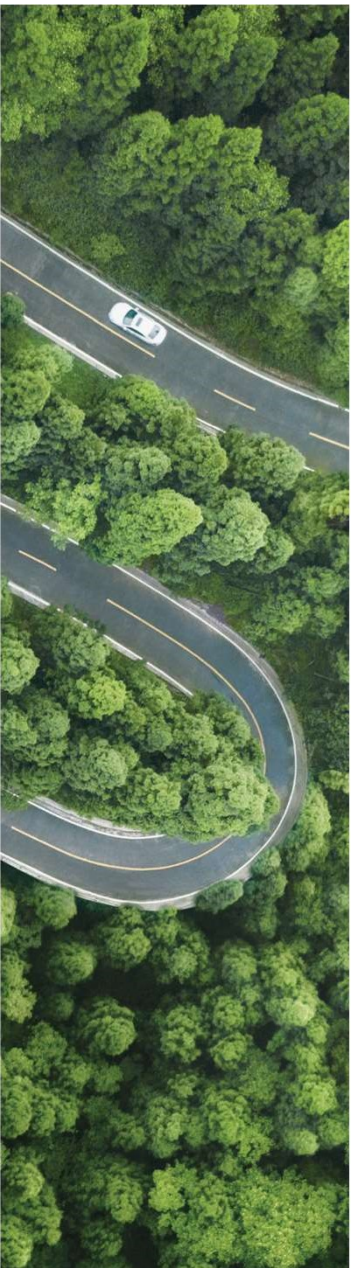
UC 1.4 / 2-Level Voltage Source Traction Inverter Design using 2kV Infineon SiC Power Modules

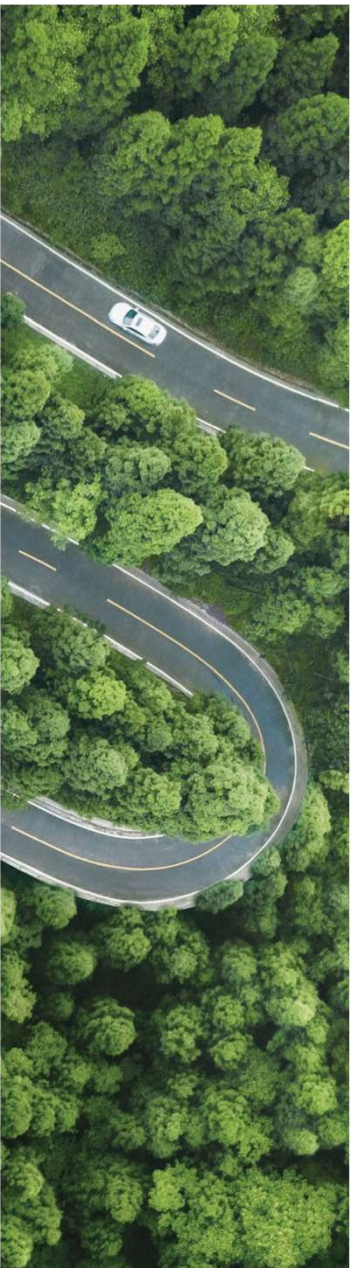
Enes Ayaz, KTH

The project has been accepted for funding within the Key Digital Technologies Joint Undertaking (KDT JU), a public-private partnership in collaboration with the HORIZON Framework Programme and the national Authorities of Germany, Belgium, Spain, Sweden, Netherlands, Austria, Italy, Greece, Latvia, Finland, Hungary, Romania and Switzerland, under grant agreement number 101096387. Co-funded by European Union.



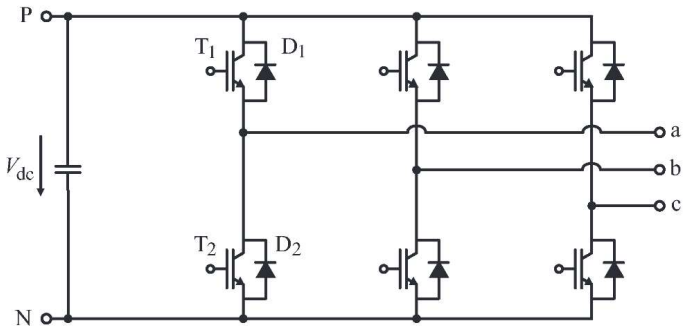
Agenda

1. Power Ratings of 2-Level Inverter
2. Power Modules (Infineon 2kV) Parameters
3. Inverter Loss Estimation with Datasheet Values
4. Harmonic Losses on the Motor
5. Die area and Switching Frequency Selection (Total Losses)

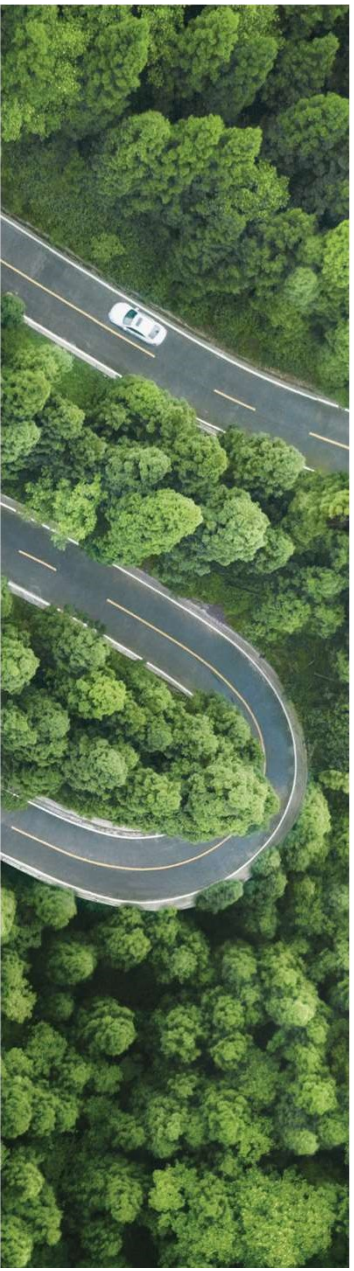


2-Level Inverter Power Ratings

- $P_{out} = 300\ kW$
- $V_{DC} = 1250\ V$
- $I_{in} = \frac{P_{out}}{V_{in}} = 240\ A$
- $\hat{V}_{l-n} = \frac{V_{in}}{2} = 625\ V\ or\ \frac{V_{in}\left(1+\frac{1}{6}\right)}{2} = 729\ V$
- $\hat{I}_l = 2\frac{P_{out}}{3\hat{V}_{l-n}} = 320\ A\ or\ 274\ A$
- $pf = 0.9$
- $\hat{I}_l = 2\frac{\frac{P_{out}}{pf}}{3\hat{V}_{l-n}} = \mathbf{355\ A}\ or\ \mathbf{304\ A}$



Efficiency (99.5%)
Semiconductor Losses (6 switches): **1500 *W***



Parameters of Infineon 2kV Bare die

A. Basic Parameters of Bare die:

Current rating @25˚C (in Amperes) $40A$

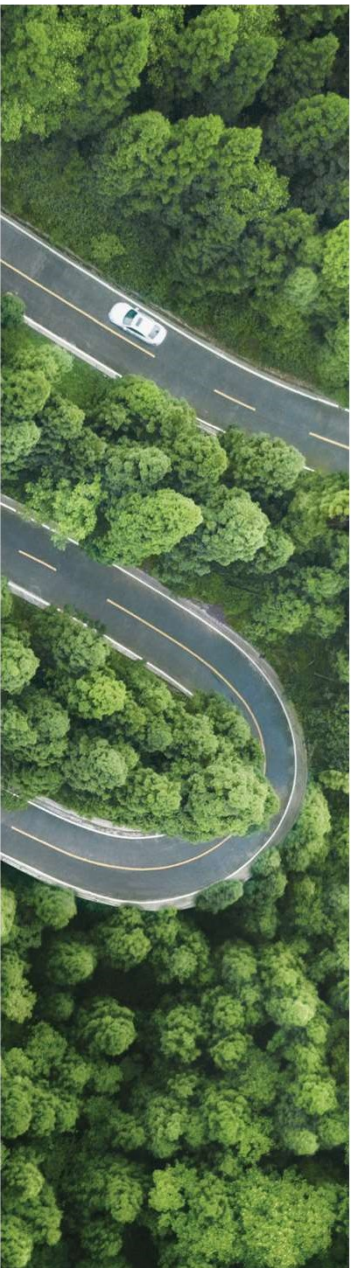
On-state resistance @25˚C (in Ohms) $26\ \mathrm{m}\Omega$

Internal gate resistance (in Ohms) ~ $7{,}2\ \Omega$

Die Size (mm x mm) 5,71 x 5,24 mm

Thermal resistance (Junction to Case) (in ˚C/W) 0.0880 K/W per Mosfet (8 or 10 dies)
Case to heat sink: 0.0330 K/W

Zero Current Loss (Output Capacitance Loss) ~ $1.25\ mJ.f_{sw}, 1\ mJ.f_{sw}$

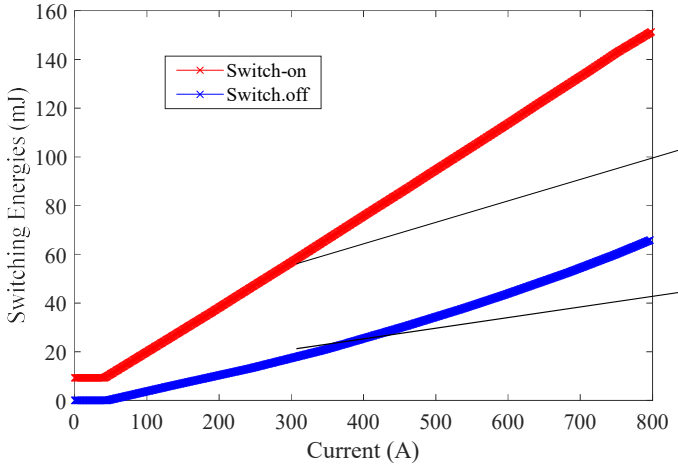


Datasheet-Driven Loss Estimation

Voltage rating: 2kV

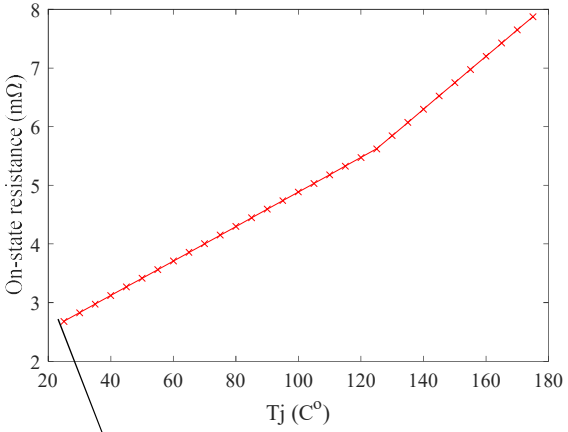
Current rating: 400A

FF3MR20KM1H using 10 dies in parallel

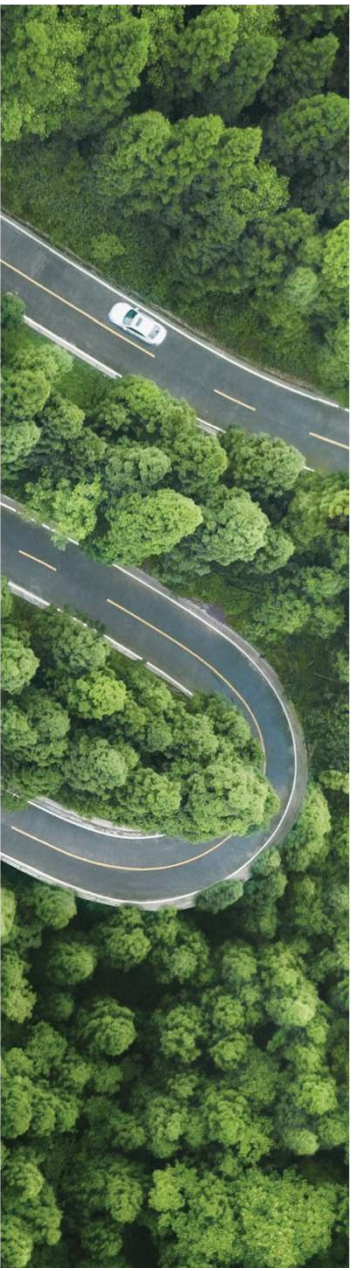


58 mJ at 304 A

17 mJ at 304 A

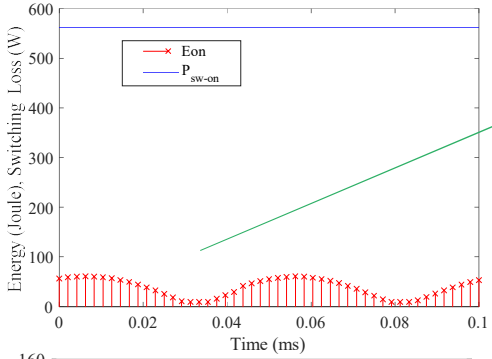


$$\frac{26}{10} = 2.6\text{m}\Omega$$

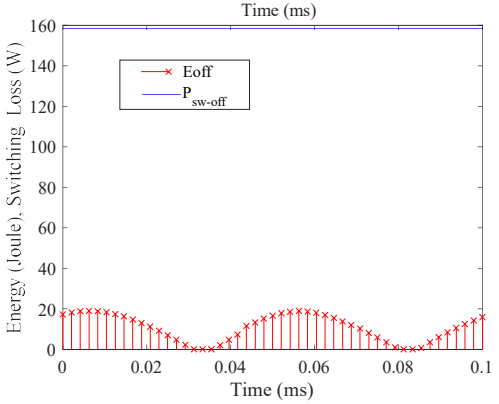


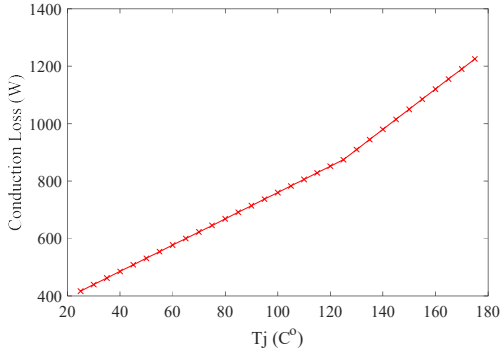
Datasheet-driven Loss Calculation

Switching frequency = **5kHz**, ma=1.15, pf=0.9 2-level 3-phase, P=300kW



The current is sinusoidal.

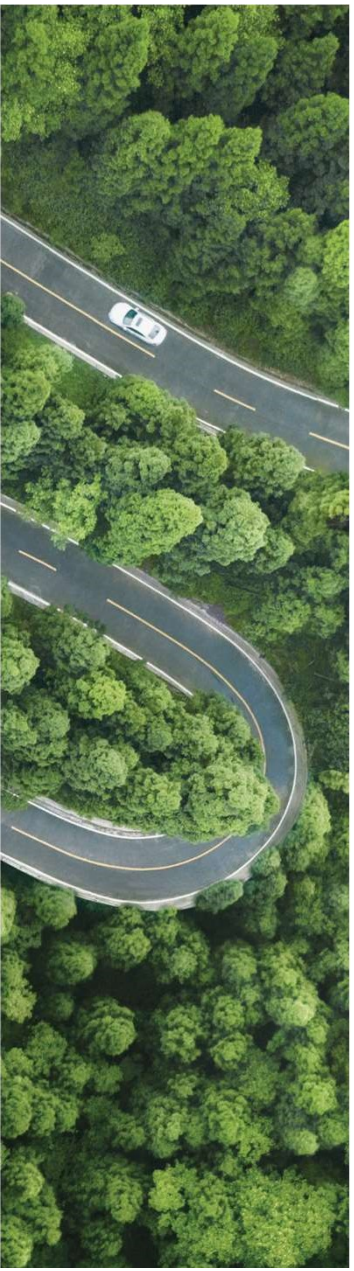




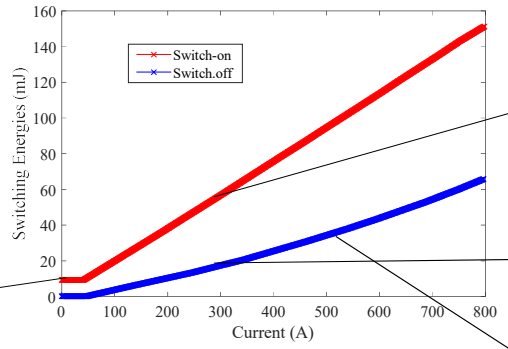
The maximum switching frequency is 5kHz since we have **slow switching speed (dv/dt) test data** in the datasheet.

T_j (C^o)	75 C^o	125C^o	150 C^o
Loss (W)	1366	1590	1770
Efficiency (%)	99.55	99.47	99.41

- Assume only conduction loss is changed with temperature.
- We do not use a thermal model here; we just find the losses for different junction temperatures.



Updating Switching Losses for Fast dv/dt



58 mJ at 304 A

17 mJ at 304 A

10mJ

Output capacitance loss

$$P_{oss} = f_{sw}\, V_{sw}\, Q_{oss}(V_{sw}),$$

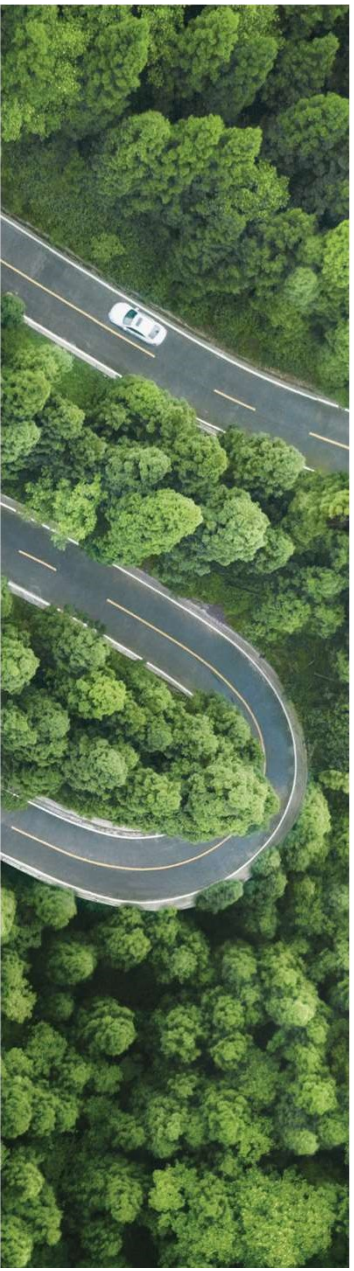
Linearly increasing by the number of dies in parallel

Overlapping loss

$$P_{vi} = f_{sw}\left(\frac{1}{2}\frac{V_{sw}^2}{dv/dt} I_{sw} + \frac{1}{2}\frac{I_{sw}^2}{di/dt} V_{sw}\right)$$

Depends on dv/dt and di/dt

$$L_S = \frac{1}{C_{ISS}\,(2\pi f_R)^2} \qquad Q = \frac{X_L}{R_G} = \frac{\omega L_S}{R_G}$$



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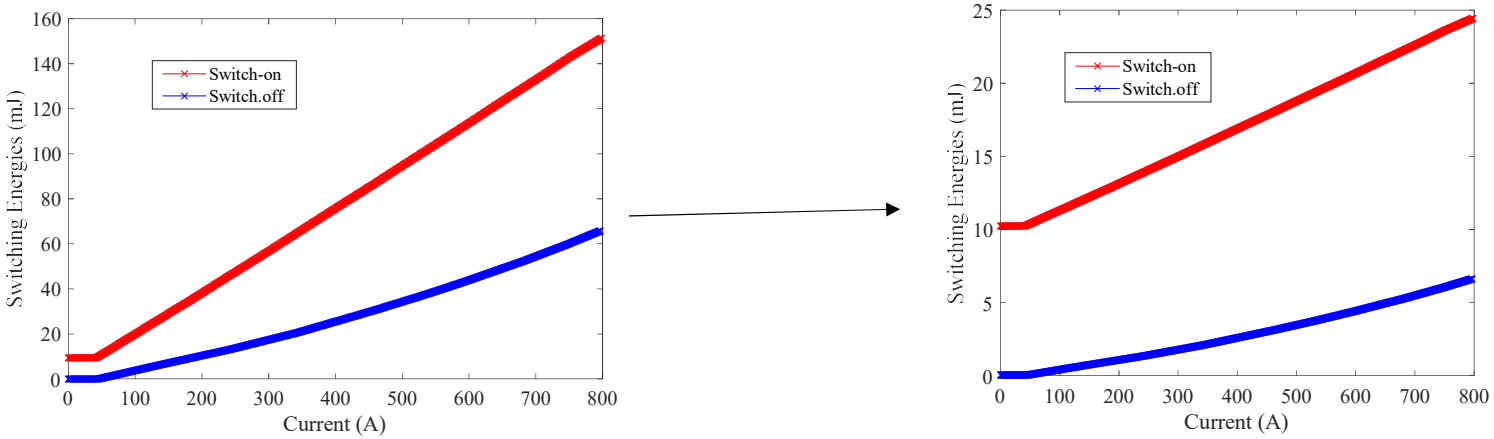
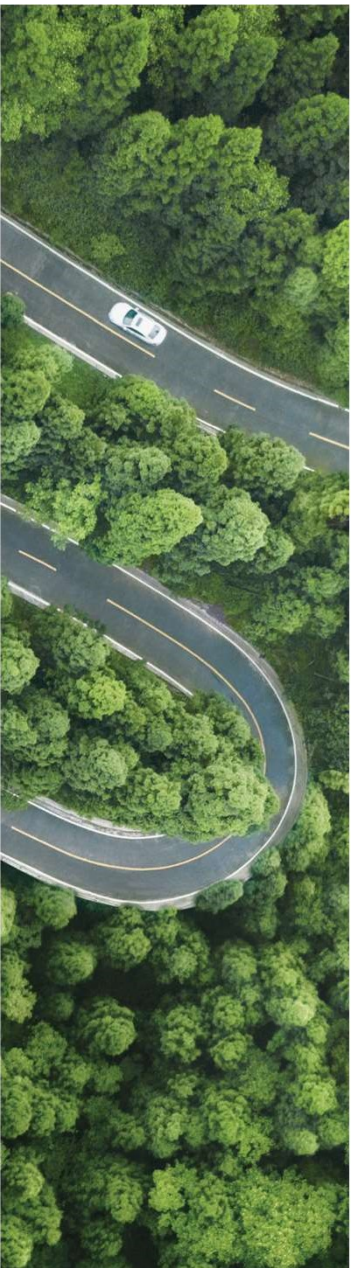
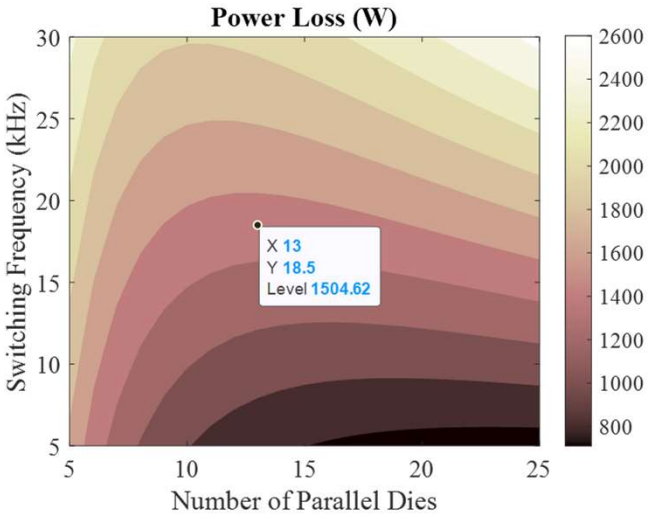


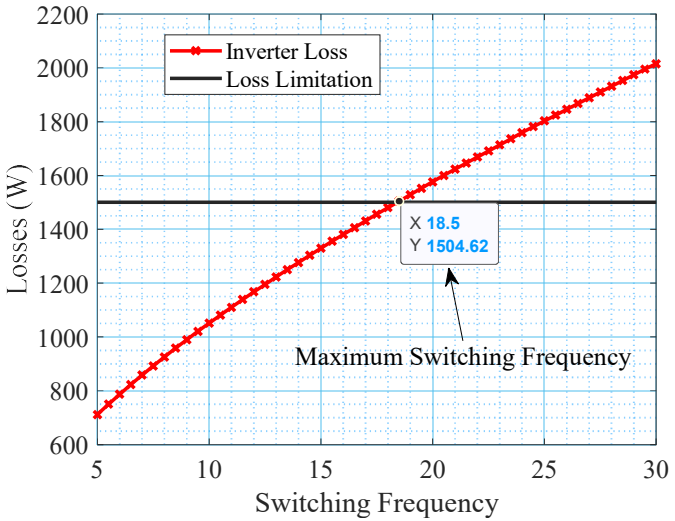
Same output capacitance loss

Updated overlapping loss

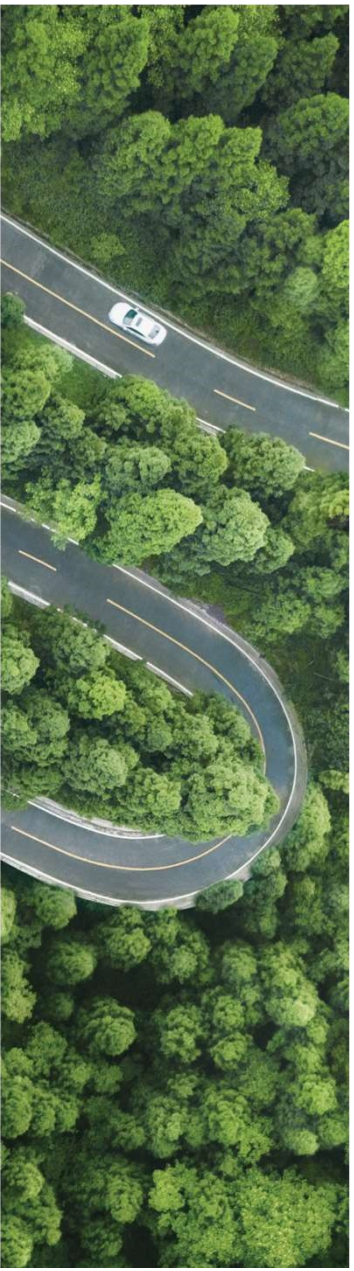


Updating Switching Losses for Fast dv/dt

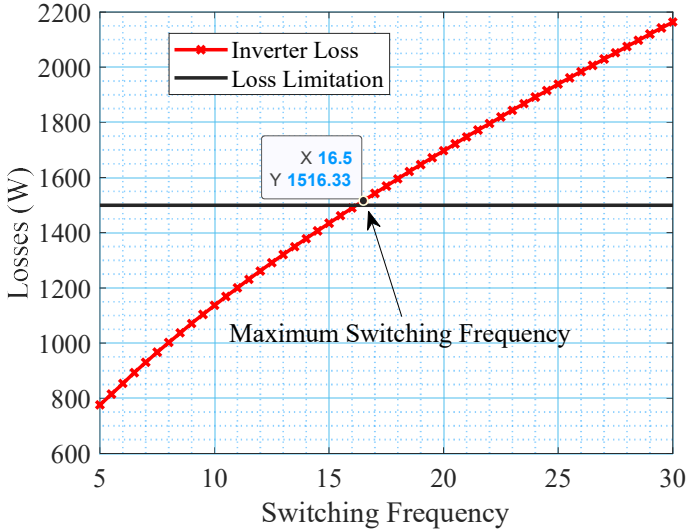




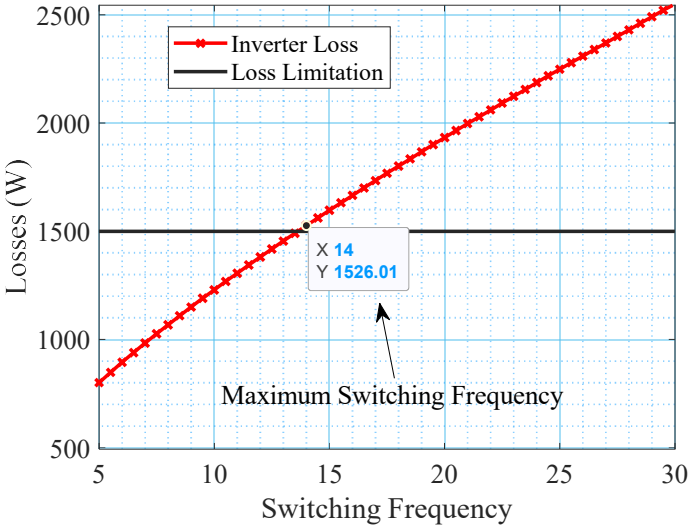
- Number of Dies area selected as minimized the losses regarding the switching frequency.
- Junction temperature is taken at 75 C^o.



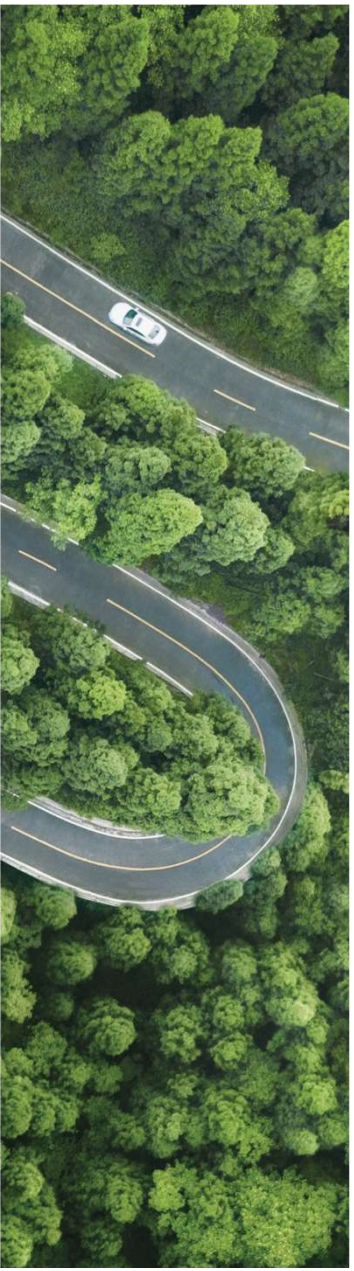
Other Cases



- If junction temperature is taken at 100 C^o

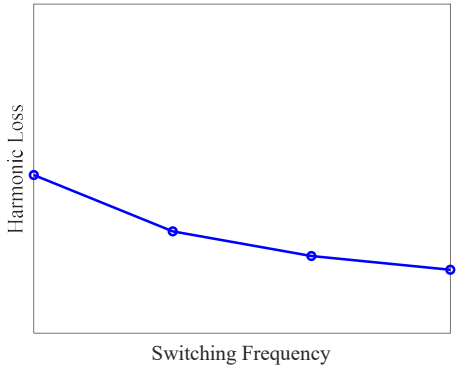


- If we lower dv/dt 2.5 times



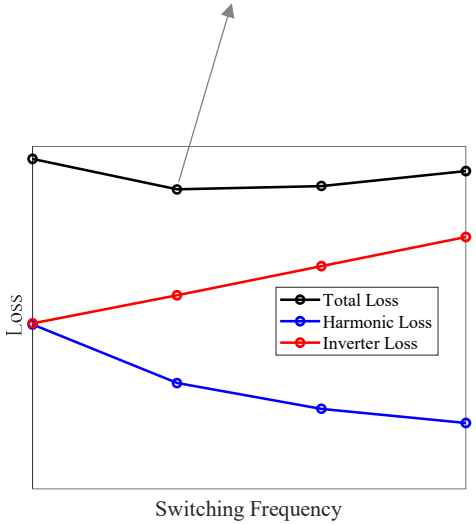
Harmonic Losses on the Motor

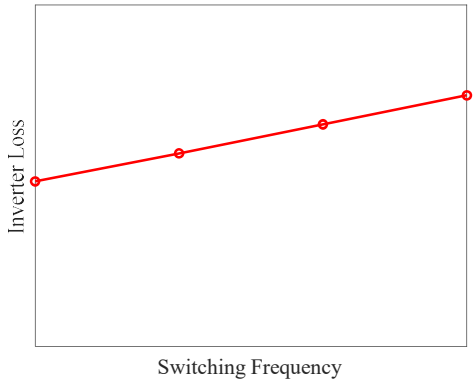
We have trade-off between motor harmonic losses and inverter losses.



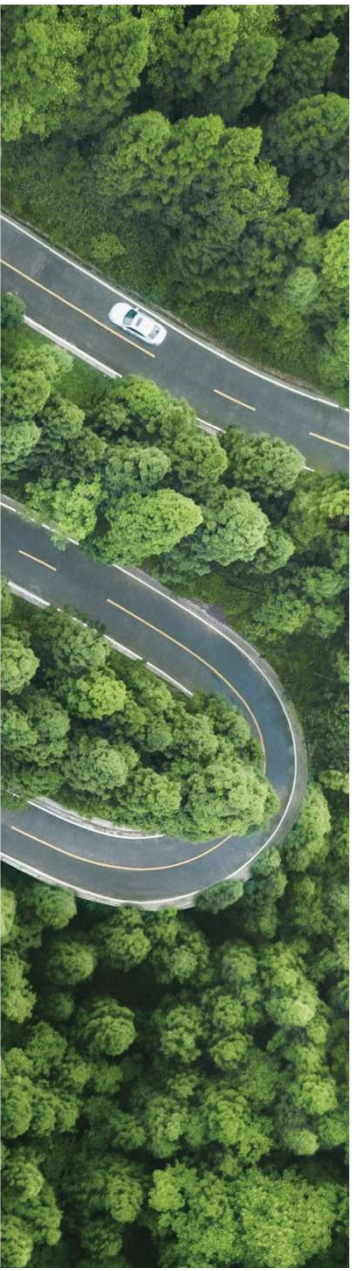
Decreasing trend

Optimum point

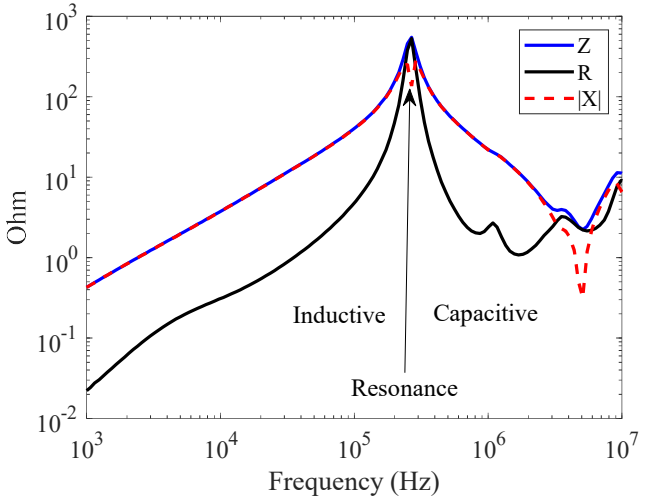


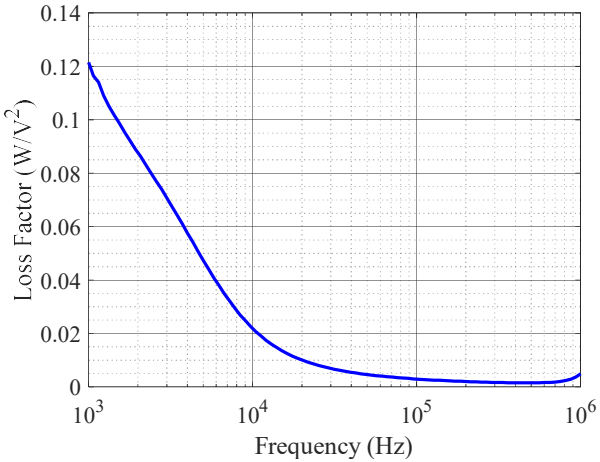


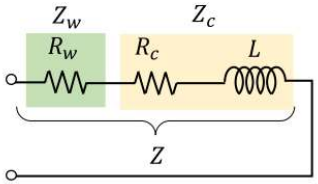
Increasing trend

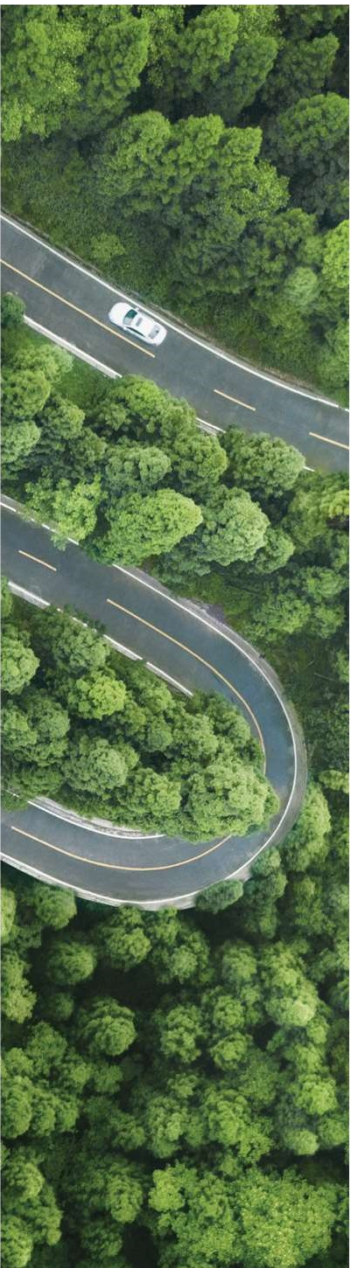


Harmonic Losses Estimation- Impedance Model









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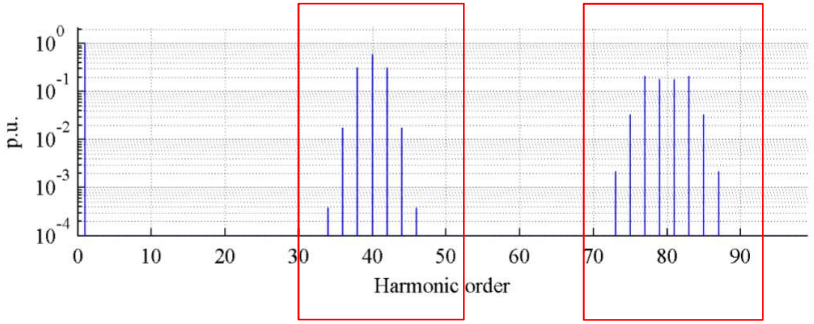
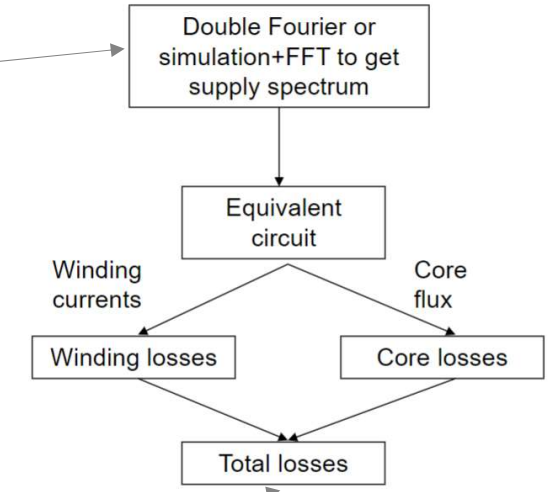
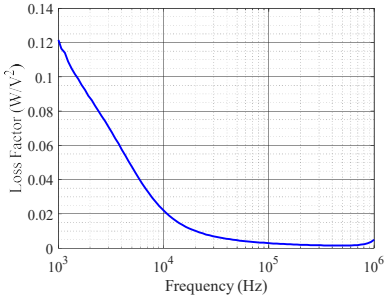
Harmonic Losses Estimation- Impedance Model

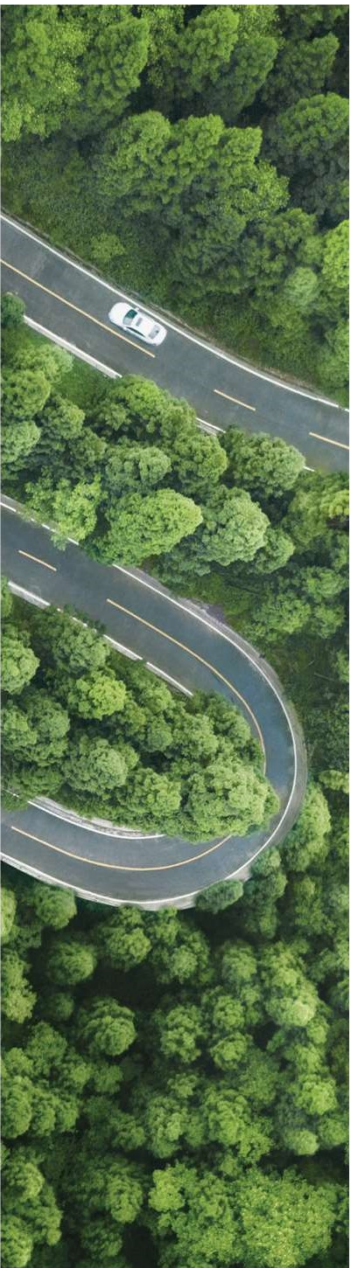


Harmonic distribution changes regarding inverter operation



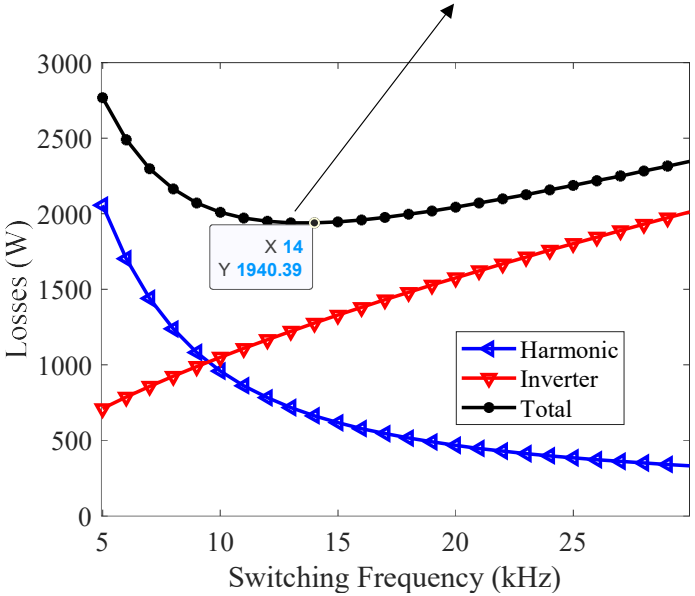


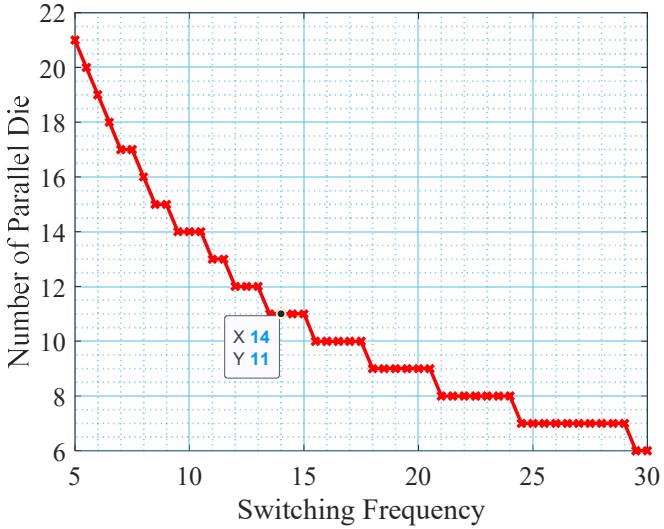
Loss Factor



Total Losses Calculation

Optimum switching frequency





Voltage rating: 2kV

Current rating: 440A

11 dies in parallel → Desired one for fast dv/dt, 14 kHz

Voltage rating: 2kV

Current rating: 400A

FF3MR20KM1H
10 dies in parallel

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