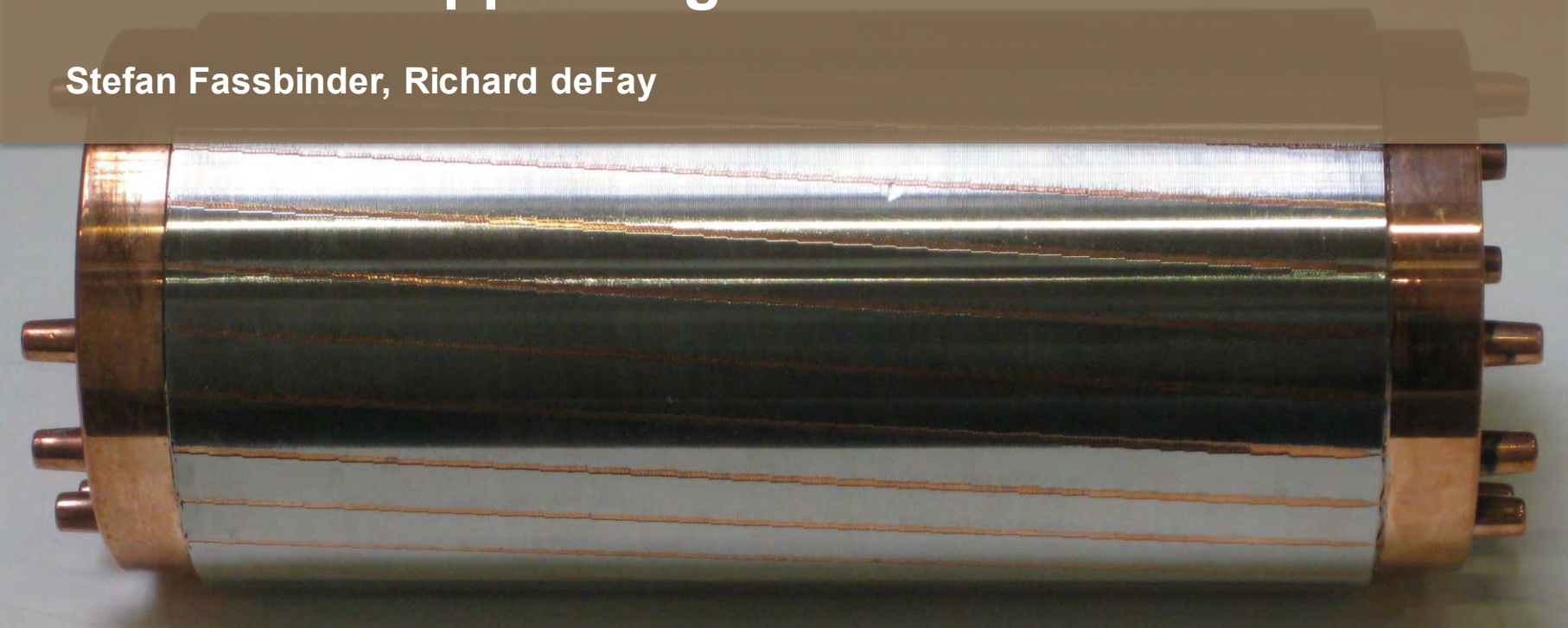
Deutsches Kupferinstitut
Copper Alliance

Comparative Efficiency Measurements on Permanent Magnet Synchronous Motors and Cast Copper Cage Induction Motors

Stefan Fassbinder, Richard deFay



»The efficiencies of induction motors drop at part load«

Cu

In a recent publication, the efficiency of an induction motor drops at half load

from 96.2% to 96.0% (75 kW) or
from 93.9% to 93.3% (30 kW), respectively.

At half load, the efficiency of a synchronous reluctance motor from the same publication drops

from 93.3% to 93.1% (30 kW).

It is always mentioned which type of inverter is used.

Not however whether it was included in the measurement.

The author is reluctant to send a statement »due to time issues«.

The editor feels embarrassed:

»This will peter out open-ended«.

Now what really is »part load«?

Cu

Argument:

»Permanent magnet synchronous motors do not require any additional energy for excitation«.

However:

Permanent magnet synchronous motors are several times over-excited at high speed and low torque and hence require active field weakening in this operating mode.

Our US colleagues wanted to know precisely what we are at

Copper Develompment Associacion USA Inc

www.copperalliance.us, Richard deFay

commissioned

Advanced Energy Inc.

to measure the efficiencies of some

Permanent magnet synchronous motors

compared to

induction motors with squirrel cages cast of copper.

What was measured?

Cu

Available samples were:

3 **permanent magnet synchronous motors** and
1 **asynchronous motor with squirrel cage cast from copper** at

5.0	Hp	(3.7 kW),
7.5	Hp	(5.5 kW),
10.0	Hp	(7.5 kW),
20.0	Hp	(15.0 kW),

respectively.

For each **synchronous motor** an inverter »as recommended by the manufacturer« was procured.

The **asynchronous motors** were measured with 2 or 3 different »adequate« inverters each.

The overall systems efficiencies of these circuits were measured.

The difficulties began right from the start when purchasing the samples

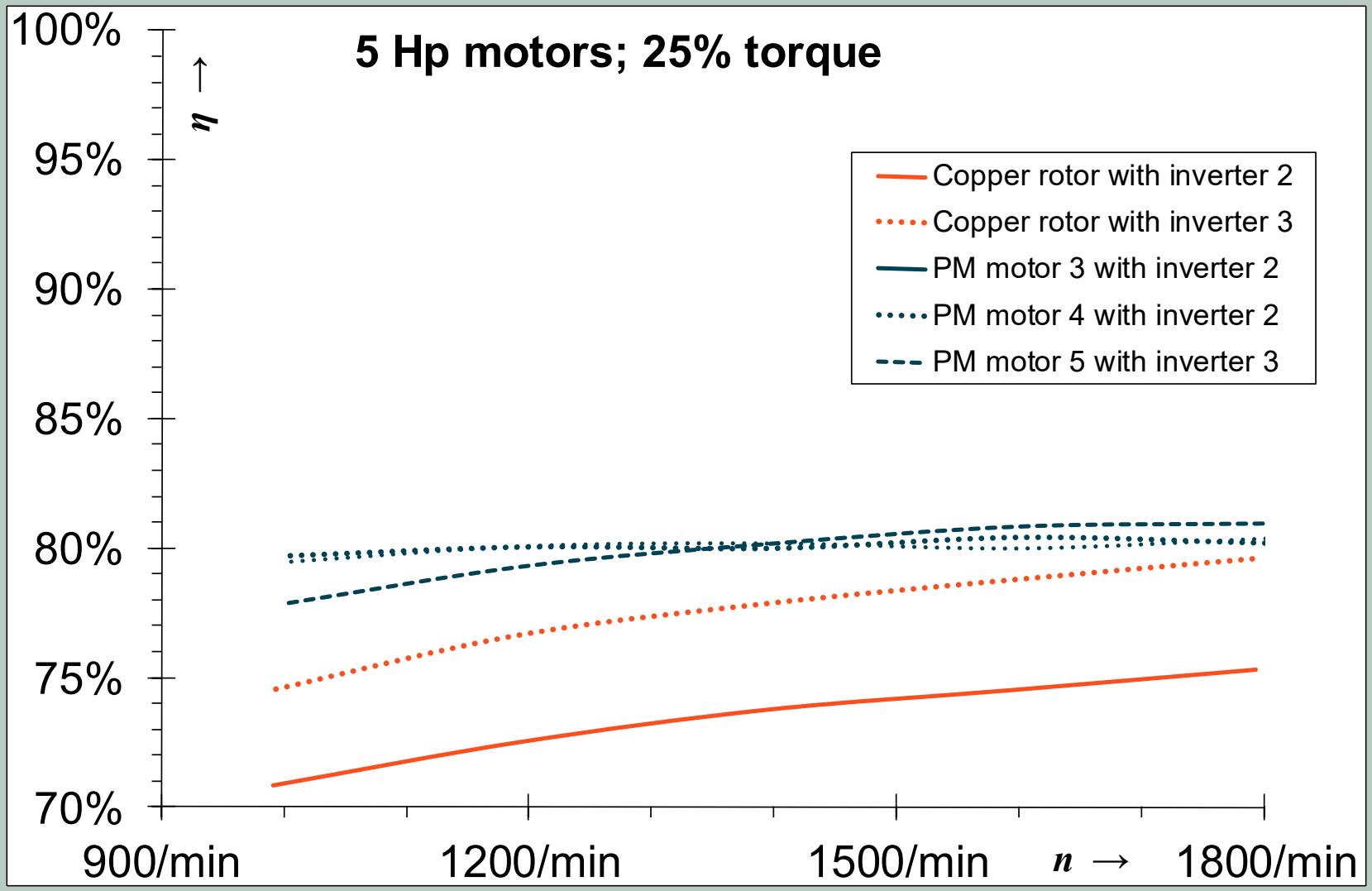
Cu

Copper rotor motors
were available off the shelf.

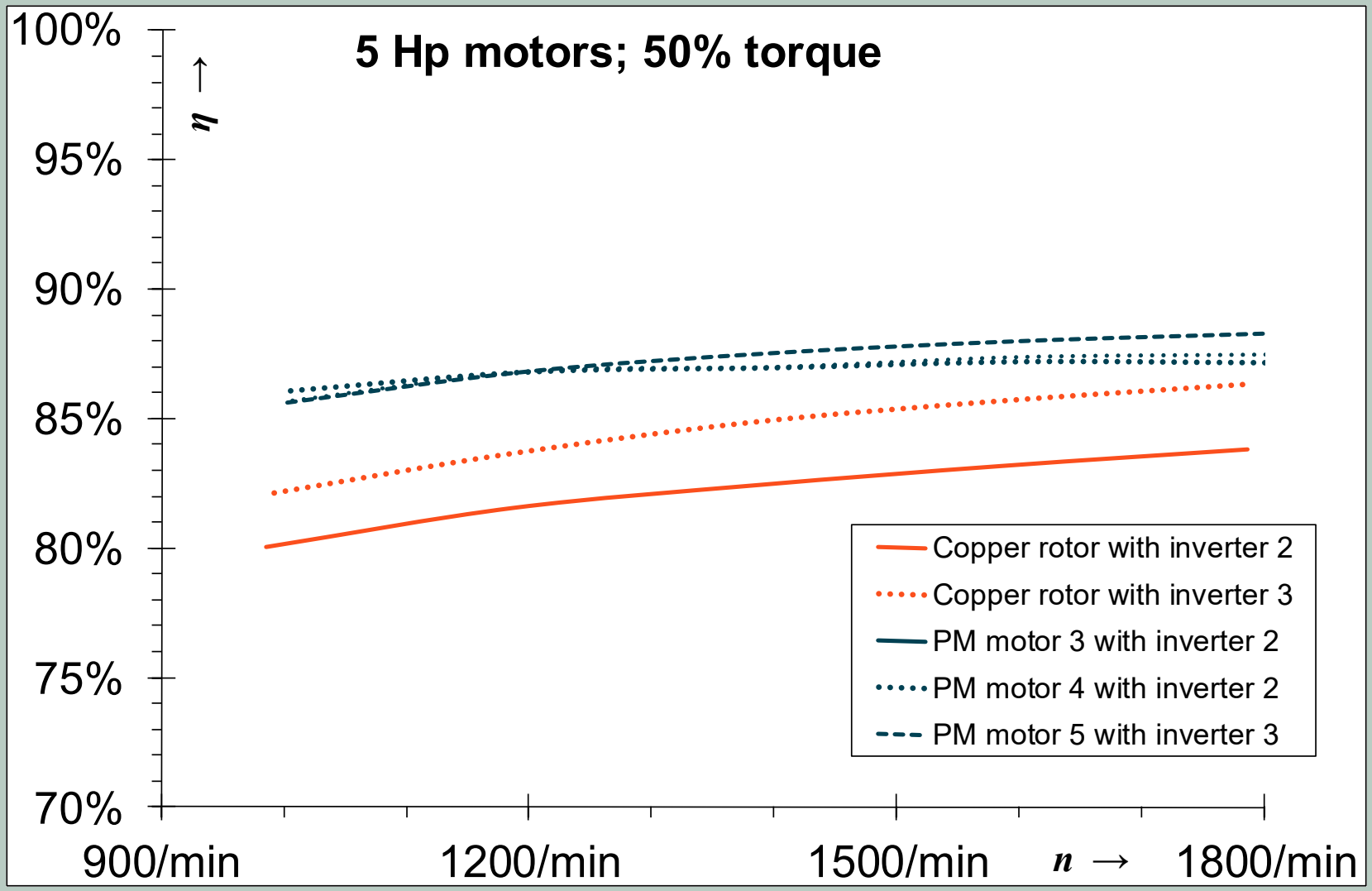
Permanent magnet motors
were assembled on commission only.

P_{2N}	Motor No.	Price	Lead time
5.0 hp	Copper rotor motor	399.85 $	few days
	Sync. PM motor 3	1432.32 $	10 days
	Sync. PM motor 4	1029.23 $	14 weeks
	Sync. PM motor 5	1587.51 $	18 weeks
7.5 hp	Copper rotor motor	565.85 $	
	Sync. PM motor 12	–	
	Sync. PM motor 14	1097.95 $	
	Sync. PM motor 15	893.15 $	
10.0 hp	Copper rotor motor	866.71 $	few days
	Sync. PM motor 21	4414.95 $	10 days
	Sync. PM motor 24	1415.02 $	8 weeks
	Sync. PM motor 23	1823.29 $	14 weeks
20.0 hp	Copper rotor motor	1372.48 $	few days
	Sync. PM motor 31	5427.58 $	1 week to 16 weeks
	Sync. PM motor 34	2035.47 $	
	Sync. PM motor 35	–	

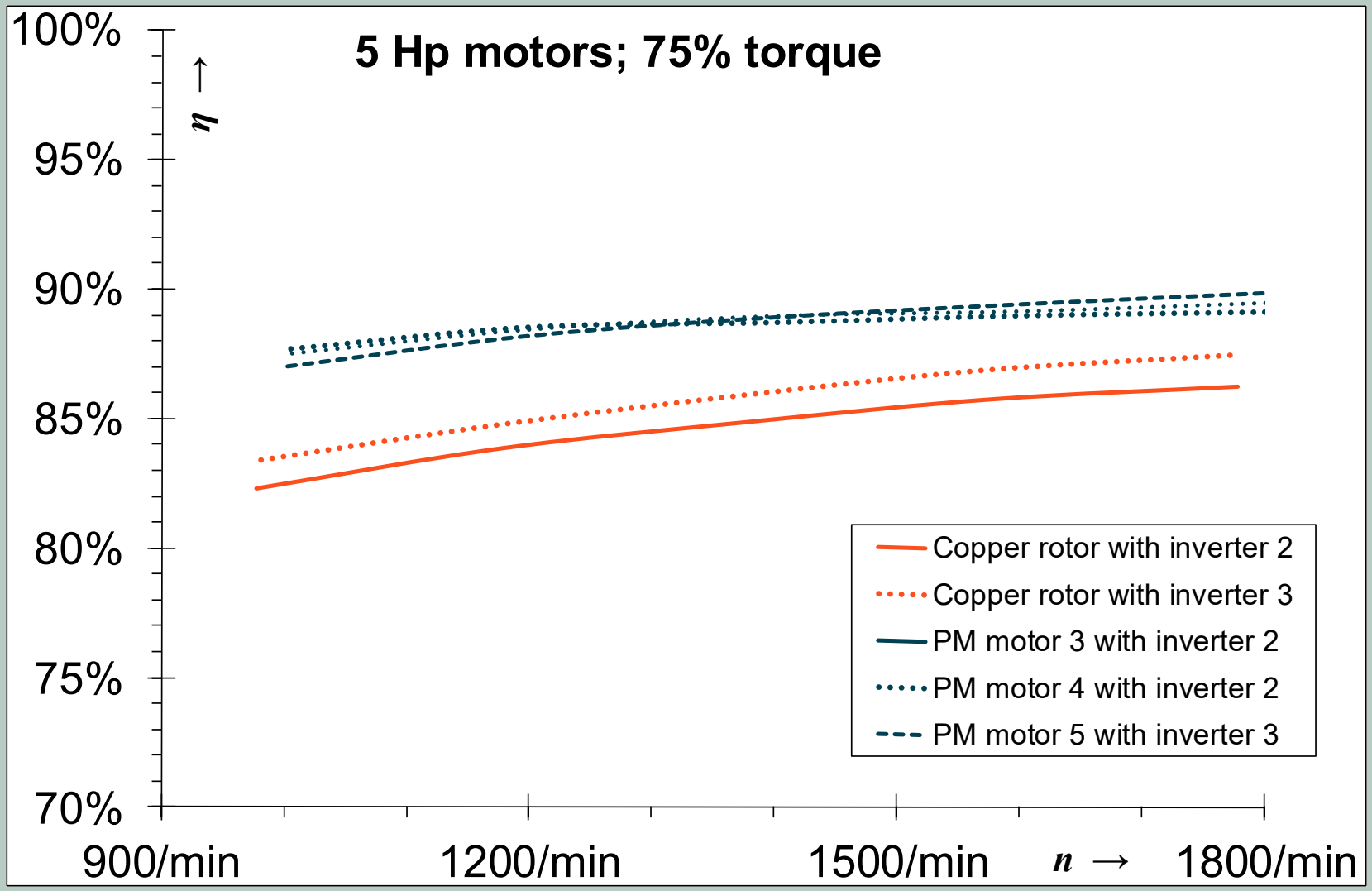
3.7 kW motors


5 Hp motors; 25% torque
100%
95%
90%
85%
80%
75%
70%
η →
Copper rotor with inverter 2
Copper rotor with inverter 3
PM motor 3 with inverter 2
PM motor 4 with inverter 2
PM motor 5 with inverter 3
900/min
1200/min
1500/min
n →
1800/min

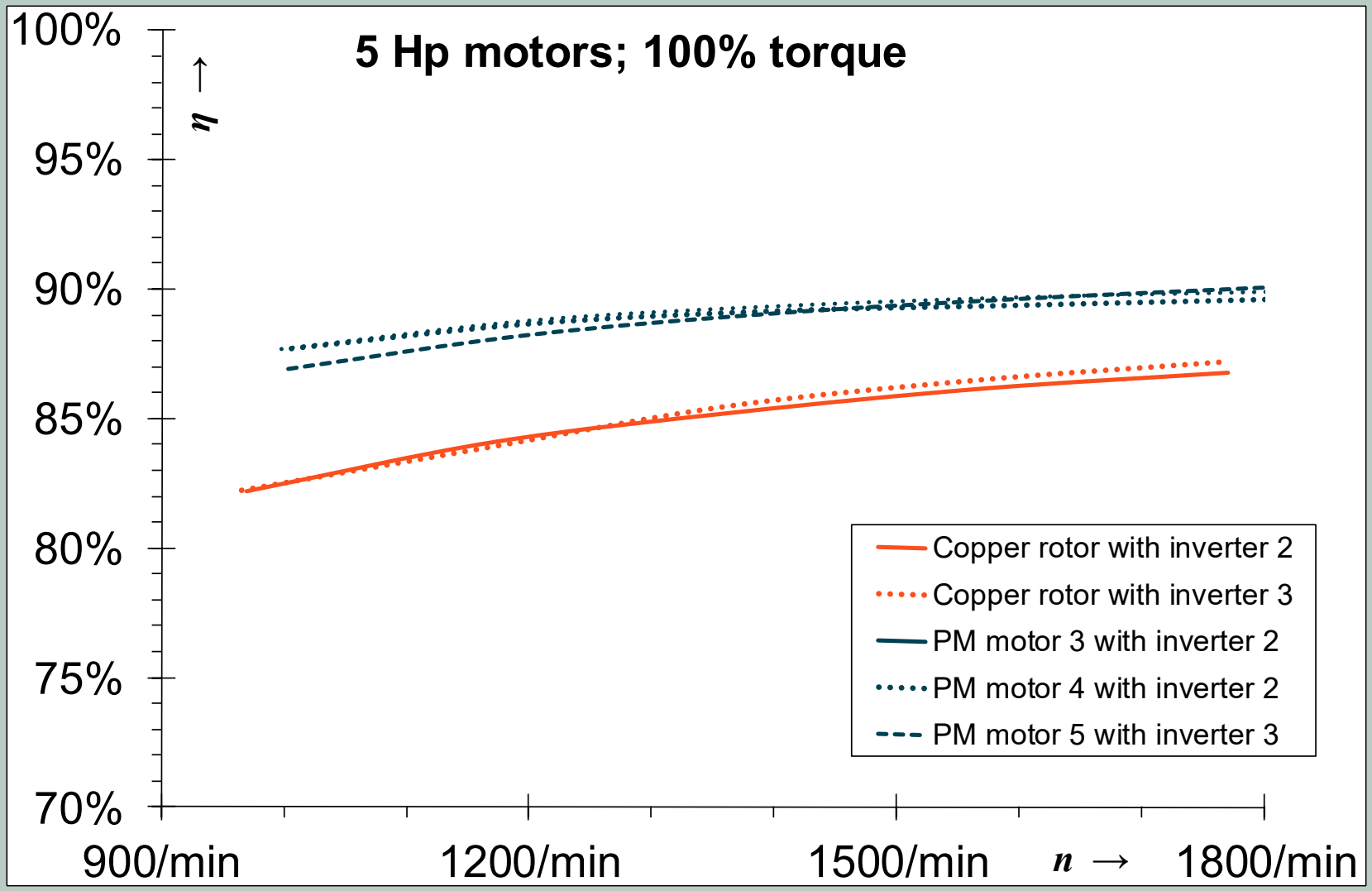
3.7 kW motors


5 Hp motors; 50% torque
100%
95%
90%
85%
80%
75%
70%
η →
900/min
1200/min
1500/min
n →
1800/min
Copper rotor with inverter 2
Copper rotor with inverter 3
PM motor 3 with inverter 2
PM motor 4 with inverter 2
PM motor 5 with inverter 3

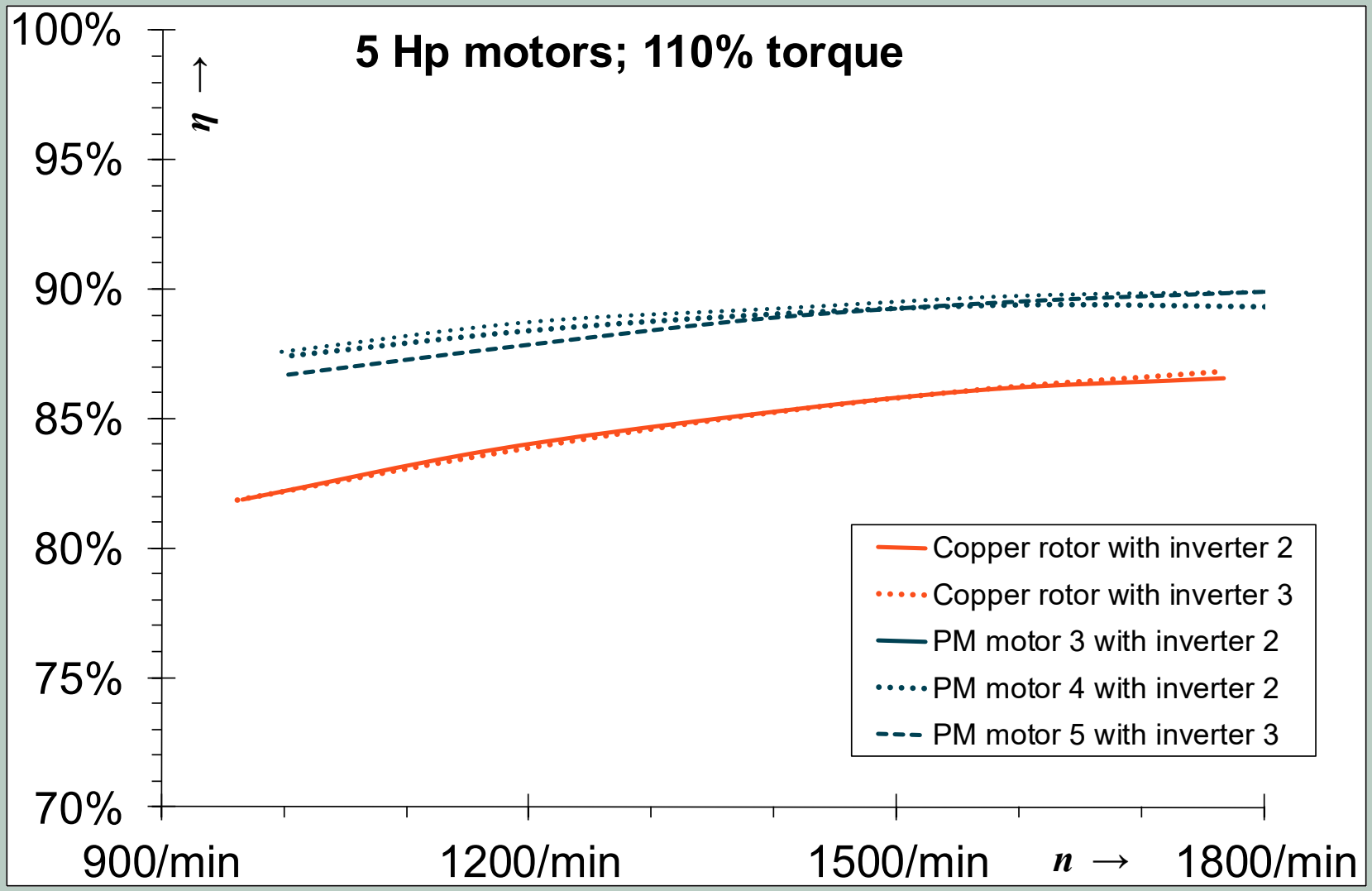
3.7 kW motors


5 Hp motors; 75% torque
100%
95%
90%
85%
80%
75%
70%
η →
900/min
1200/min
1500/min
n →
1800/min
Copper rotor with inverter 2
Copper rotor with inverter 3
PM motor 3 with inverter 2
PM motor 4 with inverter 2
PM motor 5 with inverter 3

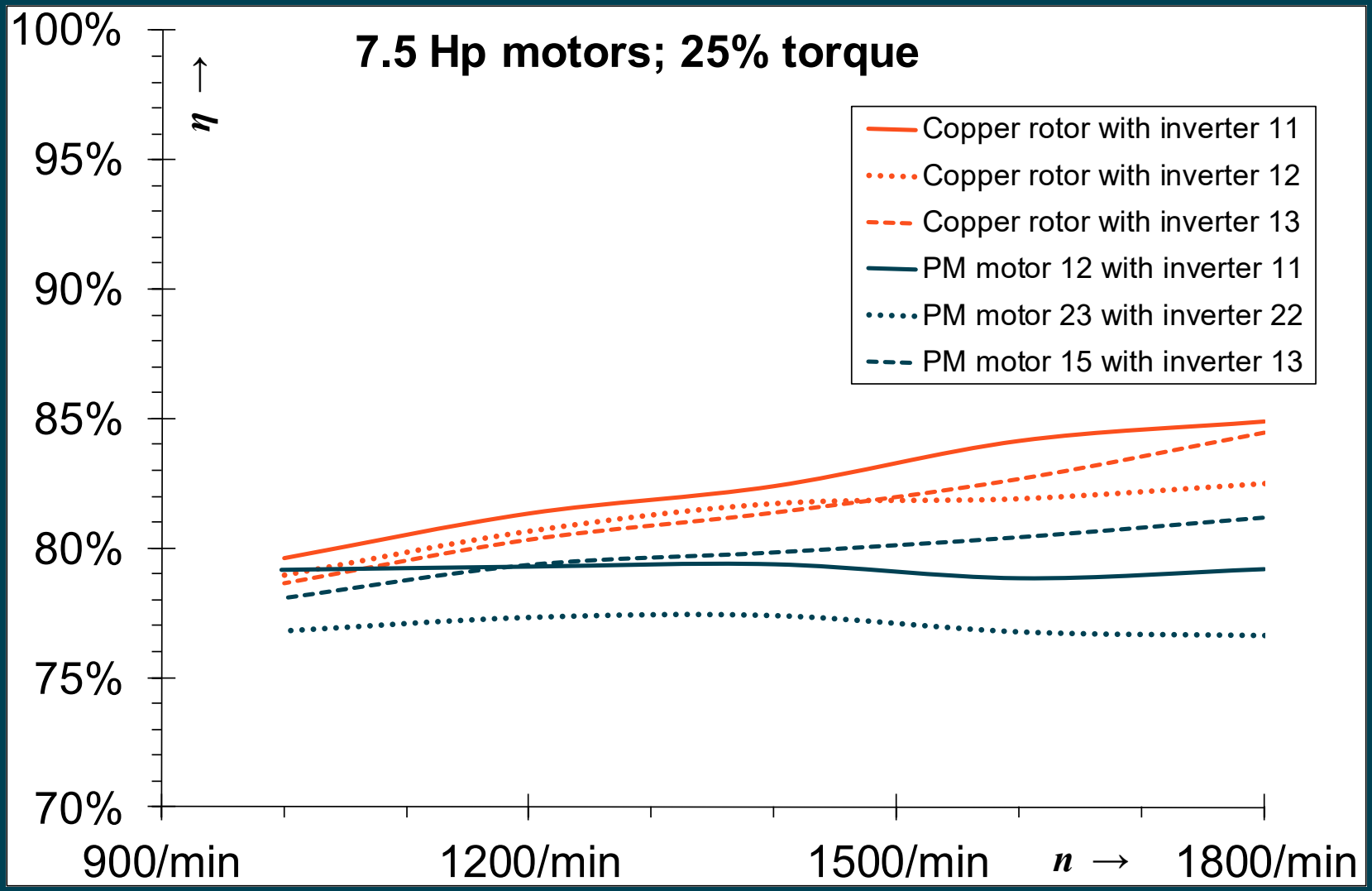
3.7 kW motors


5 Hp motors; 100% torque
100%
95%
90%
85%
80%
75%
70%
η →
900/min
1200/min
1500/min
n →
1800/min
Copper rotor with inverter 2
Copper rotor with inverter 3
PM motor 3 with inverter 2
PM motor 4 with inverter 2
PM motor 5 with inverter 3

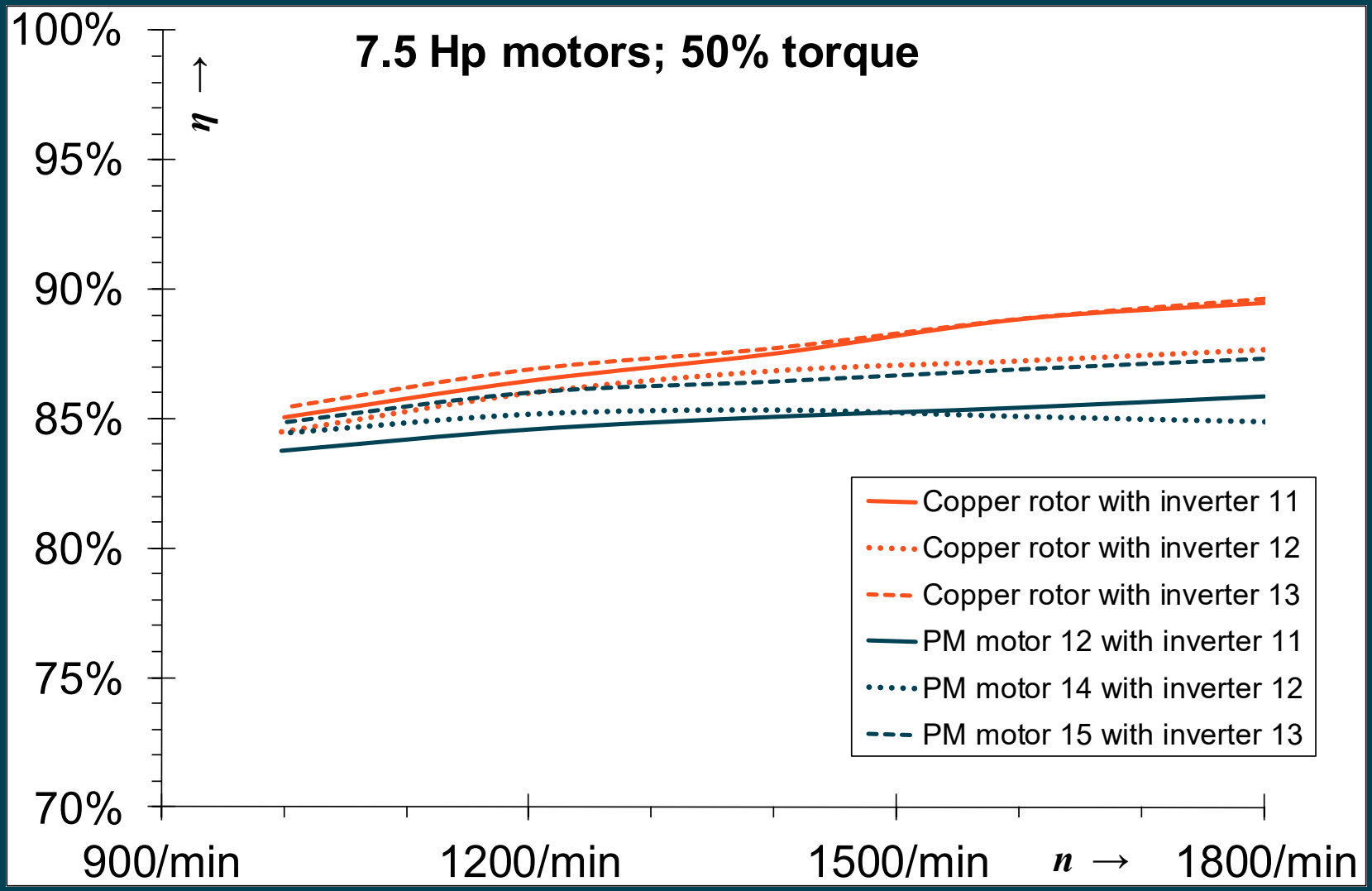
3.7 kW motors


5 Hp motors; 110% torque
100%
95%
90%
85%
80%
75%
70%
η →
900/min
1200/min
1500/min
n →
1800/min
Copper rotor with inverter 2
Copper rotor with inverter 3
PM motor 3 with inverter 2
PM motor 4 with inverter 2
PM motor 5 with inverter 3

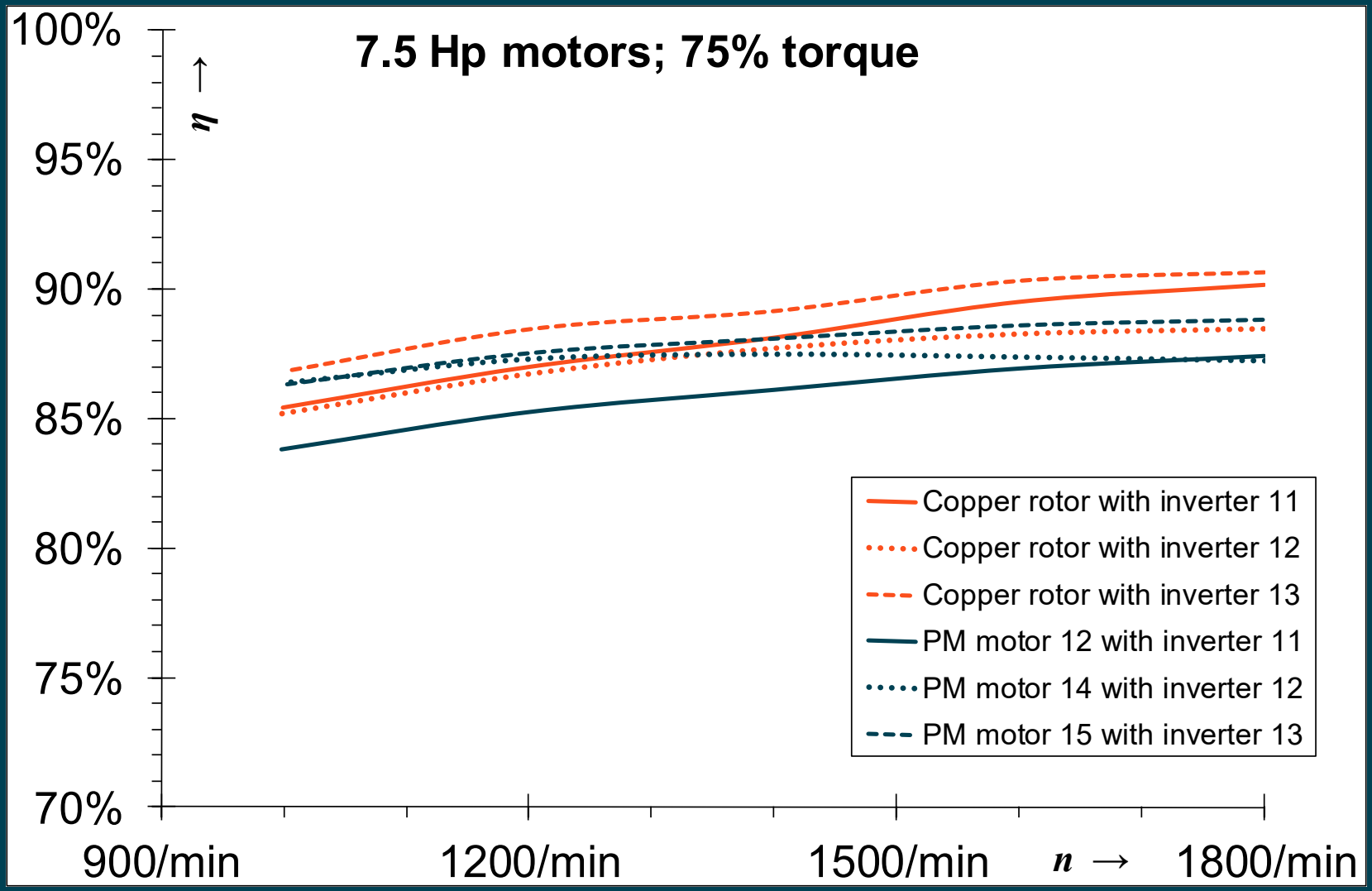
5.5 kW motors


7.5 Hp motors; 25% torque
100%
95%
90%
85%
80%
75%
70%
η →
Copper rotor with inverter 11
Copper rotor with inverter 12
Copper rotor with inverter 13
PM motor 12 with inverter 11
PM motor 23 with inverter 22
PM motor 15 with inverter 13
900/min
1200/min
1500/min
n →
1800/min

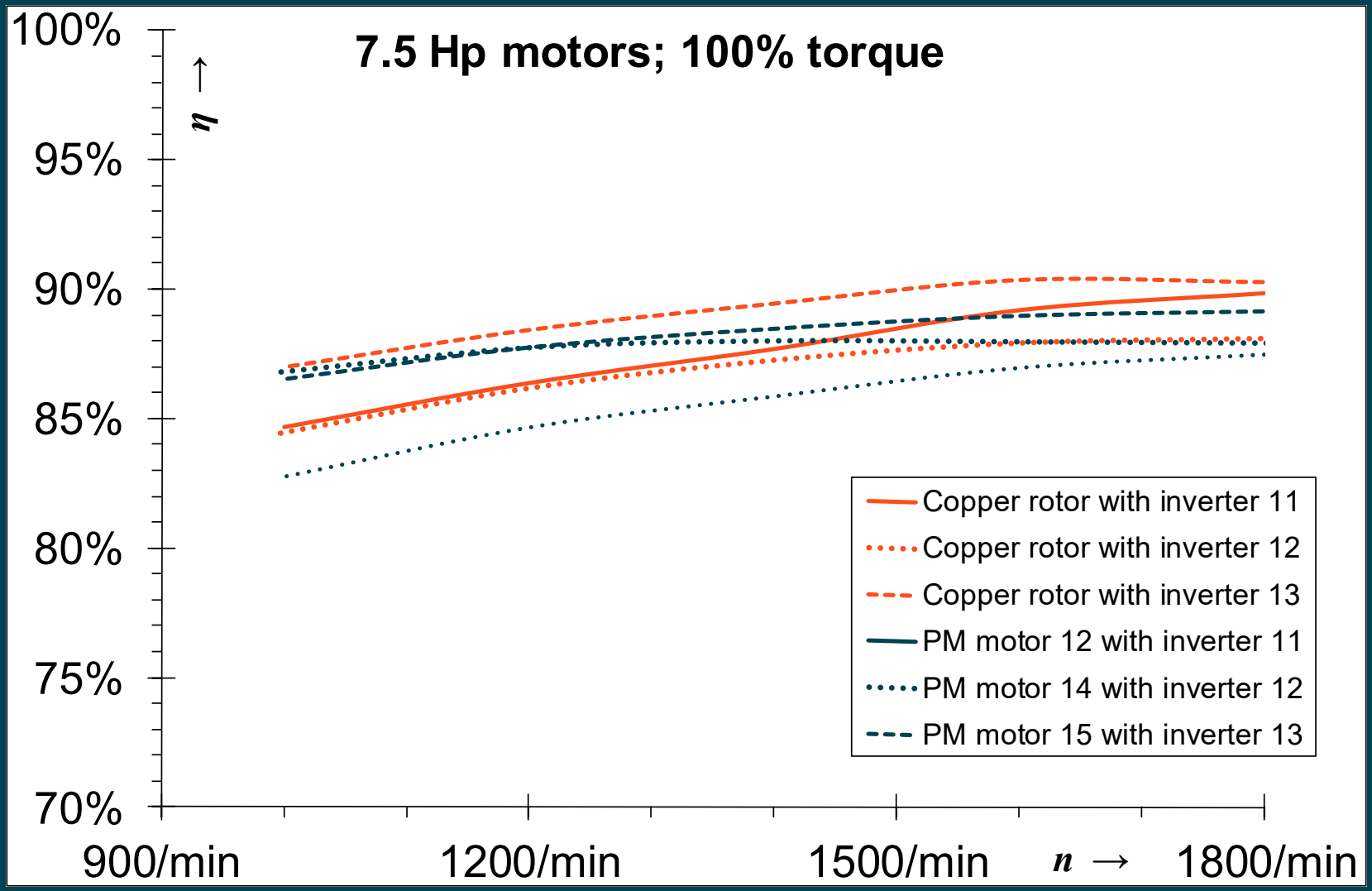
5.5 kW motors


7.5 Hp motors; 50% torque
100%
95%
90%
85%
80%
75%
70%
η →
900/min
1200/min
1500/min
n →
1800/min
Copper rotor with inverter 11
Copper rotor with inverter 12
Copper rotor with inverter 13
PM motor 12 with inverter 11
PM motor 14 with inverter 12
PM motor 15 with inverter 13

5.5 kW motors


7.5 Hp motors; 75% torque
100%
95%
90%
85%
80%
75%
70%
η →
900/min
1200/min
1500/min
n →
1800/min
Copper rotor with inverter 11
Copper rotor with inverter 12
Copper rotor with inverter 13
PM motor 12 with inverter 11
PM motor 14 with inverter 12
PM motor 15 with inverter 13

5.5 kW motors


7.5 Hp motors; 100% torque
100%
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Copper rotor with inverter 11
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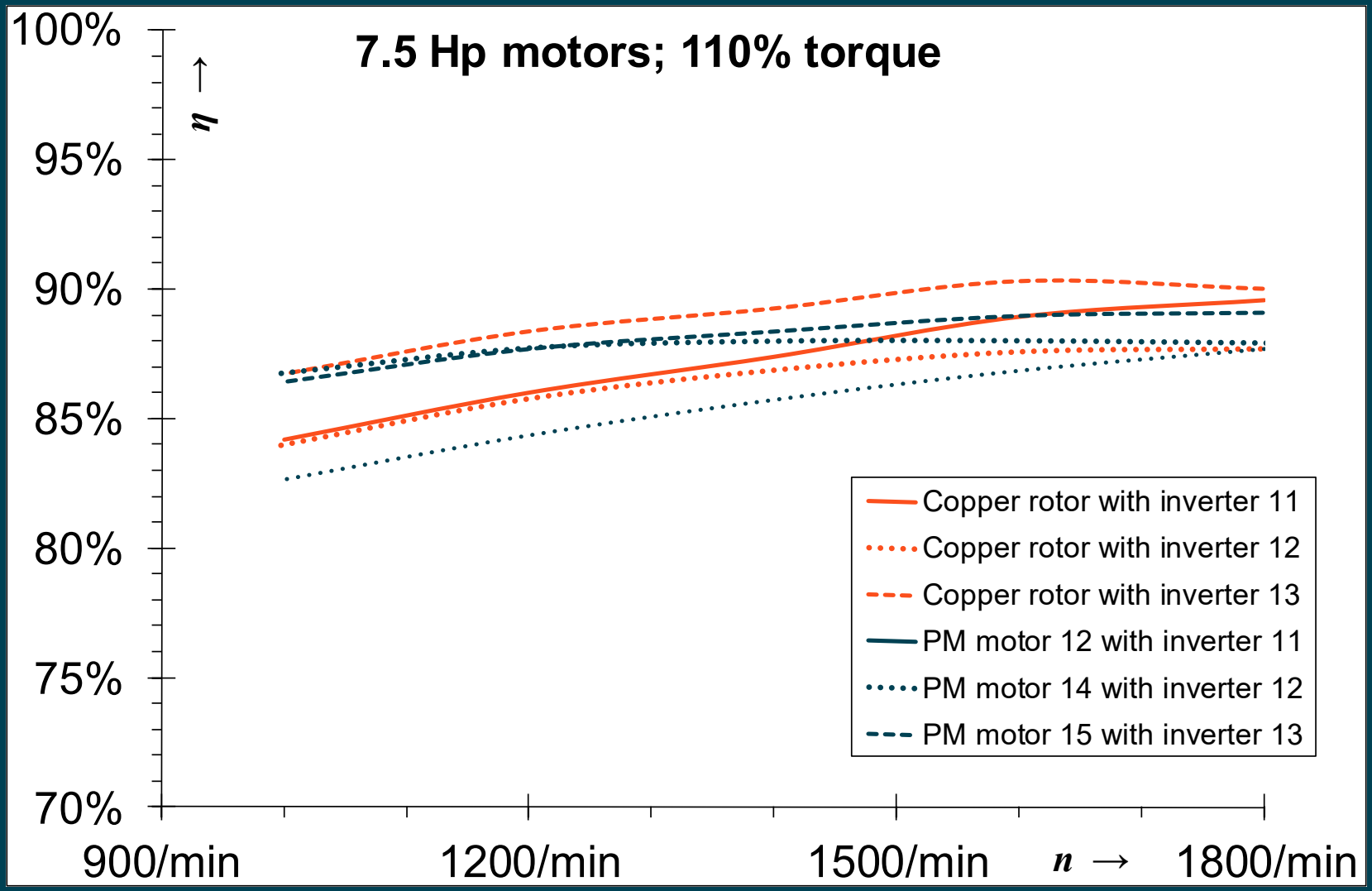
5.5 kW motors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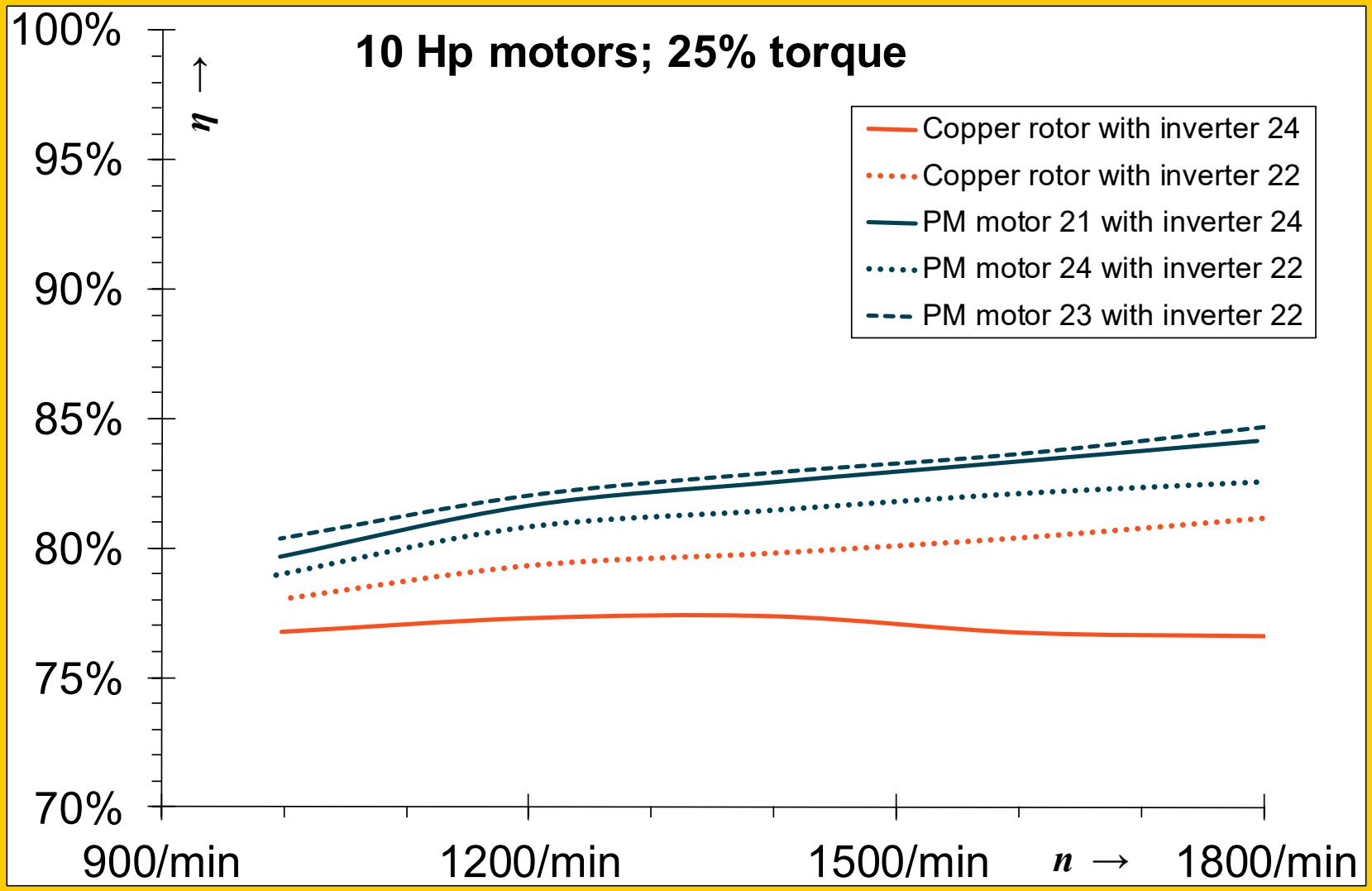
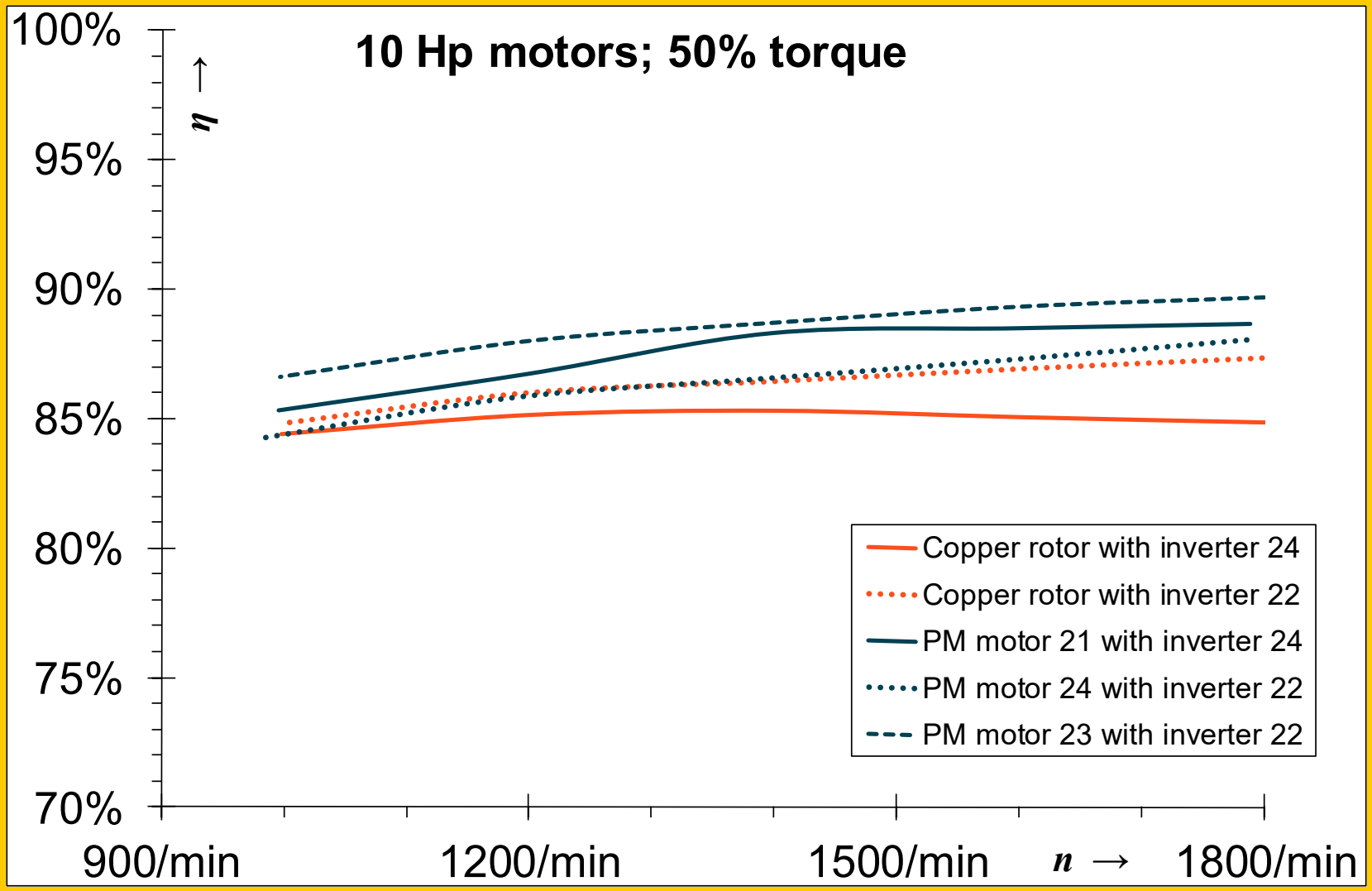
7.5 kW motors


10 Hp motors; 25% torque
η →
100%
95%
90%
85%
80%
75%
70%
Copper rotor with inverter 24
Copper rotor with inverter 22
PM motor 21 with inverter 24
PM motor 24 with inverter 22
PM motor 23 with inverter 22
900/min
1200/min
1500/min
n →
1800/min

7.5 kW motors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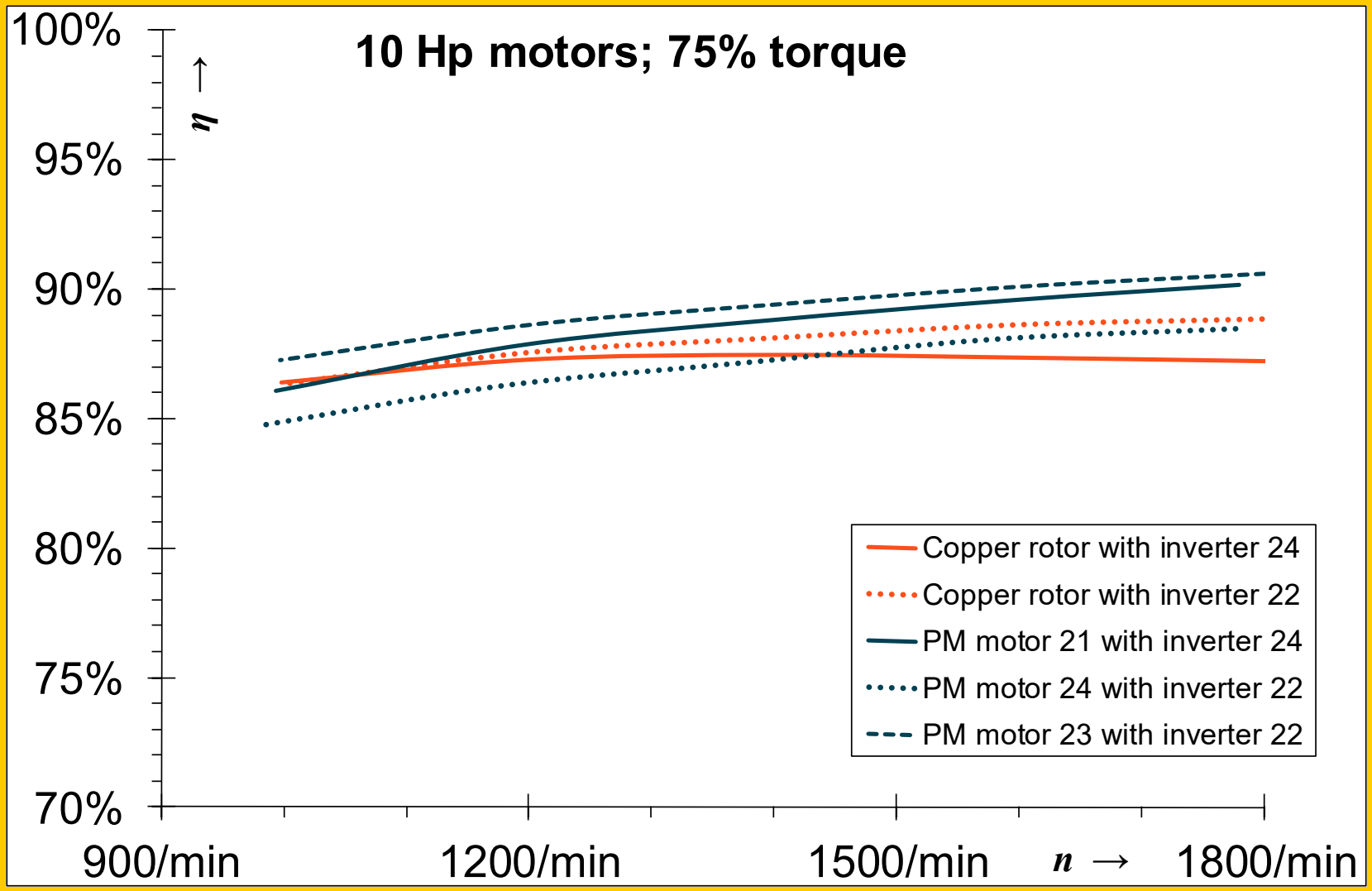
7.5 kW motors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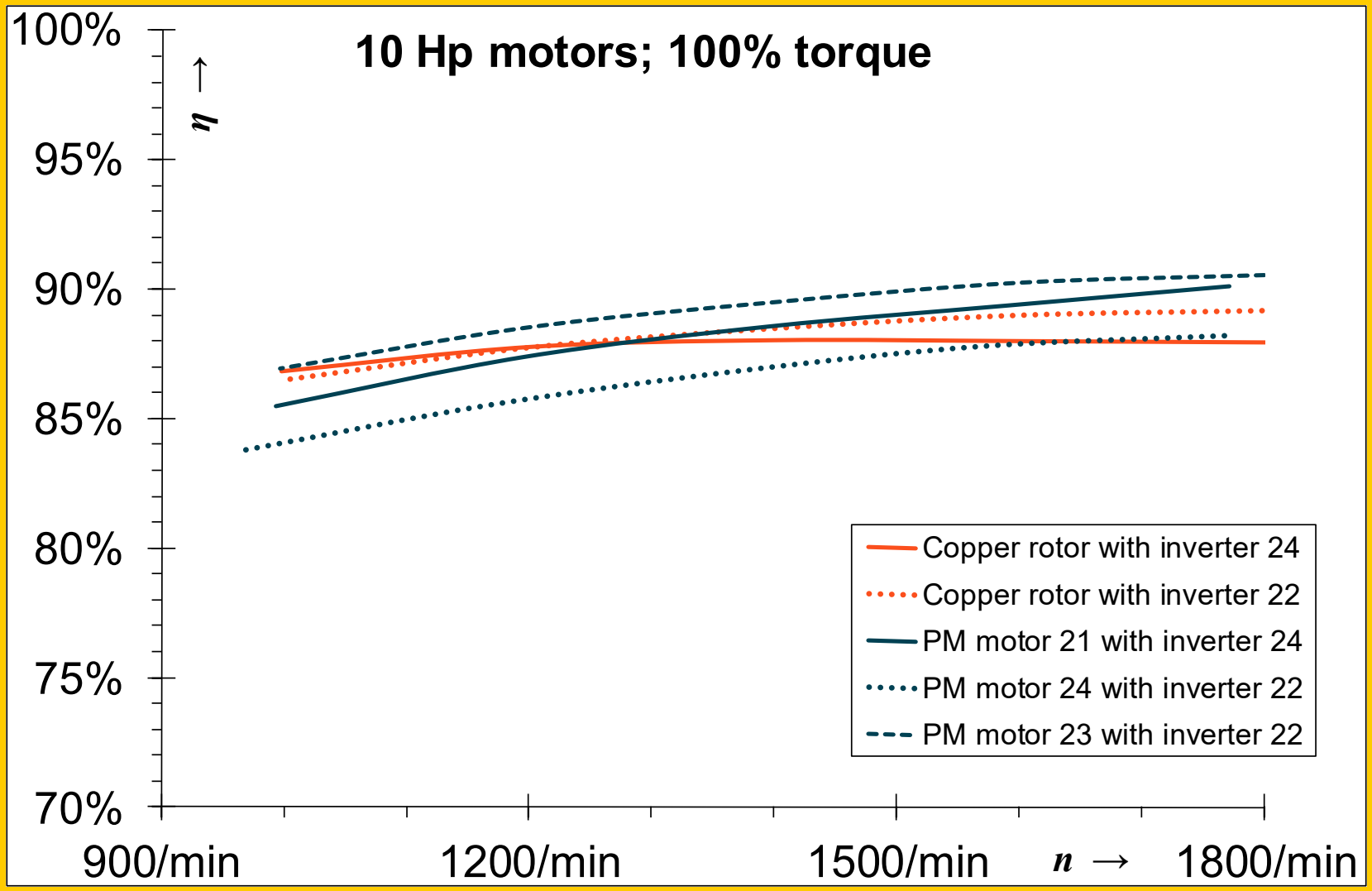
7.5 kW motors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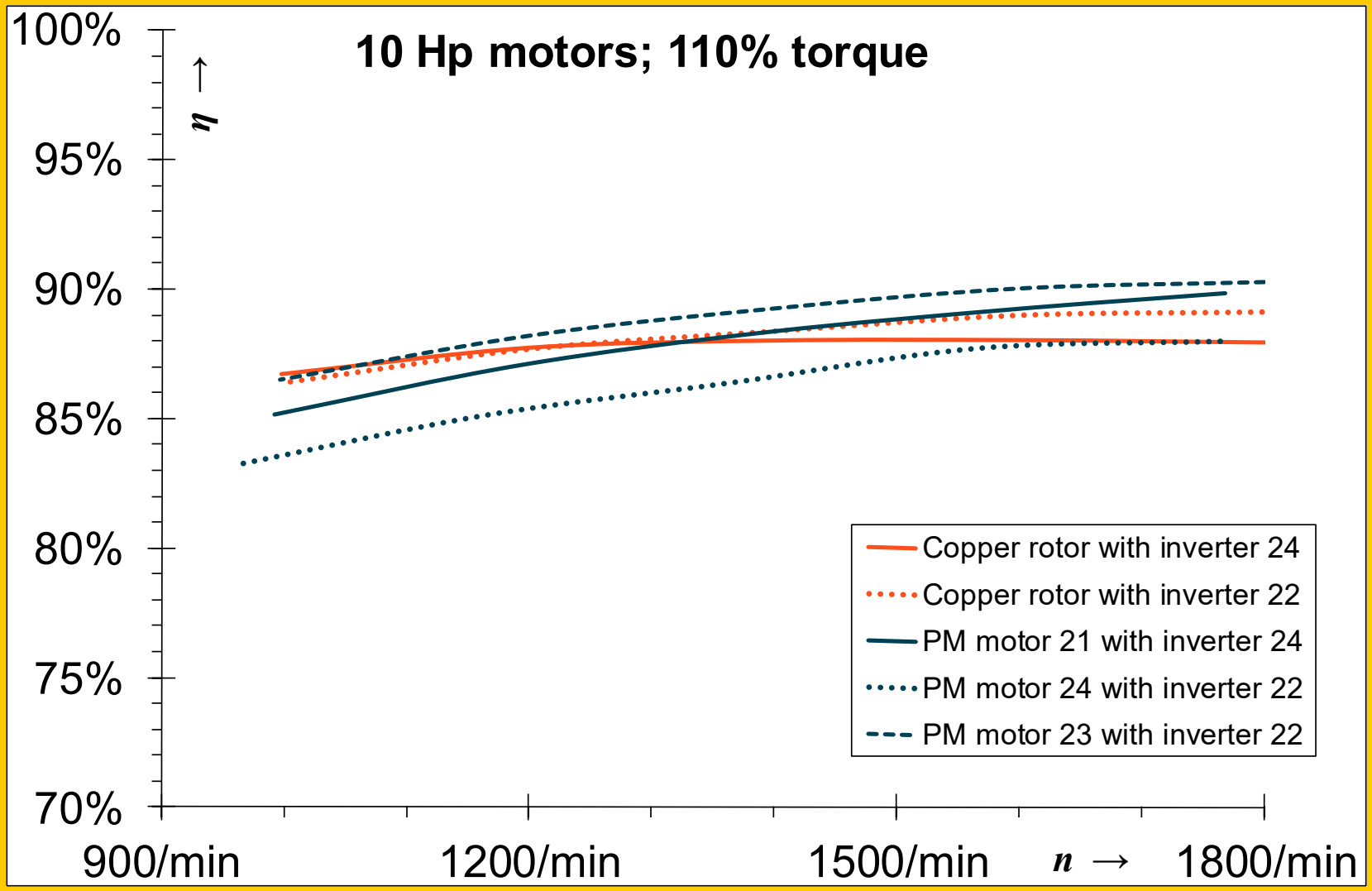
7.5 kW motors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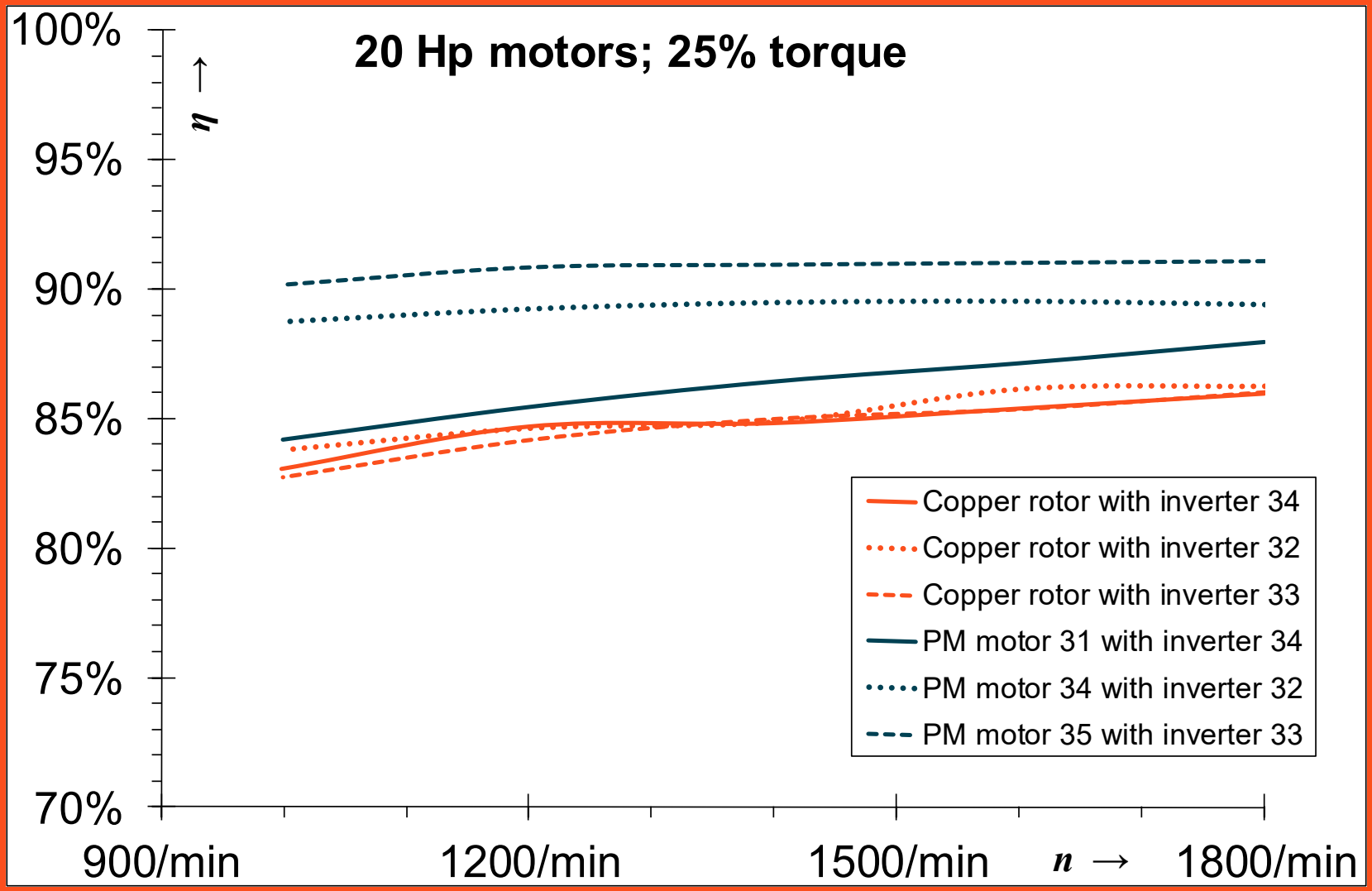
PM motor 24 with inverter 22
PM motor 23 with inverter 22

15 kW motors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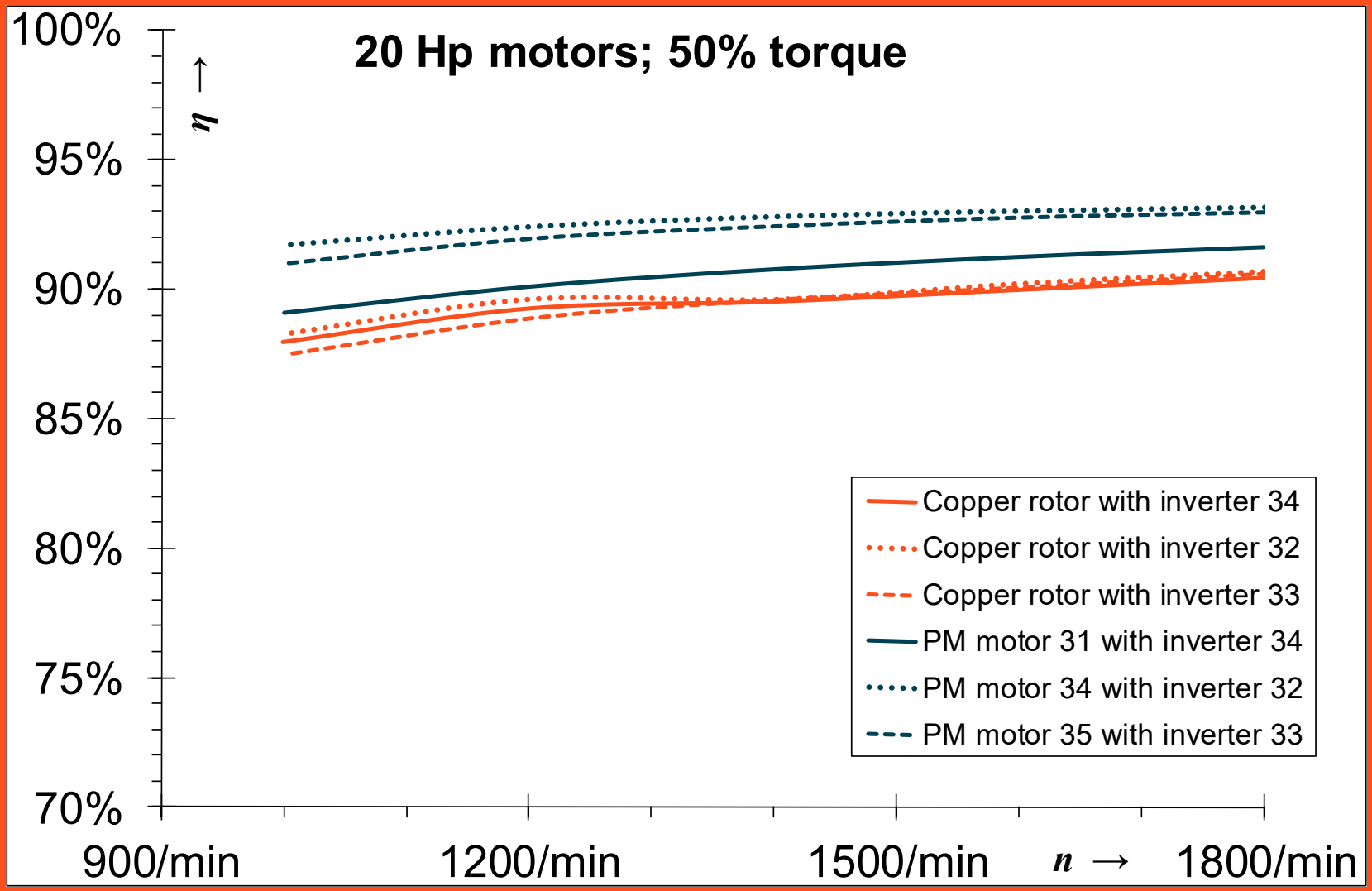
1200/min
1500/min
n →
1800/min
Copper rotor with inverter 34
Copper rotor with inverter 32
Copper rotor with inverter 33
PM motor 31 with inverter 34
PM motor 34 with inverter 32
PM motor 35 with inverter 33

15 kW motors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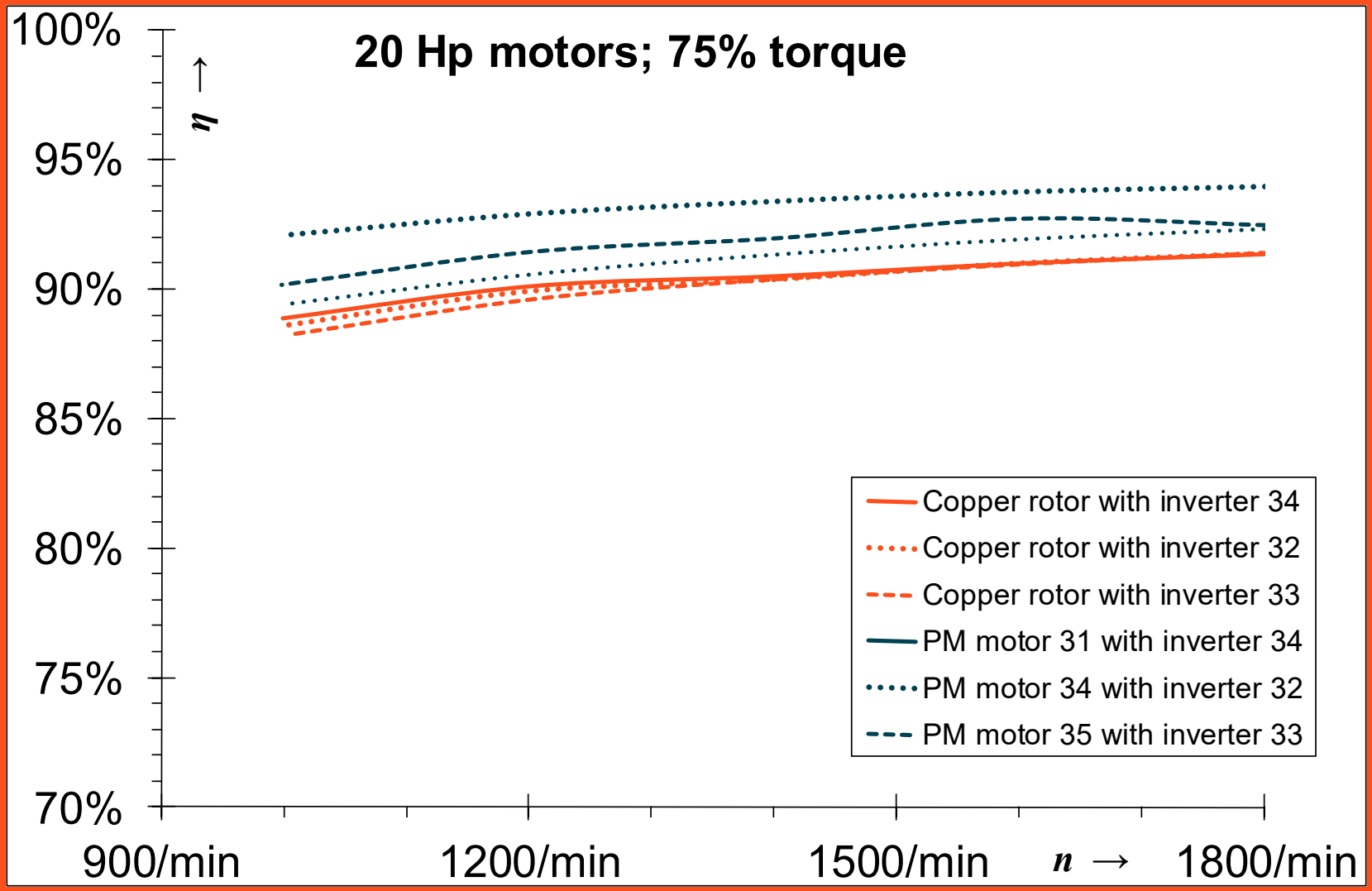
PM motor 35 with inverter 33

15 kW motors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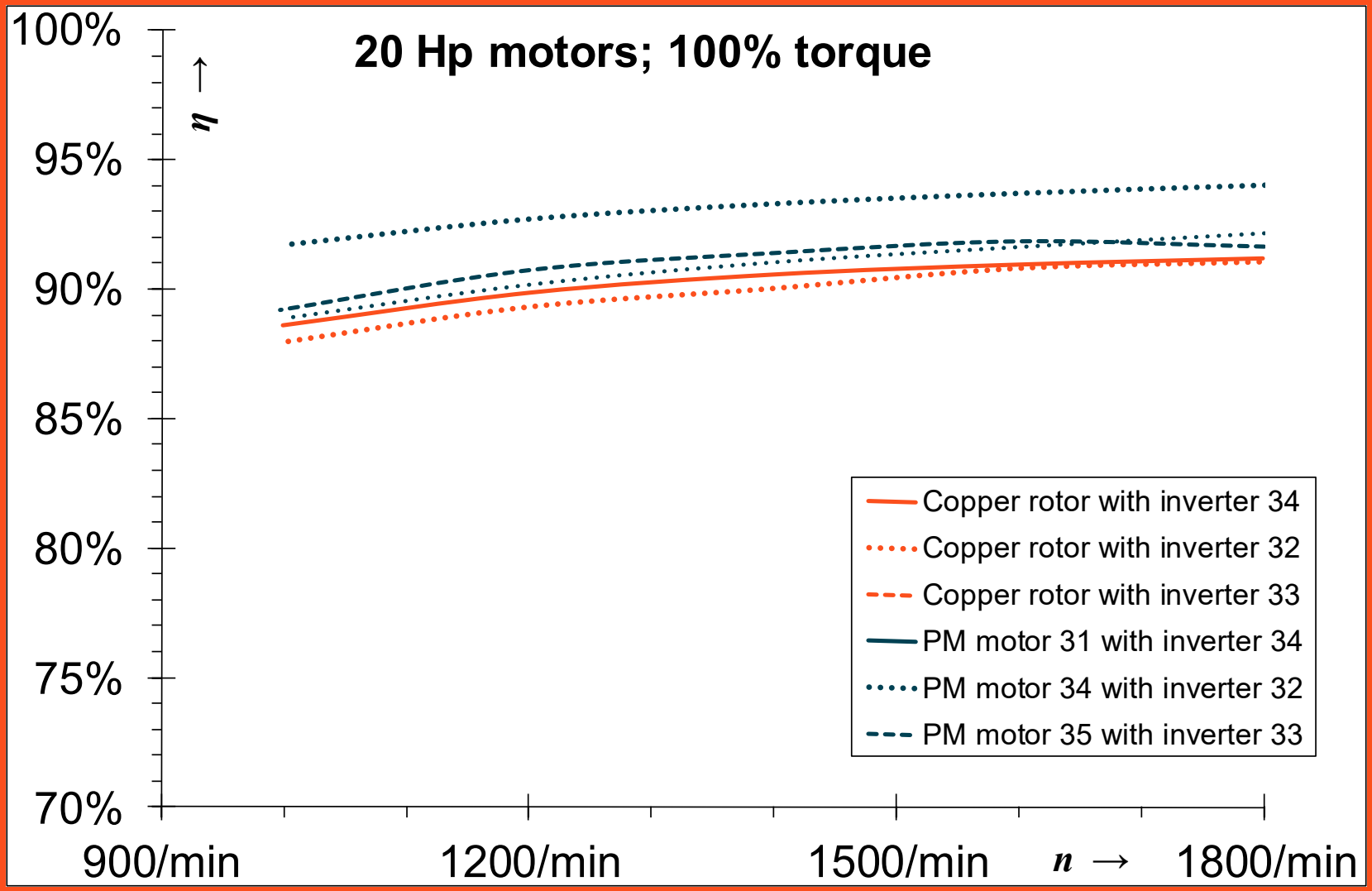
PM motor 34 with inverter 32
PM motor 35 with inverter 33

15 kW motors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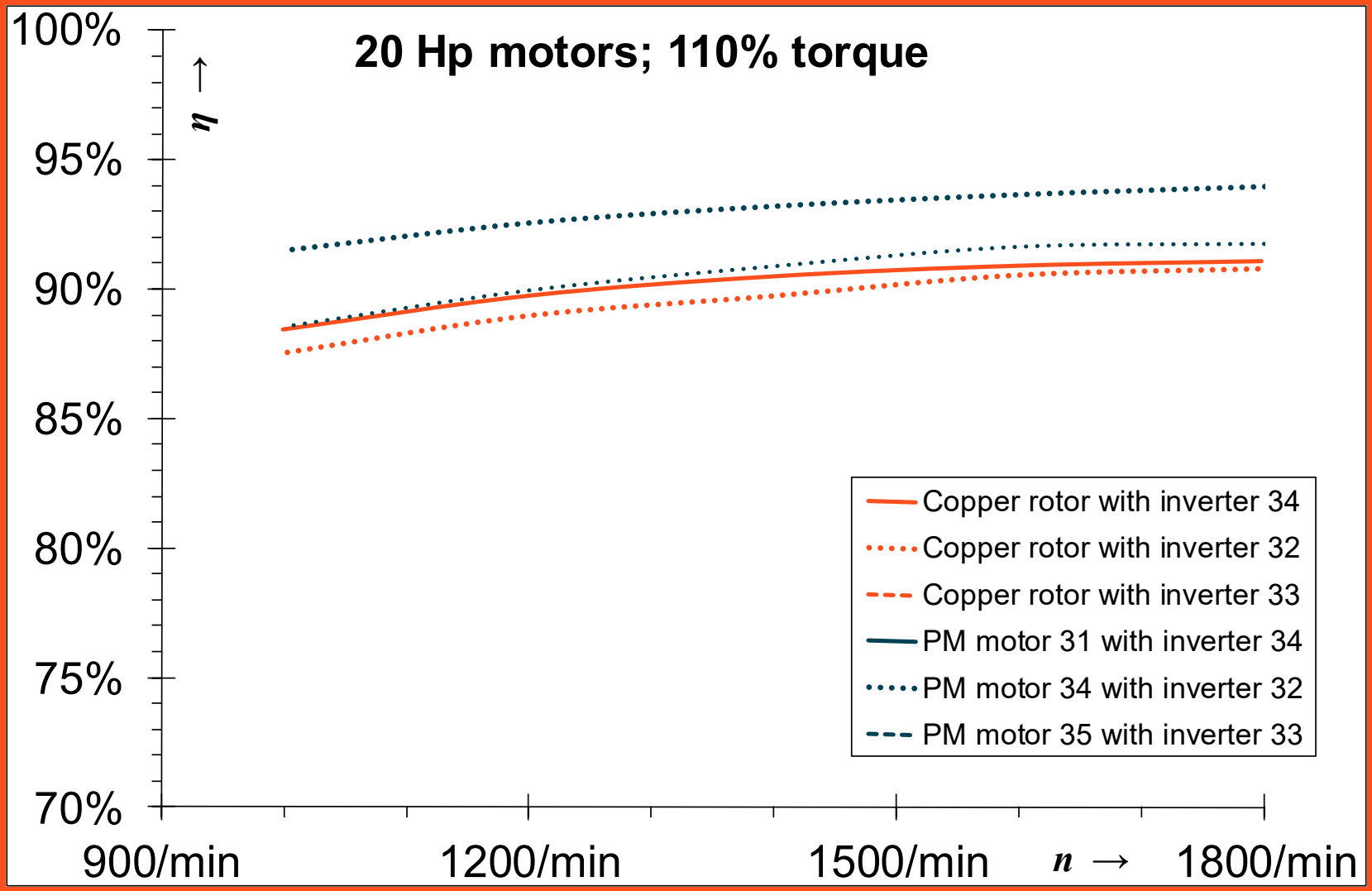
Copper rotor with inverter 33
PM motor 31 with inverter 34
PM motor 34 with inverter 32
PM motor 35 with inverter 33

15 kW motors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Copper rotor with inverter 34
Copper rotor with inverter 32
Copper rotor with inverter 33
PM motor 31 with inverter 34
PM motor 34 with inverter 32
PM motor 35 with inverter 33

Payback periods (in permanent duty): It‘s like a tit for tat ...

Cu

All PM motors of equal power ratings summarized into one mean value

Motors (mean)			n	$M = 110\% M_N$		$M = 100\% M_N$		$M = 75\% M_N$		$M = 50\% M_N$		$M = 25\% M_N$	
PM	CRM	P_N		ΔP_{loss}	Payback	ΔP_{loss}	Amort.	ΔP_{loss}	Amort.	ΔP_{loss}	Amort.	ΔP_{loss}	Amort.
1201.22 €	355.87 €	5.0 hp	1800/min	158 W	2.58 a	136 W	2.99 a	96 W	4.23 a	68 W	5.99 a	50 W	8.11 a
			1600/min	161 W	2.53 a	137 W	2.97 a	93 W	4.37 a	72 W	5.62 a	55 W	7.44 a
			1400/min	165 W	2.47 a	142 W	2.87 a	100 W	4.08 a	72 W	5.65 a	55 W	7.41 a
			1200/min	166 W	2.46 a	148 W	2.76 a	101 W	4.02 a	74 W	5.47 a	58 W	7.06 a
			1000/min	162 W	2.52 a	142 W	2.86 a	96 W	4.26 a	70 W	5.78 a	59 W	6.88 a
886.04 €	503.61 €	7.5 hp	1800/min	-52 W	-3.57 a	-72 W	-2.54 a	-93 W	-1.97 a	-99 W	-1.87 a	-100 W	-1.84 a
			1600/min	-55 W	-3.32 a	-62 W	-2.98 a	-73 W	-2.52 a	-75 W	-2.45 a	-77 W	-2.41 a
			1400/min	-16 W	-11.19 a	-27 W	-6.92 a	-38 W	-4.84 a	-44 W	-4.17 a	-46 W	-4.03 a
			1200/min	5 W	38.50 a	-2 W	-77.34 a	-18 W	-10.45 a	-24 W	-7.59 a	-27 W	-6.77 a
			1000/min	26 W	7.14 a	10 W	18.15 a	-2 W	-102.90 a	-8 W	-23.04 a	-9 W	-19.77 a
2270.47 €	771.37 €	10.0 hp	1800/min	197 W	3.66 a	158 W	4.56 a	86 W	8.39 a	28 W	25.70 a	-17 W	-41.60 a
			1600/min	221 W	3.27 a	189 W	3.82 a	104 W	6.92 a	44 W	16.25 a	-2 W	-303.35 a
			1400/min	259 W	2.79 a	212 W	3.41 a	127 W	5.67 a	62 W	11.64 a	20 W	36.25 a
			1200/min	274 W	2.63 a	233 W	3.09 a	139 W	5.18 a	83 W	8.74 a	25 W	28.40 a
			1000/min	286 W	2.52 a	245 W	2.94 a	151 W	4.79 a	88 W	8.24 a	41 W	17.41 a
3321.06 €	1221.51 €	20.0 hp	1800/min	254 W	3.98 a	-174 W	-5.82 a	210 W	4.81 a	186 W	5.43 a	170 W	5.96 a
			1600/min	229 W	4.42 a	-161 W	-6.29 a	221 W	4.58 a	187 W	5.42 a	161 W	6.30 a
			1400/min	205 W	4.94 a	-150 W	-6.76 a	196 W	5.16 a	177 W	5.71 a	159 W	6.35 a
			1200/min	176 W	5.73 a	-151 W	-6.71 a	167 W	6.07 a	142 W	7.14 a	136 W	7.42 a
			1000/min	163 W	6.21 a	-158 W	-6.42 a	162 W	6.23 a	145 W	6.98 a	130 W	7.78 a

What to do about it?

- Go to the press with such news
- Go to other events with this presentation (VEM …)
- Join standardisation bodies to make sure the measurement techniques make a fair comparison different assessments of motors with and without inverter)
- Speak to users (VIK …)

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