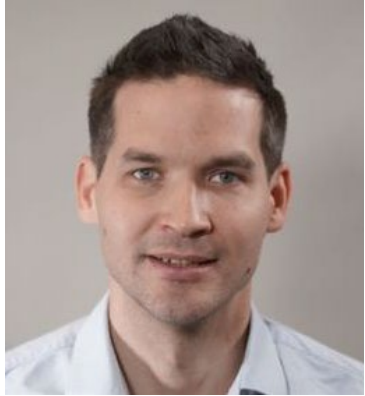


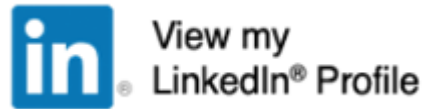
Influence of inverter switching frequency on motor efficiency

Vortragender heute



Andreas Ficsor

- Since October 2022 **Global Product Manager SPECTRA Universal Inverter**
- 2016 – 2022 Team Leader (AI Optimization & Testing)
- 2011 – 2016 Application Engineer (CAMEO)
- 2004 – 2011 Measurement Technician (PTE)



AGENDA

1

Why?

2

Challenges & Test Environment

3

Results

4

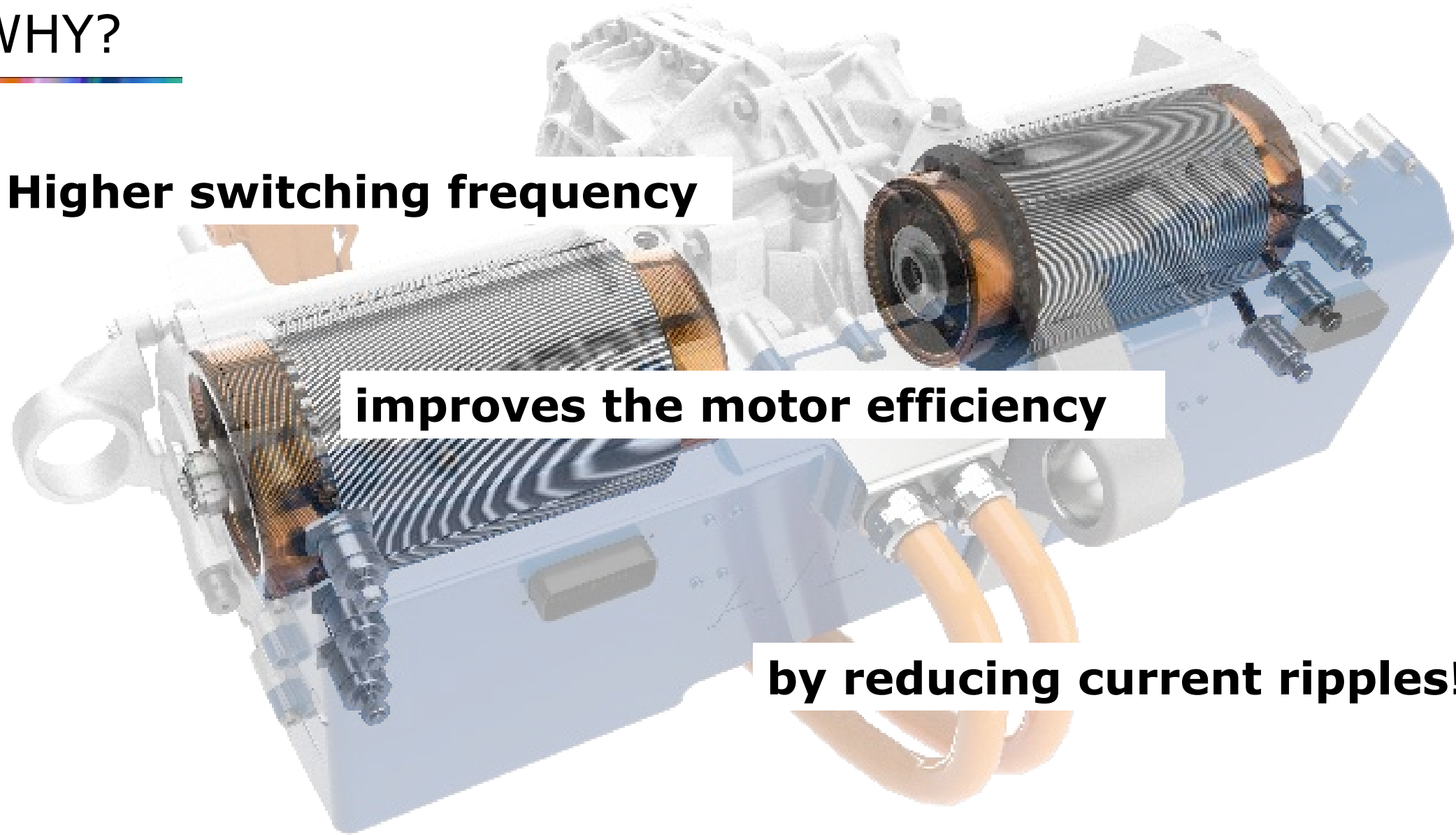
Q & A

WHY?

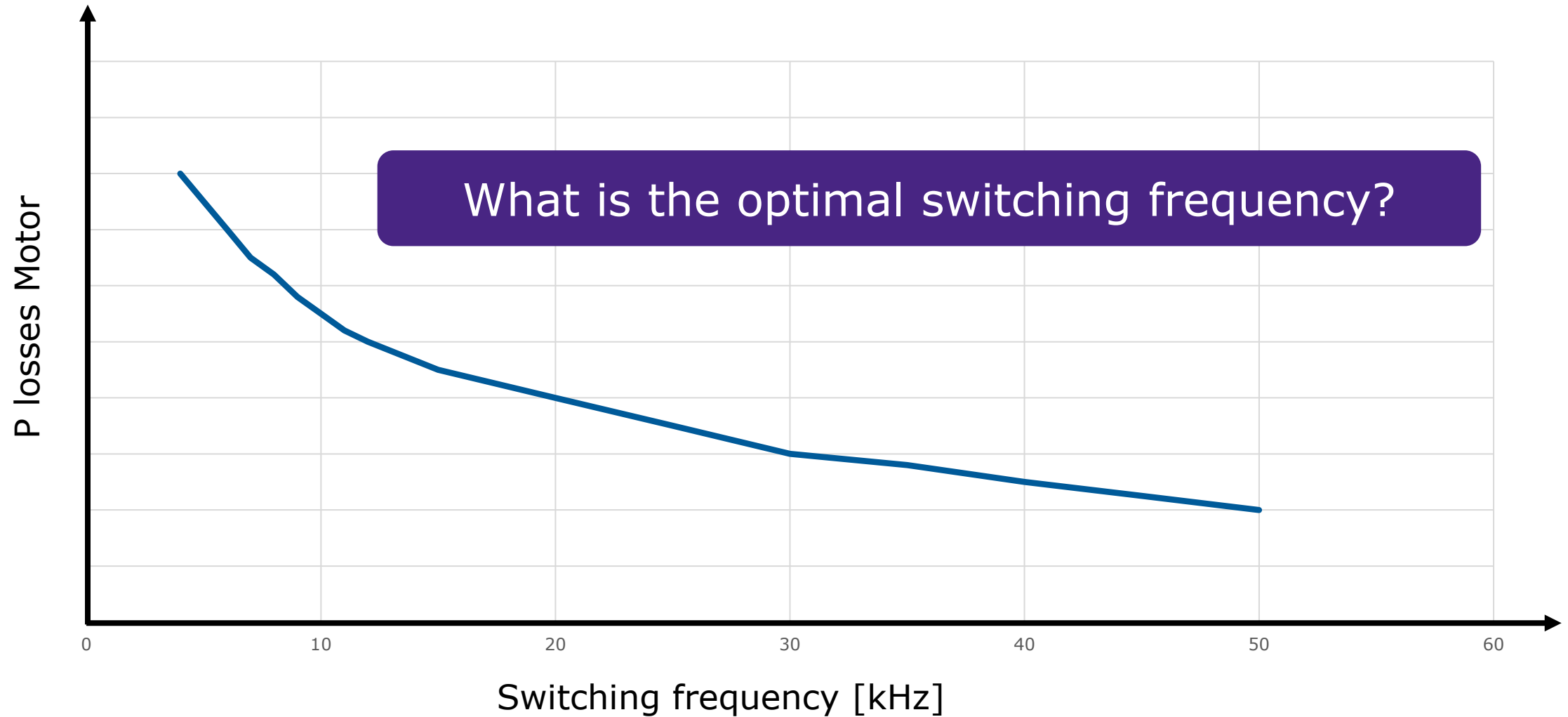
Higher switching frequency

improves the motor efficiency

by reducing current ripples!



E-MOTOR LOSSES



TASK DESCRIPTION

- Find the best Motor efficiency by changing inverter switching frequency (10-30 kHz)
- 2 & 3 Level operation
- Don't change other parameters (e.g.: i_d , i_q ,...)
- Use Inductance maps from Simulation department
- Inverter efficiency should get measured as well
- Detailed analysis of one speed / torque point
- Real Inverter is not available
- Compare results with a different motor & higher switching frequency

CHALLENGES

The real inverter is not available.

Which frequency range should my inverter provide?

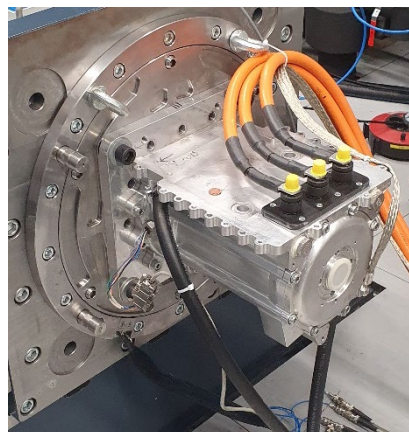


Is one frequency enough?

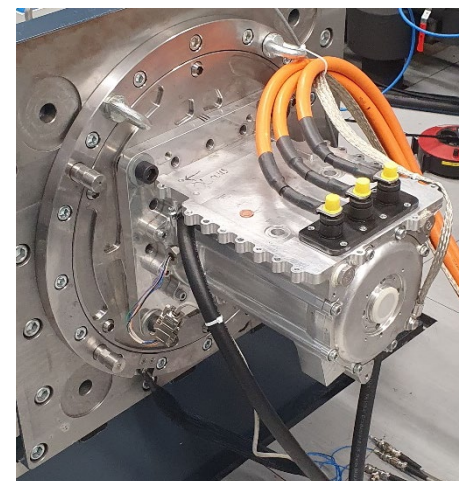
Fast testing by using Simulation data.

Can I improve E-Motor efficiency without having losses in inverter?

THE REAL INVERTER IS NOT AVAILABLE



How to test my motor?



TOOL REQUIREMENTS\CHALLENGES

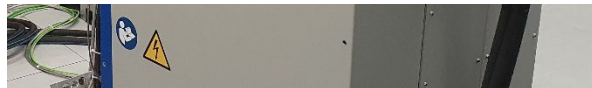
SPECTRA Universal Inverter



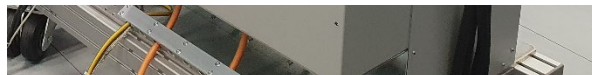
Is the motor supported?



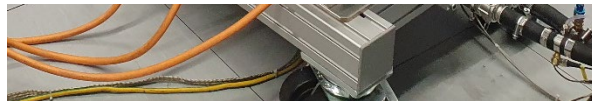
Is the switching frequency changeable?



Does the inverter provide the performance?



Speed/Torque mode possible?



XION Power Analyzer

Online FFT analysis

Signal Recording

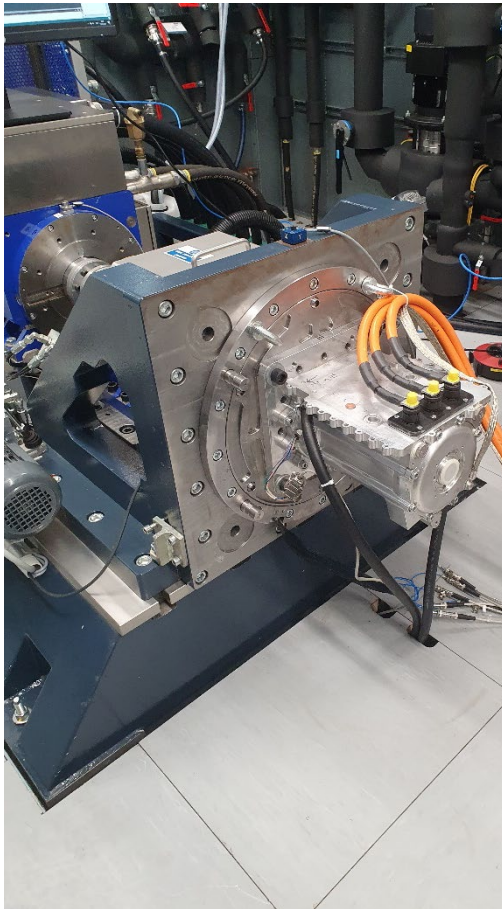
AC Voltage measurements

High sample rate



TEST ENVIRONMENT

Dyno & Motor



XION



SPECTRA Universal Inverter



Software



UUT INFO

E- Motor

PMSM

Speed: 9.500 (8.000) rpm

Torque: 600 (280) Nm

Max Current: 700 Arms

Resolver

EESM

Speed: 15.000 rpm

Torque: 300 Nm

Max Current: 500 Arms

Resolver

Testbed



Inverter

880 kVA SiC

1260 ARMS

40 - 1000 VDC

fsw 2-96 kHz

Water cooled

440 kVA SiC

630 ARMS

40 - 1000 VDC

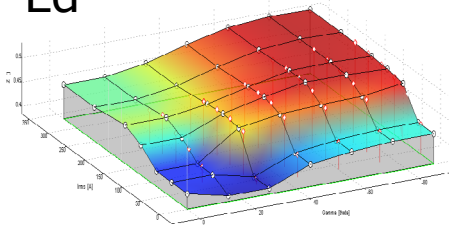
fsw 2-96 kHz

Water cooled

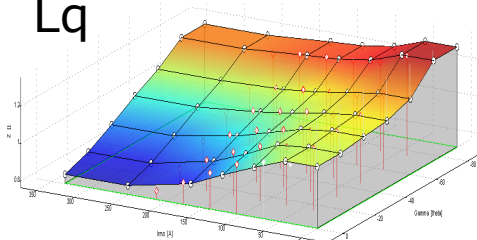
FAST TESTING BY USING SIMULATION RESULTS

Inductance maps

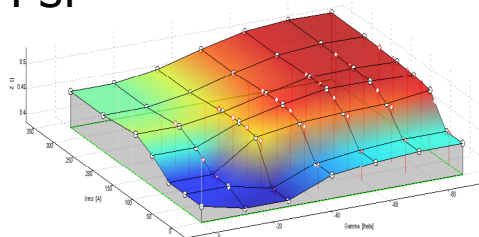
L_d



L_q



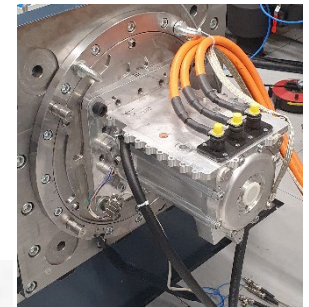
Ψ



Parameterize Inverter



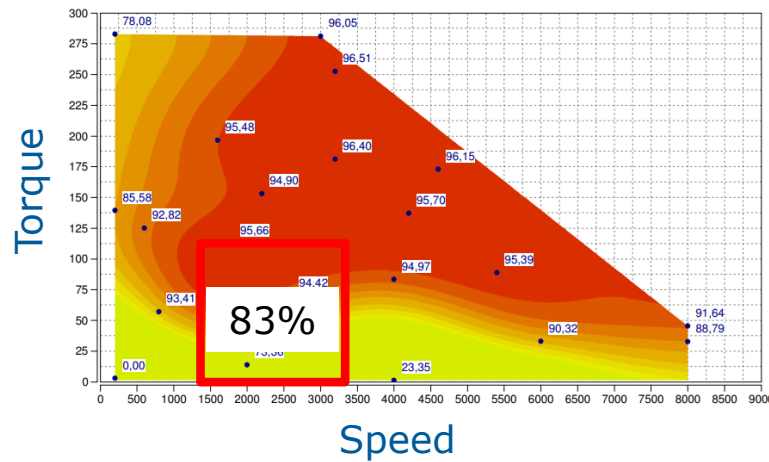
Motor Efficiency



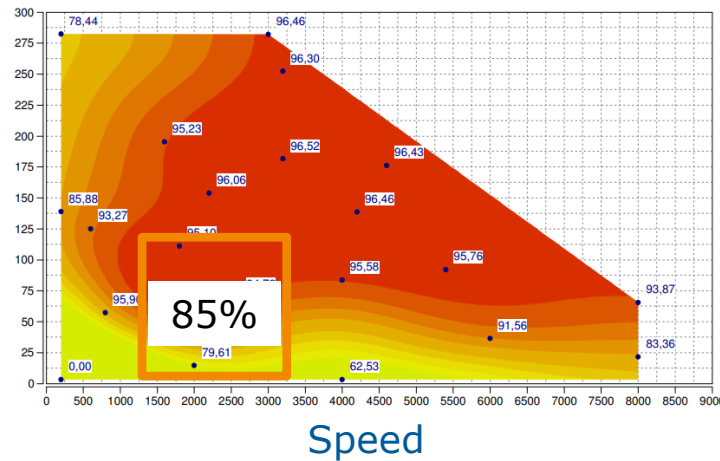
MOTOR EFFICIENCY

Motor Efficiency

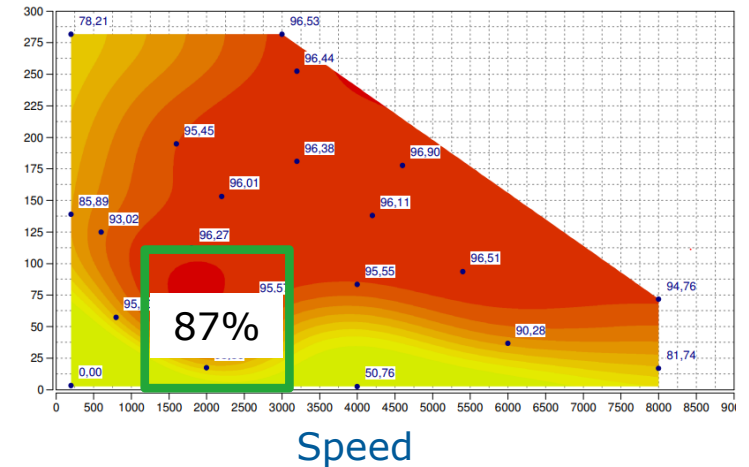
10 kHz (2 Level Operation)



20 kHz (2 Level Operation)



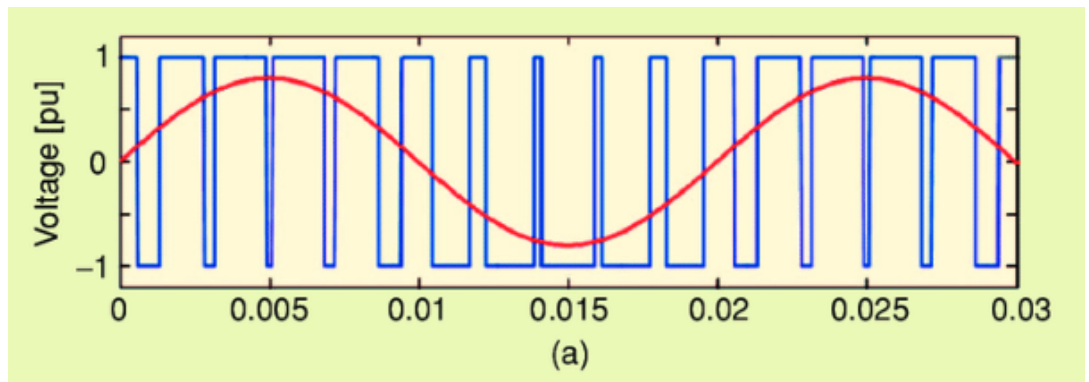
30 kHz (3 Level Operation)



Full operating range measured – focus on 2000 rpm - 20 Nm

2 LEVEL VS. 3 LEVEL INVERTER

2 Level Inverter

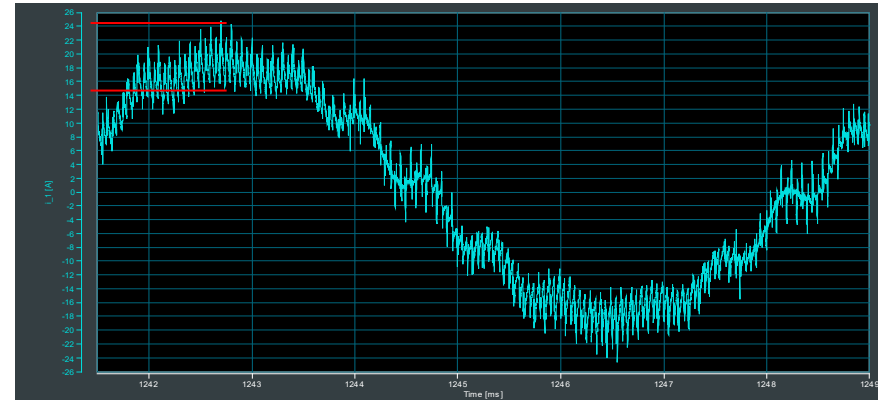
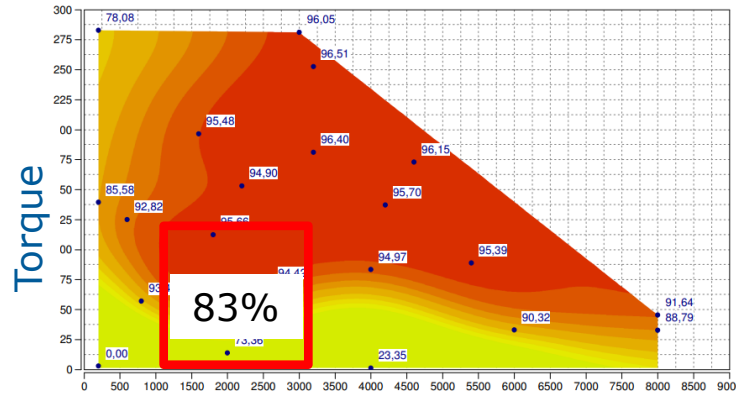


3 Level Inverter

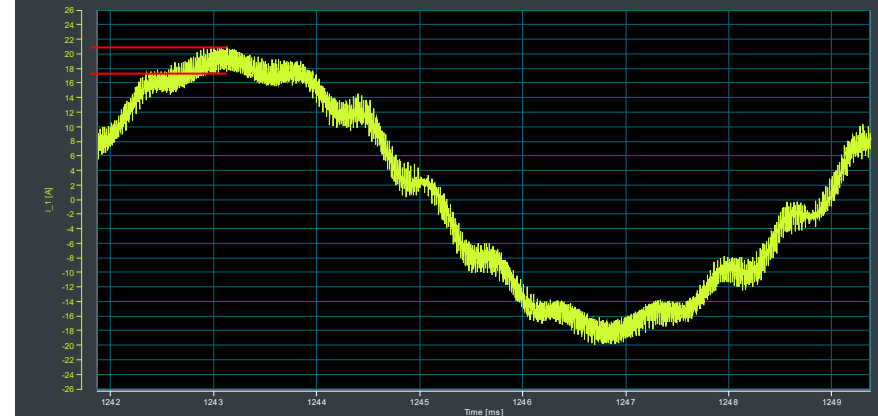
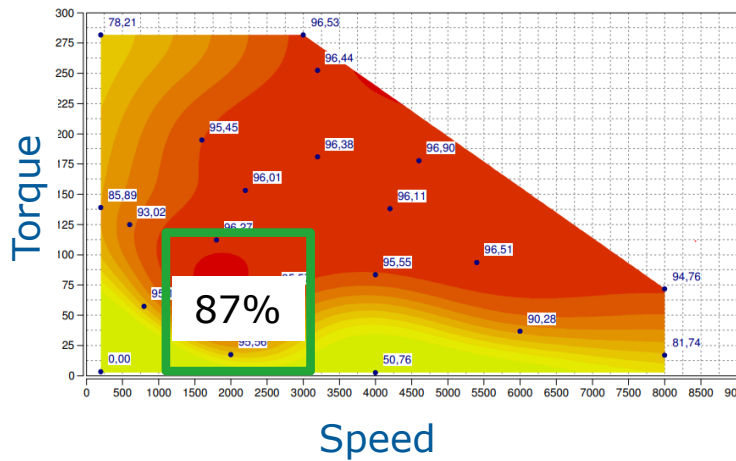
2-Level inverter controls the voltage waveform of the converter output with 2 electric potentials while a 3-level inverter controls it with 3 electric potentials

MOTOR EFFICIENCY 10 kHz VS. 30 kHz

10 kHz



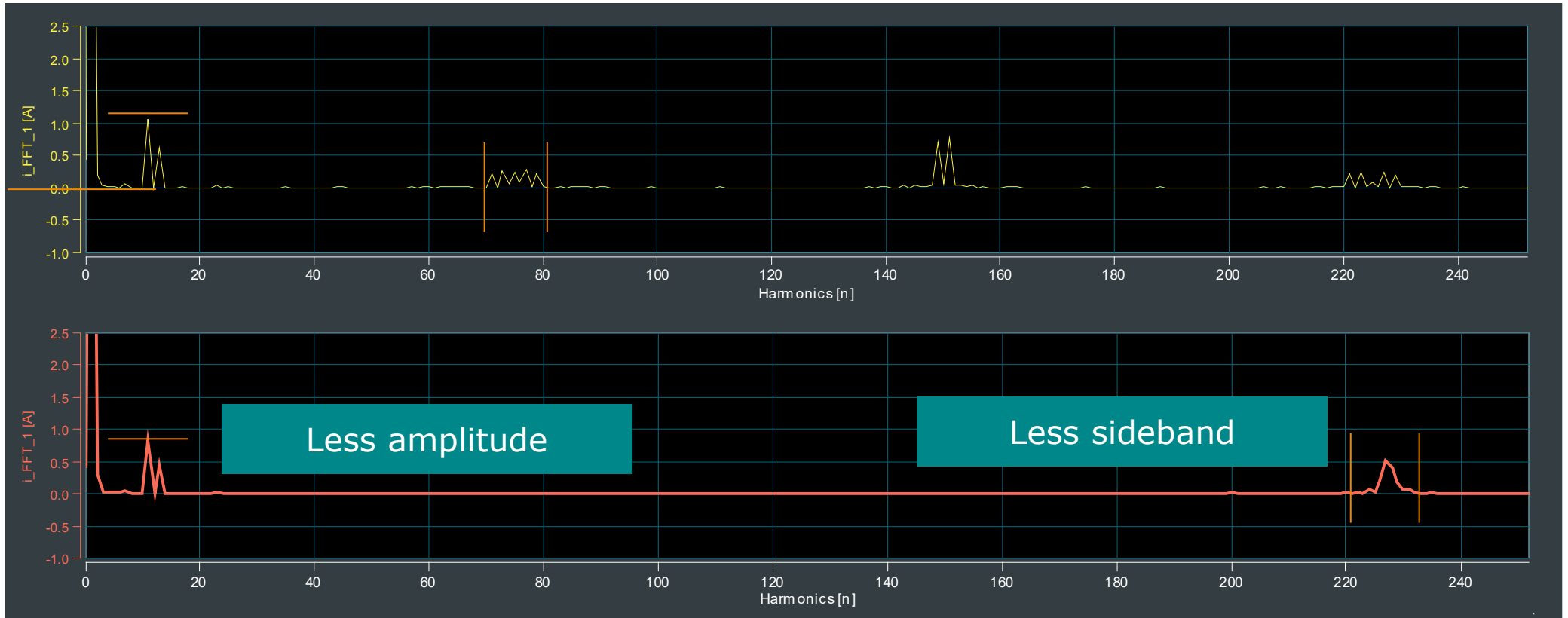
30 kHz



30 kHz shows fewer current ripples

FFT (fast Fourier transform) ANALYSIS

10 kHz



30 kHz

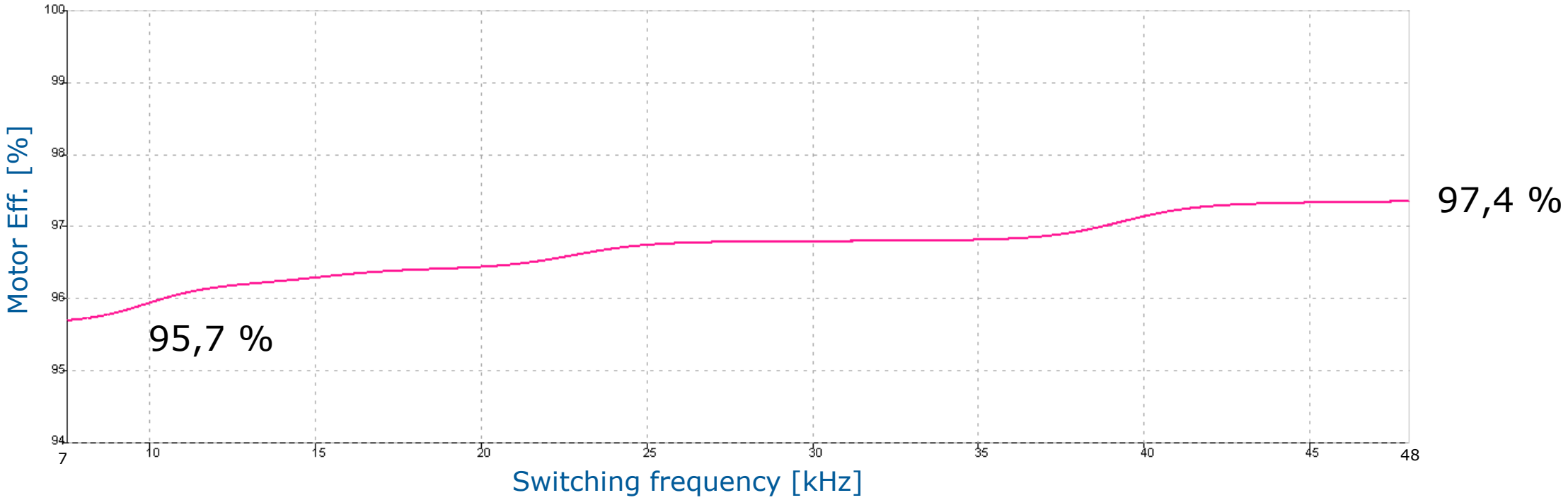
Fundamental

10 kHz

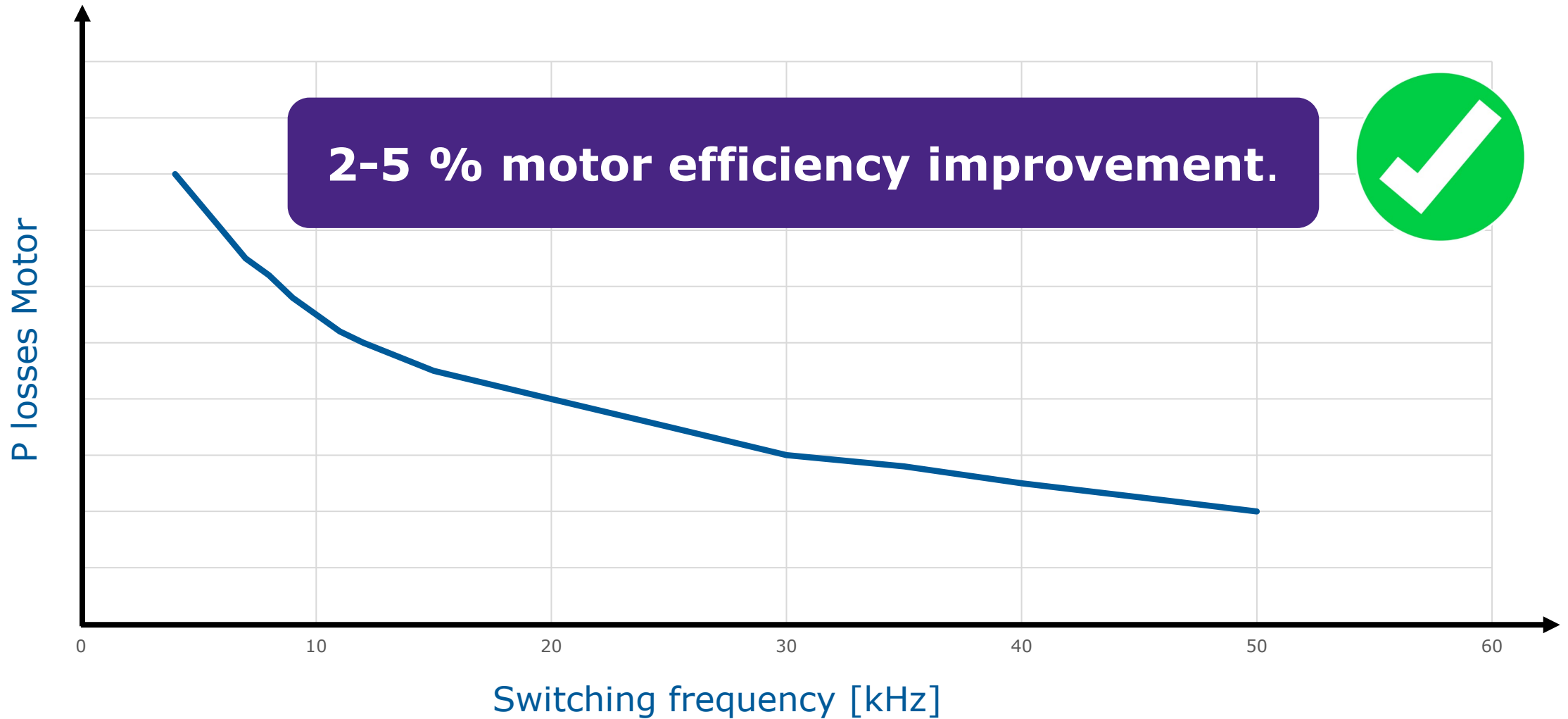
30 kHz

SECOND MOTOR RESULTS

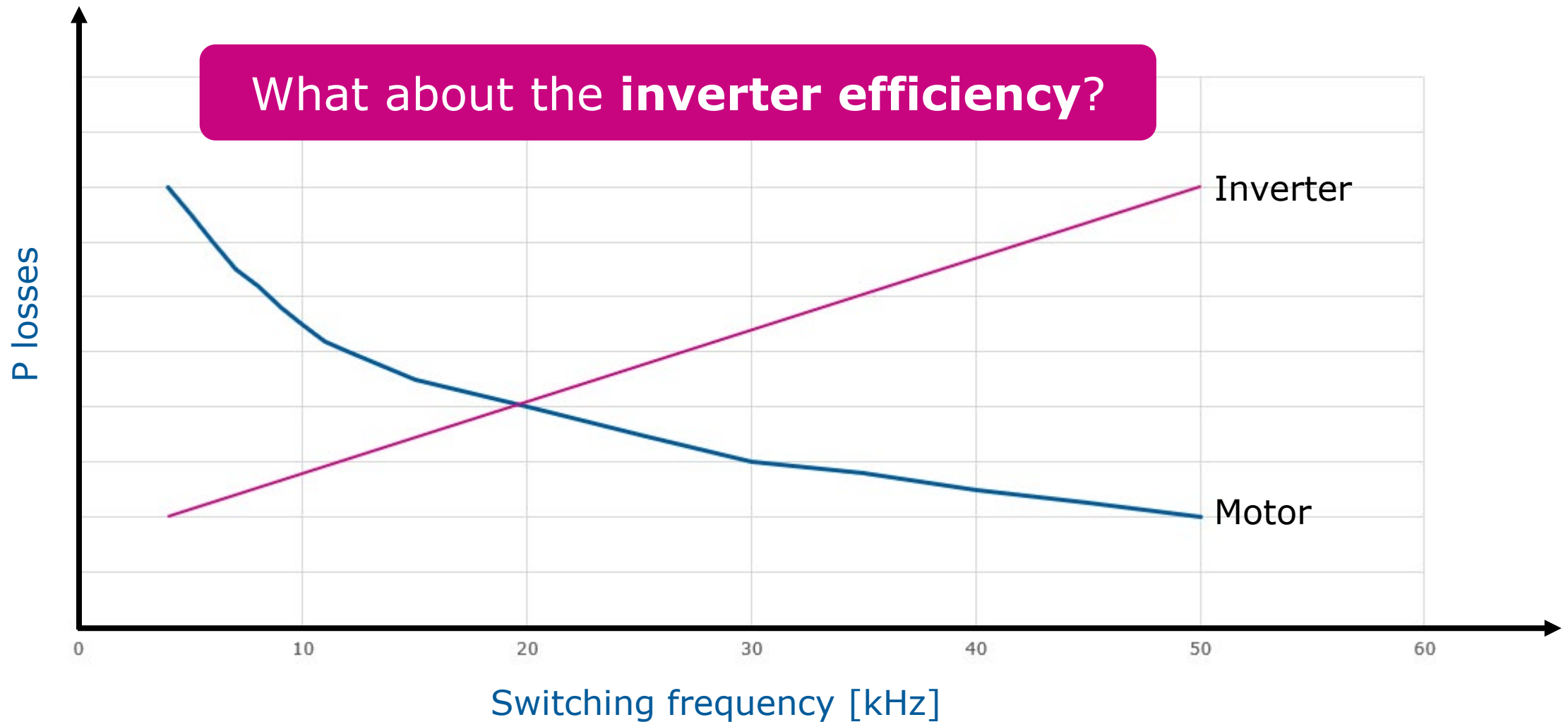
2500 rpm – 60 Nm



E-MOTOR EFFICIENCY

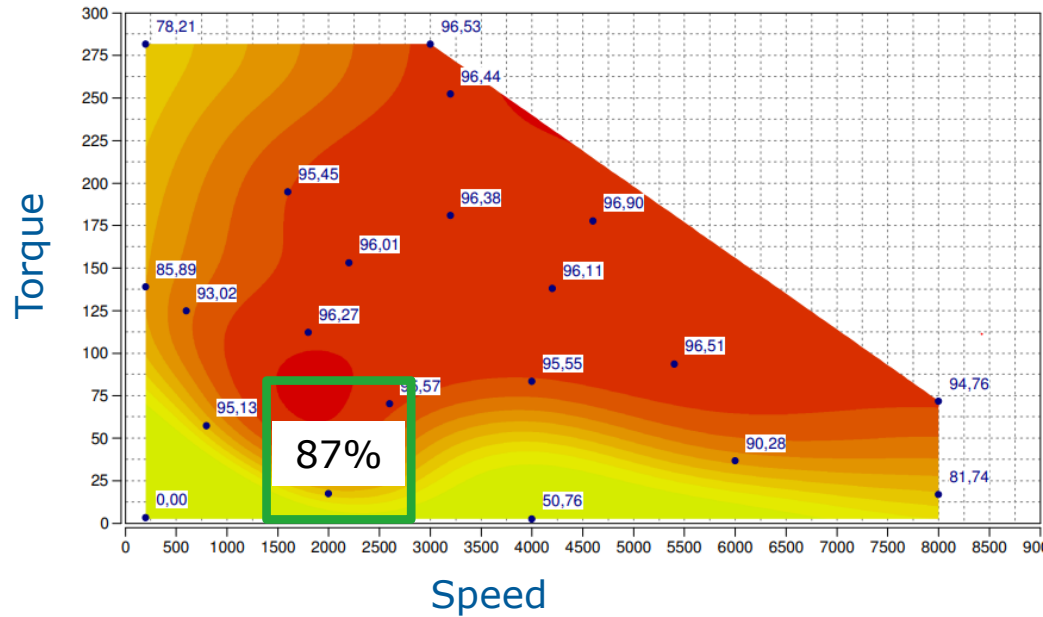


CAN I IMPROVE E-MOTOR EFFICIENCY WITHOUT HAVING LOSSES IN INVERTER?

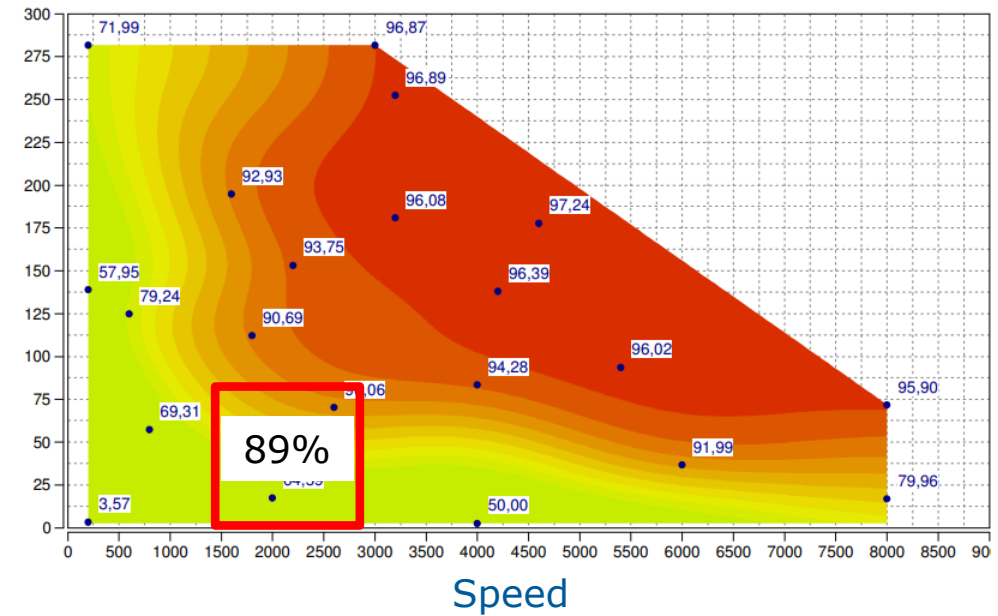


CAN I IMPROVE E-MOTOR EFFICIENCY WITHOUT HAVING LOSSES IN INVERTER?

Motor Efficiency
30 kHz (3 Level Operation)



Inverter Efficiency
30 kHz (3 Level Operation)

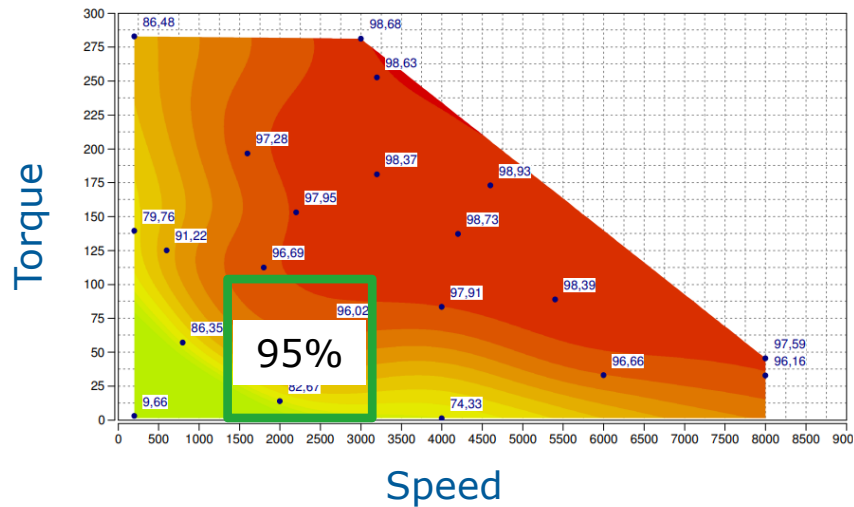


Inverter losses are getting higher

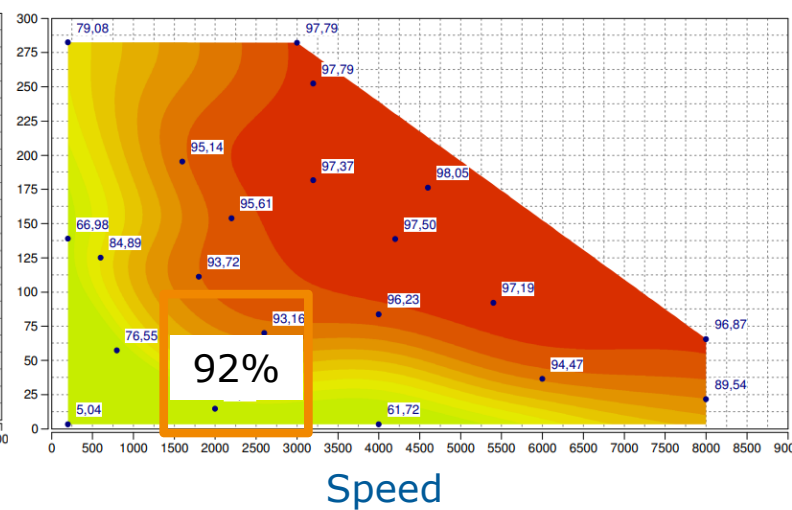
CAN I IMPROVE E-MOTOR EFFICIENCY WITHOUT HAVING LOSSES IN INVERTER?

Inverter Efficiency

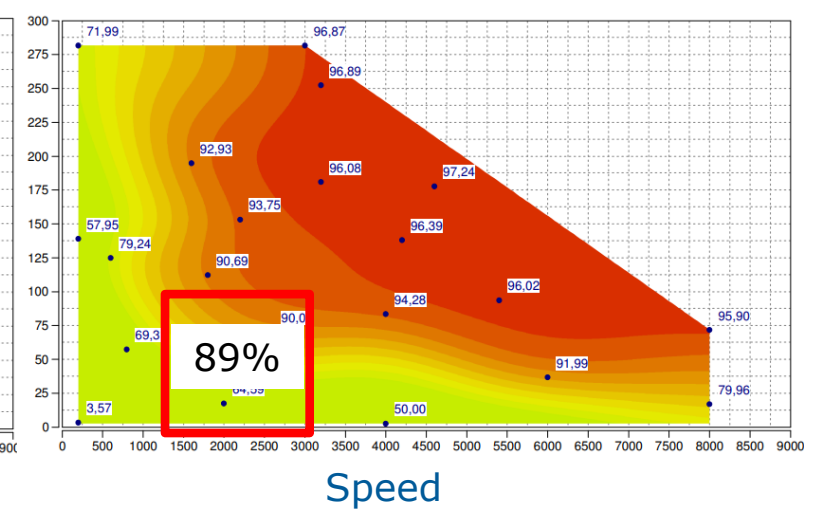
10 kHz (2 Level Operation)



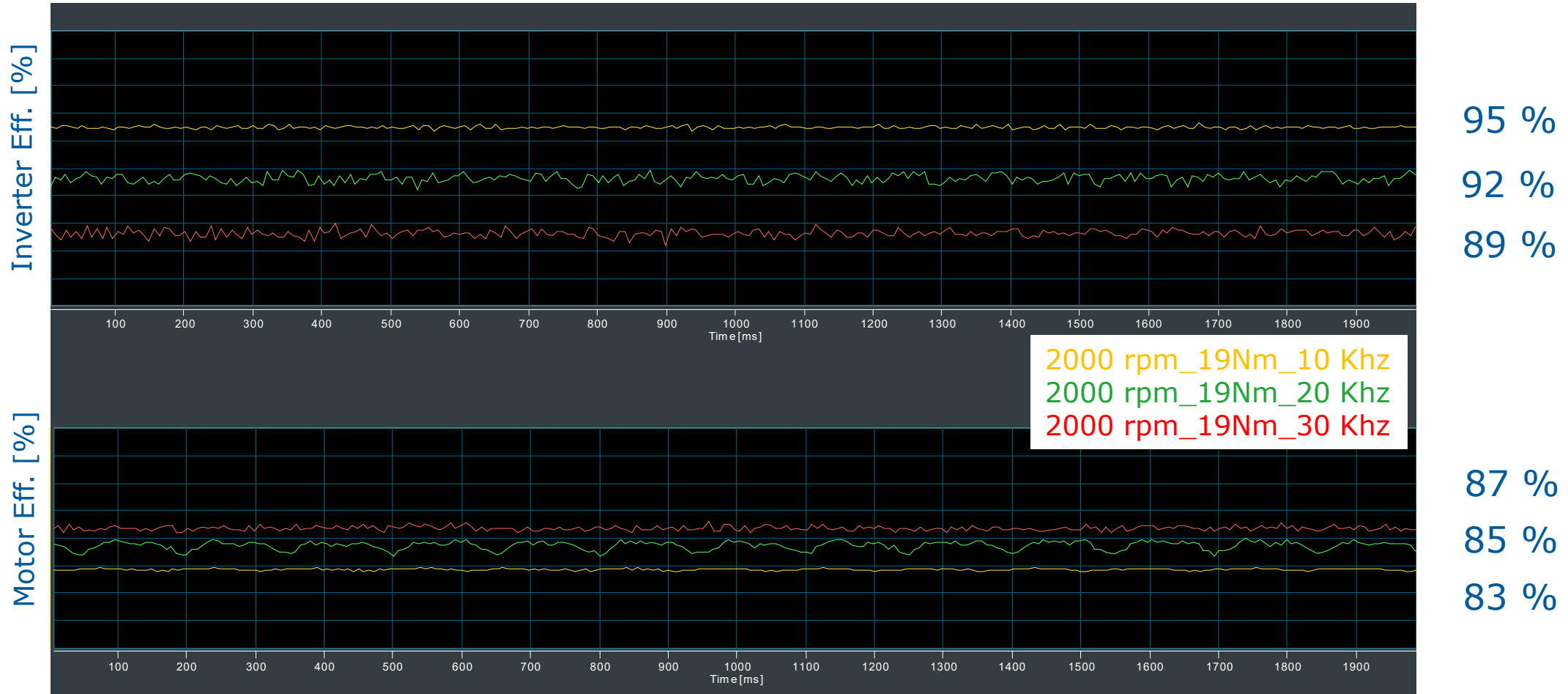
20 kHz (2 Level Operation)



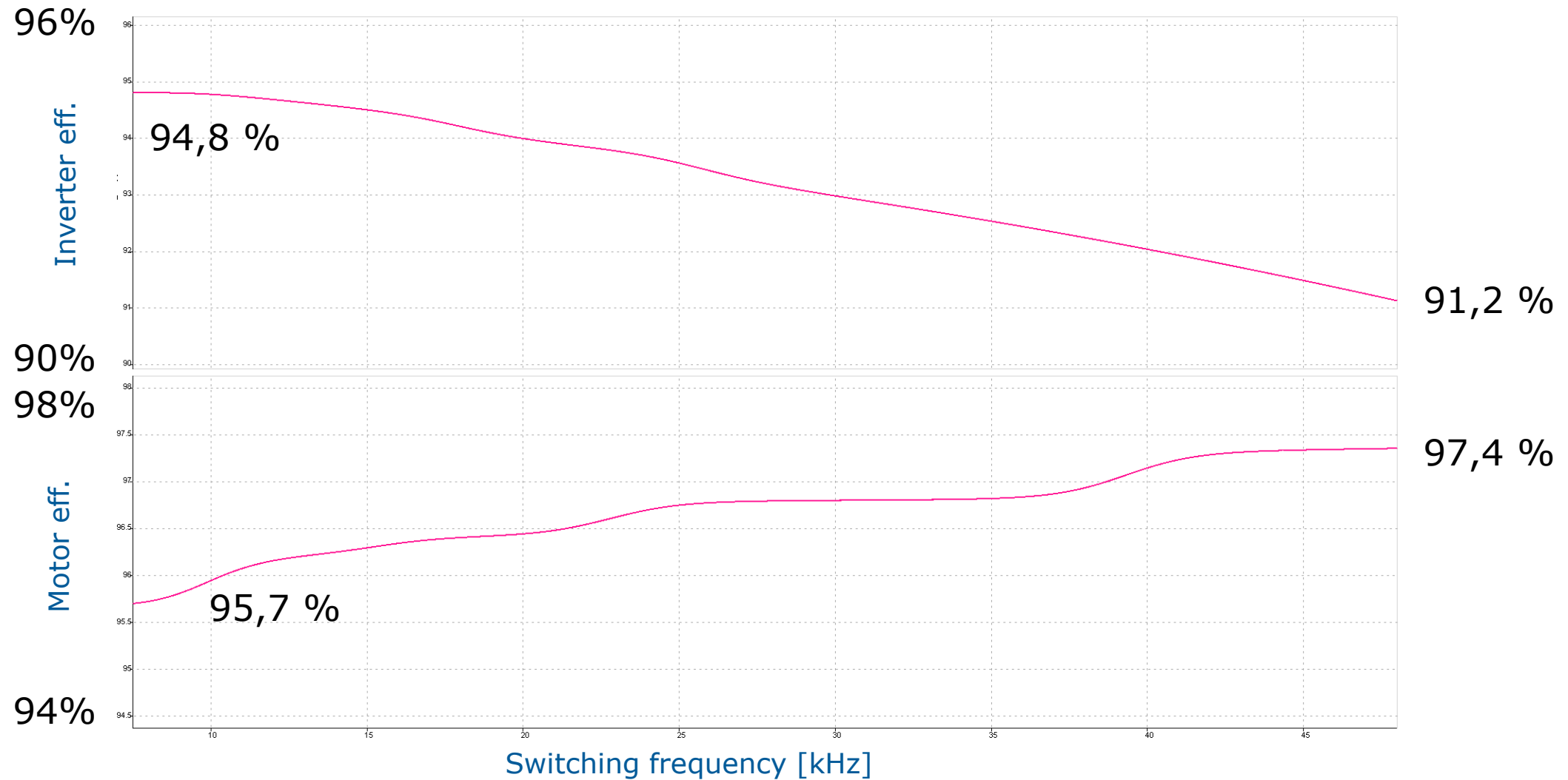
30 kHz (3 Level Operation)



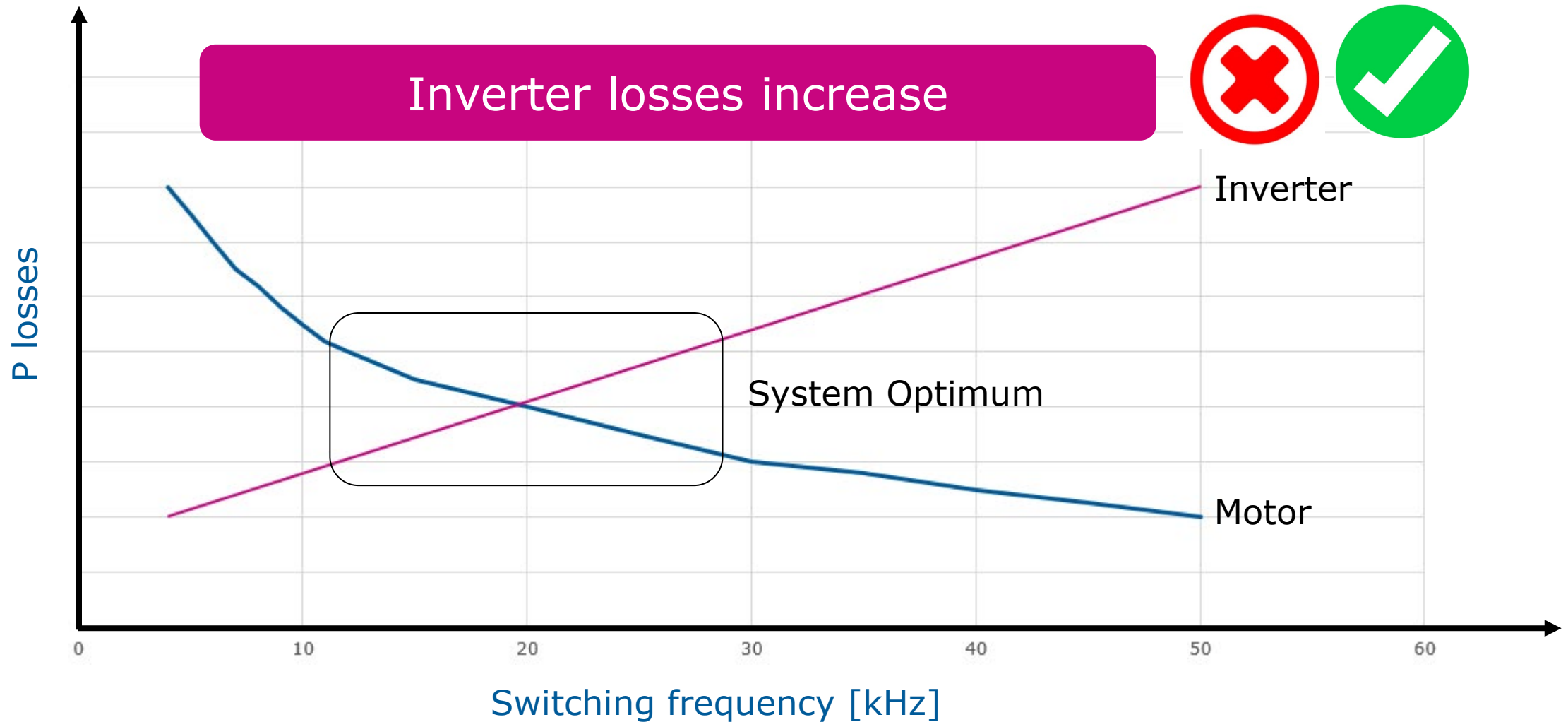
INVERTER VS. MOTOR EFFICIENCY



SECOND MOTOR RESULTS



CAN I IMPROVE E-MOTOR EFFICIENCY WITHOUT HAVING LOSSES IN INVERTER?



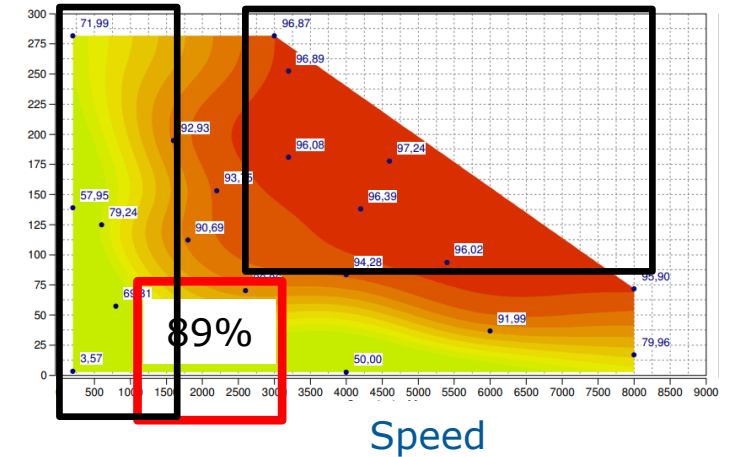
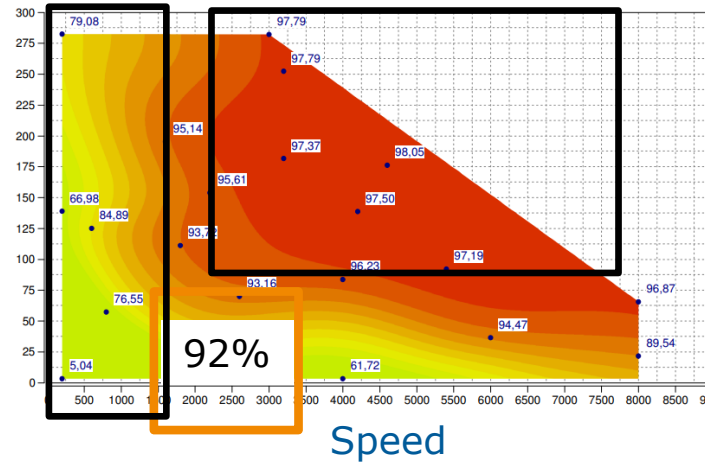
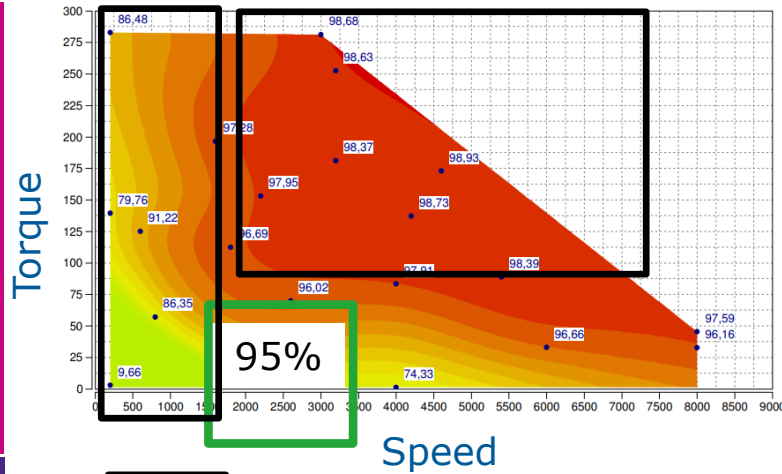
IS ONE SWITCHING FREQUENCY ENOUGH?

10 kHz (2 Level Operation)

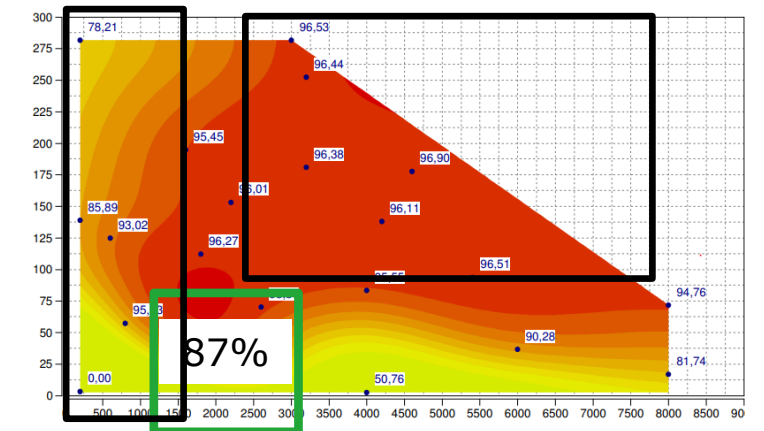
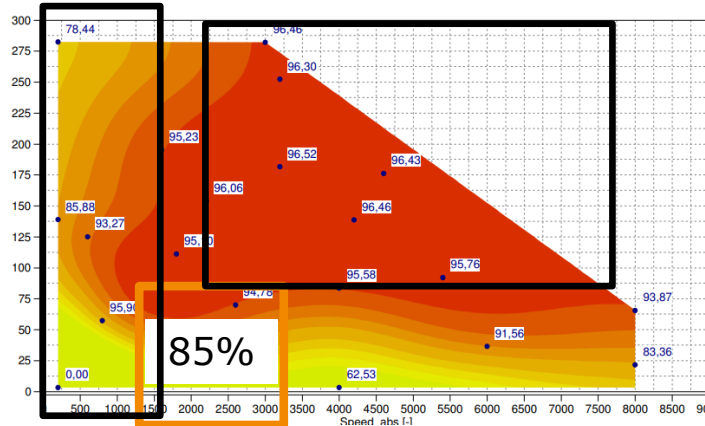
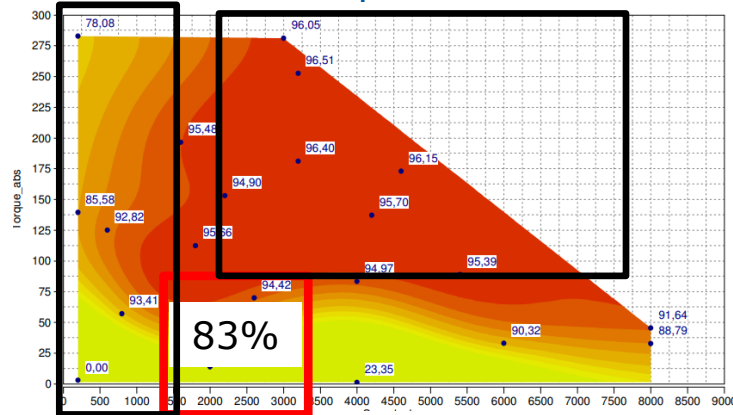
20 kHz (2 Level Operation)

30 kHz (3 Level Operation)

Inverter Efficiency



Motor Efficiency



Summary

- Higher Switching frequency improves the motor efficiency.
- Higher Switching frequency increases inverter losses.
- Further efficiency improvements could be achieved with better control SW:
 - Flexible switching frequency for speed/ torque points
 - Other PWM
 - Id/ Iq
- Universal Inverter can be used for such investigations

Q & A



Vielen Dank



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