IEC

New Developments in IEC Standards for Motors Driven by Frequency Converters

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Energy Efficiency Classification - Overview

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Energy Efficiency Classification – Testing Standards

Standard	Working Group	Status
IEC 60034-2-1	IEC TC2 WG 28 (Axel Möhle)	ed 2.0 published (2014-06)
IEC/TS 60034-2-3	IEC TC2 WG 28 (Axel Möhle)	ed 1.0 published (2013-11)
IEC 61800-9-3	IEC SC22G WG18 (Tim Schumann)	NWIP accepted 22G/277/NP (2014-09)

Energy Efficiency Classification – Classification Standards

Standard	Working Group	Status
IEC 60034-30-1	IEC TC2 WG 31 (Martin Doppelbauer)	ed 1.0 published (2014-03)
IEC 60034-30-2	IEC TC2 WG 31 (Martin Doppelbauer)	2CD in preparation (Q1 2015)
IEC 61800-9-2	IEC SC22G WG18 (Tim Schumann)	NWIP accepted 22G/277/NP (2014-09)

IEC 60034-30-1 Energy Efficiency Classification of Grid-Fed Motors as a Component

- All motor technologies
  (single- and three-phase, induction and line-start synchronous)
- Classes IE1, IE2, IE3, IE4 for 50 Hz and 60 Hz
- Power range 0.12 kW up to 1000 kW
- 2-, 4-, 6-, 8-poles

IEC 60034-30-2 Energy Efficiency Classification
of Frequency Converter Fed-Motors as a Component

Work in Progress !

- All motor technologies
  (induction, PM-synchronous, reluctance-synchronous, ...)
- Classes IE1, IE2, IE3, IE4
- Power range 0.12 kW up to 1000 kW
- Rated speed 600 up to 6000 1/min
- Constant flux / constant torque operation
  (so far no field-weakening / constant power operation,
  no over-load operation)

- Efficiency determined at six load-points
- Classification will be based on weighted average of load-points
- Interpolation procedure to determine energy consumption
  at any load-point

IEC 60034-30-2 Energy Efficiency Interpolation

Stator and rotor winding losses (P_{LS} + P_{LR})

$$P_{LSR}(f,T) = P_{LSR} \cdot \frac{I_0}{I_N} + P_{LSR} \cdot \left(1 - \frac{I_0}{I_N}\right) \cdot T^2$$

Iron losses (P_{Lfe})

$$P_{Lfe}(f,T) = \frac{1}{2} \cdot P_{Lfe} \cdot f + \frac{1}{2} \cdot P_{Lfe} \cdot f^2$$

Additional load losses (P_{LL})

$$P_{LL}(f,T) = \frac{1}{2} \cdot P_{LL} \cdot f + \frac{1}{2} \cdot P_{LL} \cdot f^2$$

Friction and windage losses (P_{Lfw})

$$L_{Lfw}(f,T) = \frac{1}{2} \cdot P_{Lfw} \cdot f + \frac{1}{2} \cdot P_{Lfw} \cdot f^3$$

Additional harmonic losses (P_{LHL})

$$P_{LHL}(f,T) = P_{LHL}$$

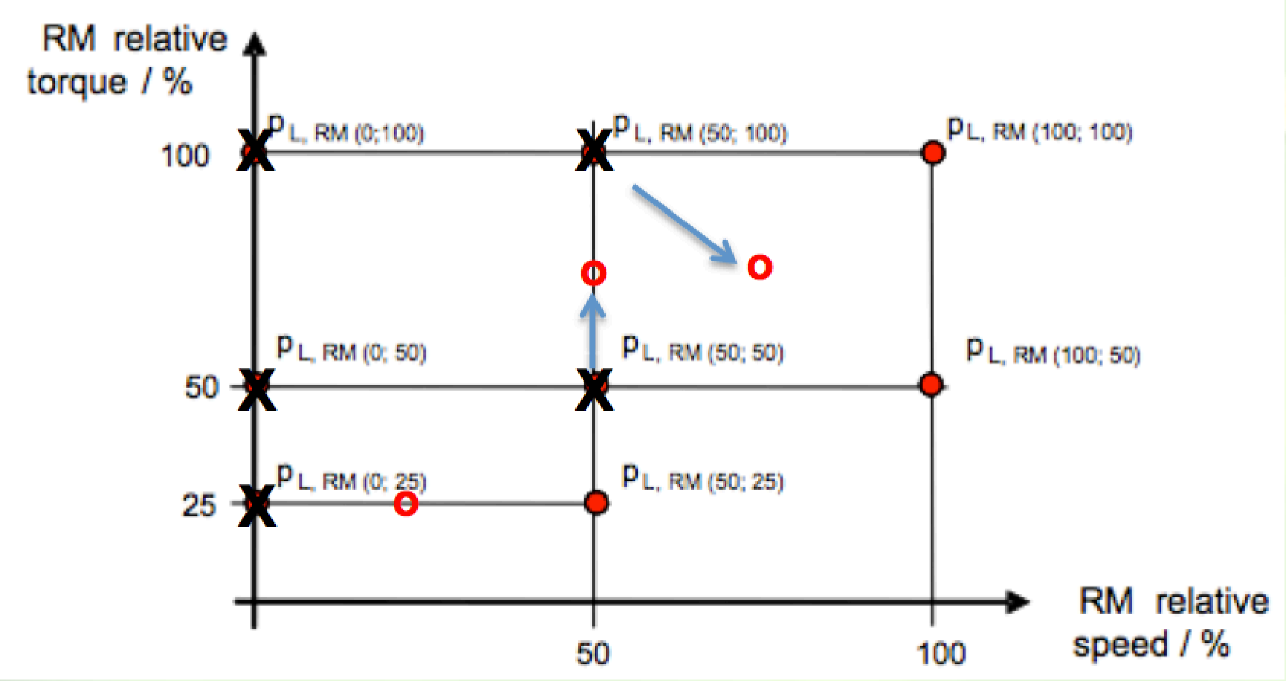
Interpolation

$$\boldsymbol{P_L(f,T) = A + B \cdot f + C \cdot f^2 + D \cdot f^3 + E \cdot T + F \cdot T^2}$$

IEC 60034-30-2 Energy Efficiency Interpolation

#	*f*	*T*	*P*	Comment
1	1	1	1	No change
2	*0.75*	*0,75*	0.56	New, was (0.5,1)
3	1	0.5	0.50	No change
4	*0.5*	*0.75*	0.375	New, was (0.5,0.5)
5	0.5	0.25	0.13	No change
6	0.25	0.25	0.0625	New

Reference to
EN 50598-2



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Interpolation Stability Index (ISI)

Q_{ISI} is the standard deviation of the interpolation errors at 16 load points

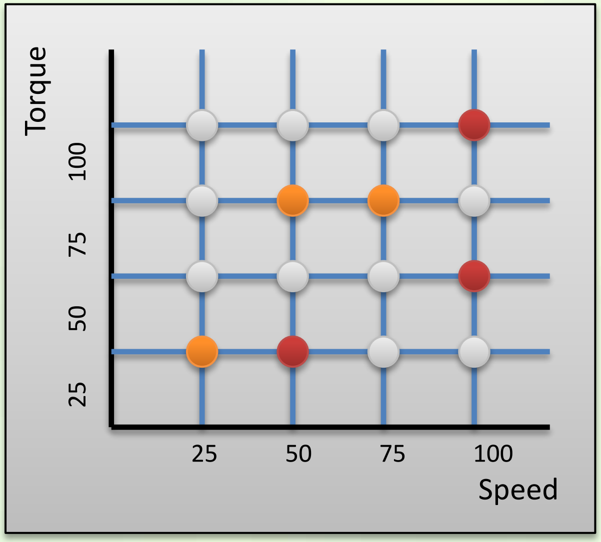
$$Q_{ISI} = \sqrt{\frac{1}{16}\sum_{f}\sum_{T}\left(\frac{P_{L(f,T)}^{measured} - P_{L(f,T)}^{interpolated}}{P_{L(f,T)}^{measured}}\right)^2}$$

Q_{ISI} <= 10 % good
Q_{ISI} <= 20 % acceptable

By using a grid of 16 measurement points at 25, 50, 75 and 100% speed and torque, the quality of the interpolation can be assessed.

Best-fit interpolation

- Same interpolation formula
- No differences from a user perspective!
- Incorporates all 16 load-points
- The coefficients are determined numerically by a search for the minimum Q_{ISI}



IEC 60034-30-2 Energy Efficiency Interpolation

Example 1: Losses of a large induction motor

Measured Efficiencies:

Torque					
1	0,8073	0,8844	0,9149	0,9272	
0,75	0,8321	0,8935	0,9199	0,9348	
0,5	0,8379	0,8893	0,9139	0,9301	
0,25	0,7881	0,8468	0,8733	0,8960	
	0,25	*0,5*	*0,75*	*1*	**Speed**

Analytically determined coefficients (6-points): Q_{ISI} = 4.4 %

A=	0,010968
B=	0,044137
C=	-0,037814
D=	0,017059
E=	-0,031258
F=	0,075424

Error of interpolated losses

Torque					
1	7%	7%	6%	0%	
0,75	3%	0%	0%	2%	
0,5	-4%	-7%	-6%	0%	
0,25	0%	0%	-1%	8%	
	0,25	*0,5*	*0,75*	*1*	**Speed**

Numerically improved coefficients (16-points): Q_{ISI} = 2.1 %

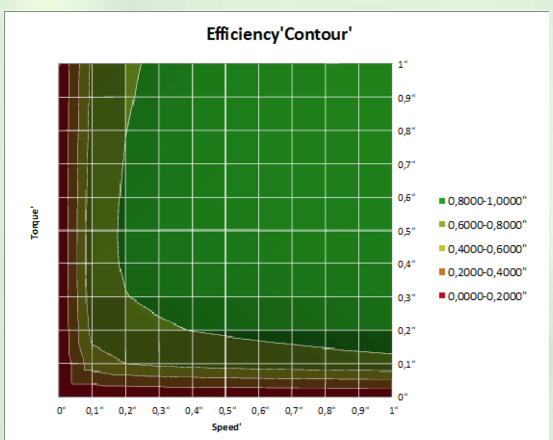
A=	0,005712
B=	0,048941
C=	-0,041625
D=	0,017320
E=	-0,012270
F=	0,056906

Error of interpolated losses

Torque					
1	1%	1%	1%	-7%	
0,75	2%	1%	1%	-1%	
0,5	0%	-2%	-1%	0%	
0,25	-2%	1%	0%	3%	
	0,25	*0,5*	*0,75*	*1*	**Speed**

IEC 60034-30-2 Energy Efficiency Interpolation

Example 1: Losses of a large induction motor (16-point coefficients)



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IEC 60034-30-2 Energy Efficiency Interpolation

Example 2: Losses of a medium sized induction motor

Measured Efficiencies:

Torque					
1	0,6958	0,8220	0,8698	0,8661	
0,75	0,7625	0,8529	0,8842	0,8902	
0,5	0,7801	0,8470	0,8702	0,8861	
0,25	0,7471	0,8041	0,8209	0,8449	
	0,25	0,5	0,75	1	Speed

Analytically determined coefficients (6-points): Q_{ISI} = 15.7 %

A=	0,023472
B=	0,134738
C=	-0,211289
D=	0,139235
E=	-0,155984
F=	0,224430

Error of interpolated losses

Torque					
1	5%	14%	18%	0%	
0,75	-5%	0%	0%	3%	
0,5	-31%	-26%	-24%	0%	
0,25	0%	0%	-4%	33%	
	0,25	0,5	0,75	1	Speed

Numerically improved coefficients (16-points): Q_{ISI} = 6.4 %

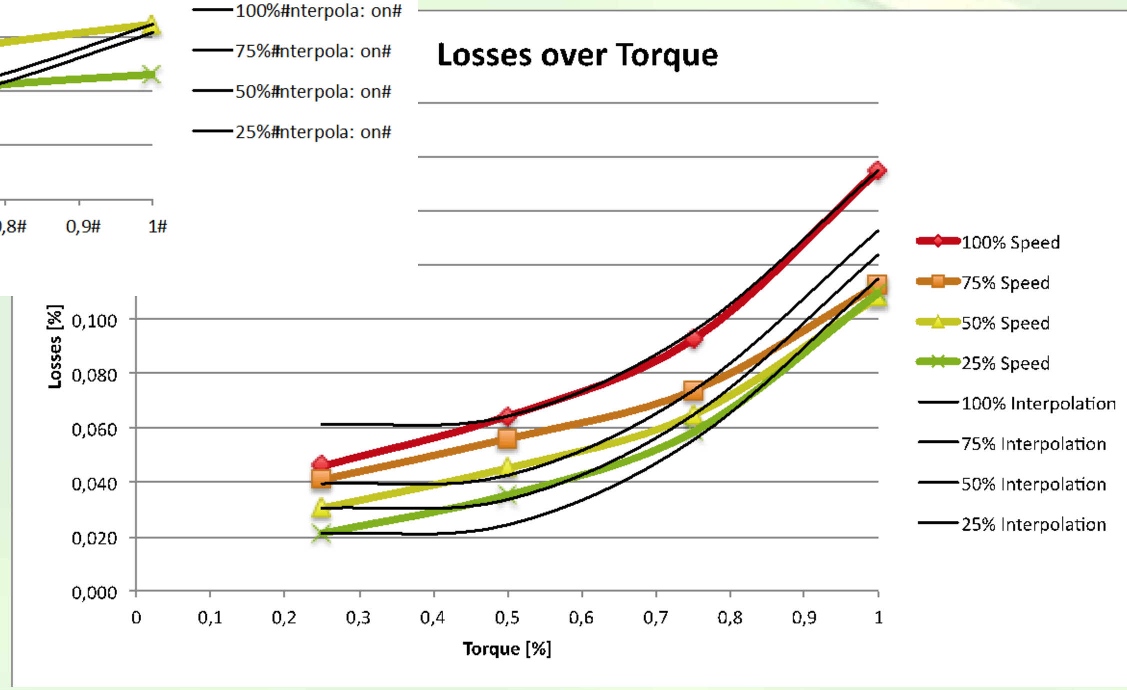
A=	0,014670
B=	0,023191
C=	0,020192
D=	-0,008191
E=	-0,028073
F=	0,107913

Error of interpolated losses

Torque					
1	-7%	2%	7%	-16%	
0,75	5%	8%	8%	-3%	
0,5	-2%	-4%	-5%	-2%	
0,25	1%	-1%	-3%	8%	
	0,25	0,5	0,75	1	Speed

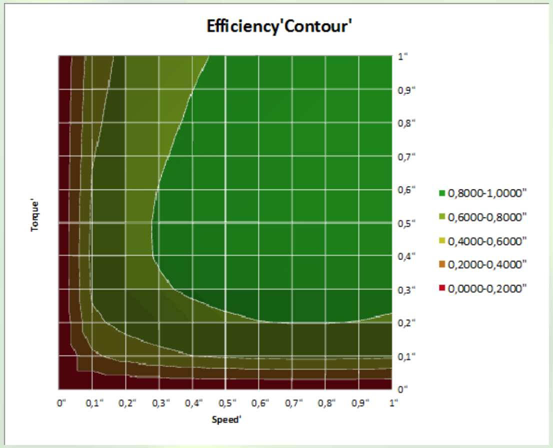
IEC 60034-30-2 Energy Efficiency Interpolation

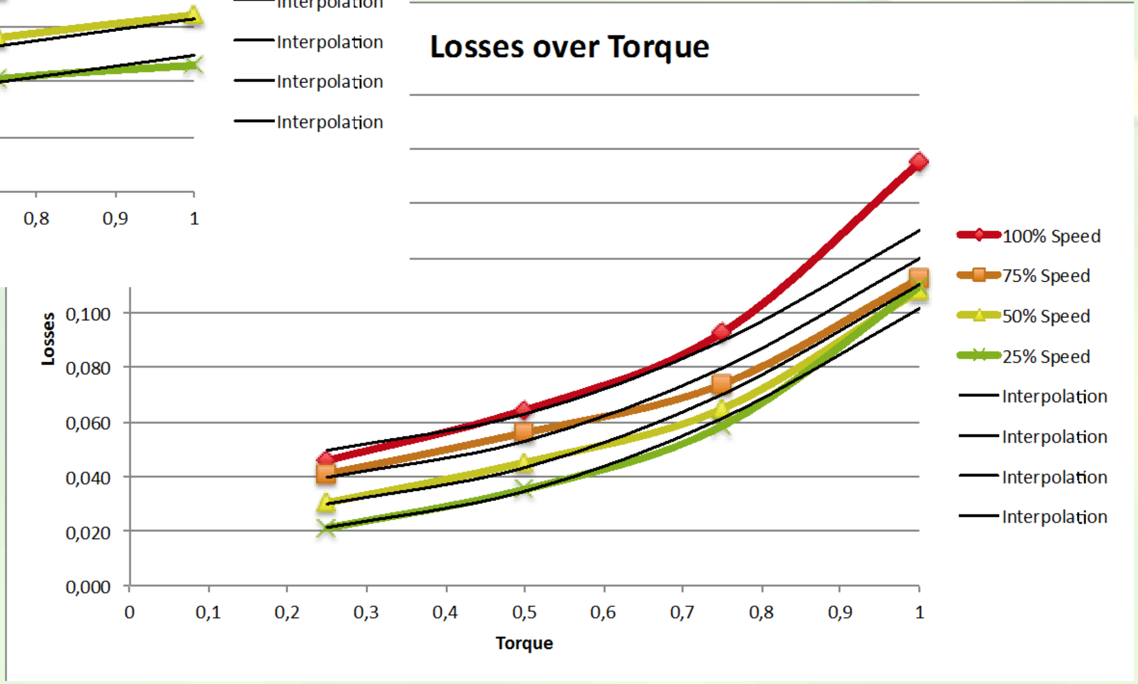
Example 2: Losses of a medium sized induction motor (6-point coefficients)



IEC 60034-30-2 Energy Efficiency Interpolation

Example 2: Losses of a medium sized induction motor (16-point coefficients)





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Physical interpolation compared to EN 50598-2 G.2.3

$$P_L(f,T) = A + B \cdot f + C \cdot f^2 + D \cdot f^3 + E \cdot T + F \cdot T^2$$

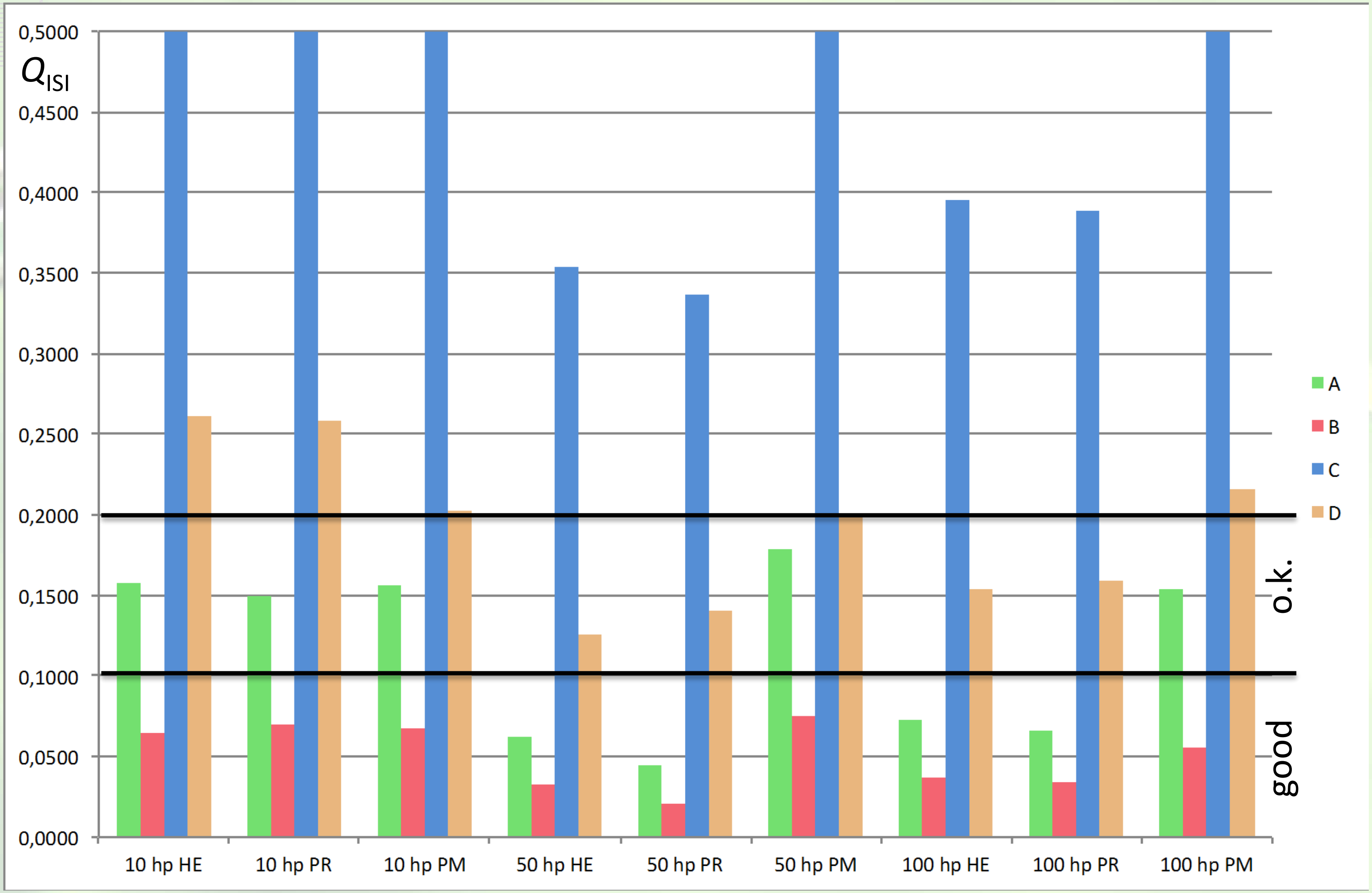
$$p_{L,Z}(f_Z, iq_Z) = p_{L,CDM(0,50)} + \frac{p_{L,CDM(50,50)} - p_{L,CDM(0,50)}}{50} \cdot f_Z + \left(\frac{\left(p_{L,CDM(0,100)} + \frac{p_{L,CDM(50,100)} - p_{L,CDM(0,100)}}{50} \cdot f_Z \right)}{50} - \frac{\left(p_{L,CDM(0,50)} + \frac{p_{L,CDM(50,50)} - p_{L,CDM(0,50)}}{50} \cdot f_Z \right)}{50} \right) \cdot (iq_Z - 50)$$

$$p_{L,Z}(f_Z, iq_Z) = p_{L,CDM(50,50)} + \frac{p_{L,CDM(90,50)} - p_{L,CDM(50,50)}}{40} \cdot (f_Z - 50) + \left(\frac{\left(p_{L,CDM(50,100)} + \frac{p_{L,CDM(90,100)} - p_{L,CDM(50,100)}}{40} \cdot (f_Z - 50) \right)}{50} - \frac{\left(p_{L,CDM(50,50)} + \frac{p_{L,CDM(90,50)} - p_{L,CDM(50,50)}}{40} \cdot (f_Z - 50) \right)}{50} \right) \cdot (iq_Z - 50)$$

$$p_{L,Z}(f_Z, iq_Z) = p_{L,CDM(0,25)} + \frac{p_{L,CDM(50,25)} - p_{L,CDM(0,25)}}{50} \cdot f_Z + \left(\frac{\left(p_{L,CDM(0,50)} + \frac{p_{L,CDM(50,50)} - p_{L,CDM(0,50)}}{50} \cdot f_Z \right)}{25} - \frac{p_{L,CDM(0,25)} + \frac{p_{L,CDM(50,25)} - p_{L,CDM(0,25)}}{50} \cdot f_Z}{25} \right) \cdot (iq_Z - 25)$$

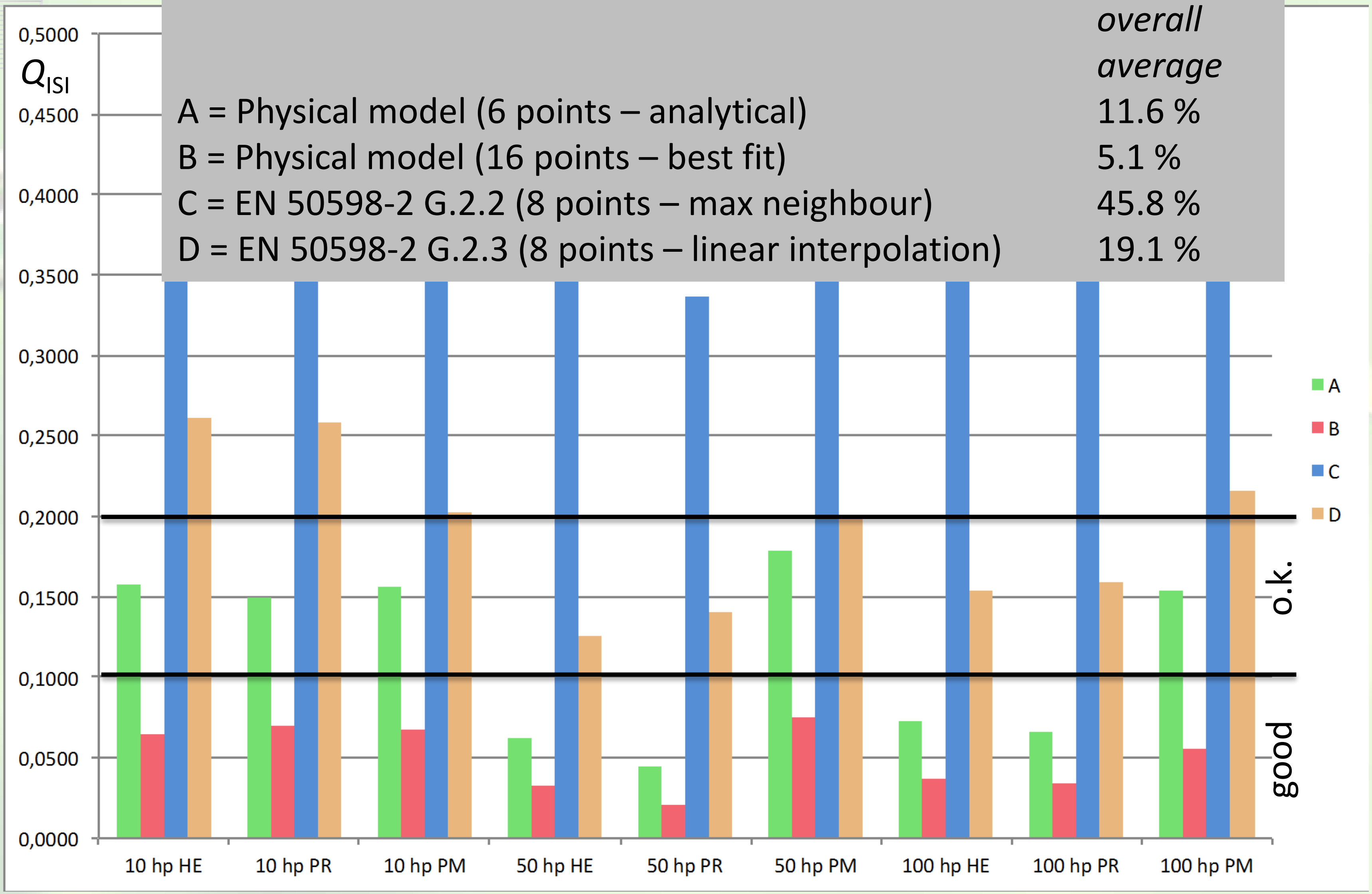
$$p_{L,Z}(f_Z, iq_Z) = p_{L,CDM(0,25)} + \frac{p_{L,CDM(50,25)} - p_{L,CDM(0,25)}}{50} \cdot f_Z + \left(\frac{\left(p_{L,CDM(50,50)} + \frac{p_{L,CDM(90,50)} - p_{L,CDM(50,50)}}{50} \cdot (f_Z - 50) \right)}{25} - \frac{p_{L,CDM(0,25)} + \frac{p_{L,CDM(50,25)} - p_{L,CDM(0,25)}}{50} \cdot f_Z}{25} \right) \cdot (iq_Z - 25)$$

Physical interpolation compared to EN 50598-2 G.2.2 and G.2.3



Physical interpolation compared to EN 50598-2 G.2.2 and G.2.3

	overall average
A = Physical model (6 points – analytical)	11.6 %
B = Physical model (16 points – best fit)	5.1 %
C = EN 50598-2 G.2.2 (8 points – max neighbour)	45.8 %
D = EN 50598-2 G.2.3 (8 points – linear interpolation)	19.1 %



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Physical interpolation

So far: Work in progress !

- No motors below 7,5 kW analyzed
- No provisions for overload
- No provisions for field-weakening operation (constant power range beyond rated speed)

=> Next meeting of TC2 WG28/WG31 in January will hopefully bring a decision

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