STUDY COMMITTEE A1- ROTATING ELECTRICAL MACHINES

WG A1.47 -Technological Feasibility Studies for Super and Ultra Premium Efficient Motors

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AGENDA

1. Introduction
2. Motor technology development
3. Survey findings
4. Conclusions
5. Reference

Ref. 1 : International co-work suggestion
Ref. 2 : Old motor status in Swiss

1. Introduction

1) 45% of the global electric energy consumed by electric motor [1, 2]

2) Save 108 nuclear reactors(108GW) by 3% efficiency up in 2030 [3]

- 378 TWh per year(30.2 billion US$)

3) In IEC 60034-30-1 (in March 2014)

- The IE4 class (super-premium efficiency) is newly included
- The IE5 to reduce the losses of IE4 motors further by some 20%

4) WG focused on

- Designs: motor type and optimization
- Materials: iron materials, magnetic materials, conductors, PM
- Product manufacturing: die-casting , coil fill factor
- Making provisional time table for mas production and setting mandatory about IE4 and IE5 motors

[1] Paul Waide, Conrad U. Brunner, Energy-Efficiency Policy Opportunities for Electric Motor-Driven Systems, International Energy Agency, 2011
[2] Electric Motors; A Global Strategic Business Report MCP-1842, Global Industry Analysts, Inc., January 2015
[3] World Energy Outlook 2011, International Energy Agency, 2011

5) List of WG Members and contributors

- 9 countries / 17 WG Members + 3 contributors(red color in below)
- 3 contributors came after the members' indication

		country	name	Affiliation (company/uni./institute)
WG Member	1	Korea	Do-Hyun Kang	Affiliation: Korea Electrotechnology Research Institute(
	2	Brazil	Erli Figueiredo	Affiliation: Rio de Janeiro State University
	3	China	Chunlin Li	Affiliation: Xiangtan Electric Manufacturing Co. Ltd
	4	China	Daniel Liang	Affiliation: International Copper Association
	5	Croatia	Stjepan Car	Affiliation: Končar Institute
	6	Croatia	Damir Žarko	Affiliation: University of Zagreb
	7	Finland	Antero Arkkio	Affiliation: Aalto University
	8	Finland	Hannu Vaananen	Affiliation: ABB
	9	India	Samsul Ekram	Affiliation: Crompton Greaves Ltd
	10	India	K.N. Hemanth Kumar	Affiliation: International Copper Association India
	11	Japan	Takeshi OBATA	Affiliation: Hitachi Industrial Equipment Systems Co., Ltd
	12	Japan	Hiroaki KOBAYASHI	Affiliation: Toshiba Mitsubishi-Electric Industrial Systems
	13	Korea	Byeng-Hui Kang	Affiliation: Hyosung Corporation
	14	Korea	Ji-Hyun Kim	Affiliation: POSCO
	15	Switzerland	Jan Krückel	Affiliation: ABB Switzerland Ltd
	16	USA	Yang-Ki Hong	Affiliation: The University of Alabama Tuscaloosa
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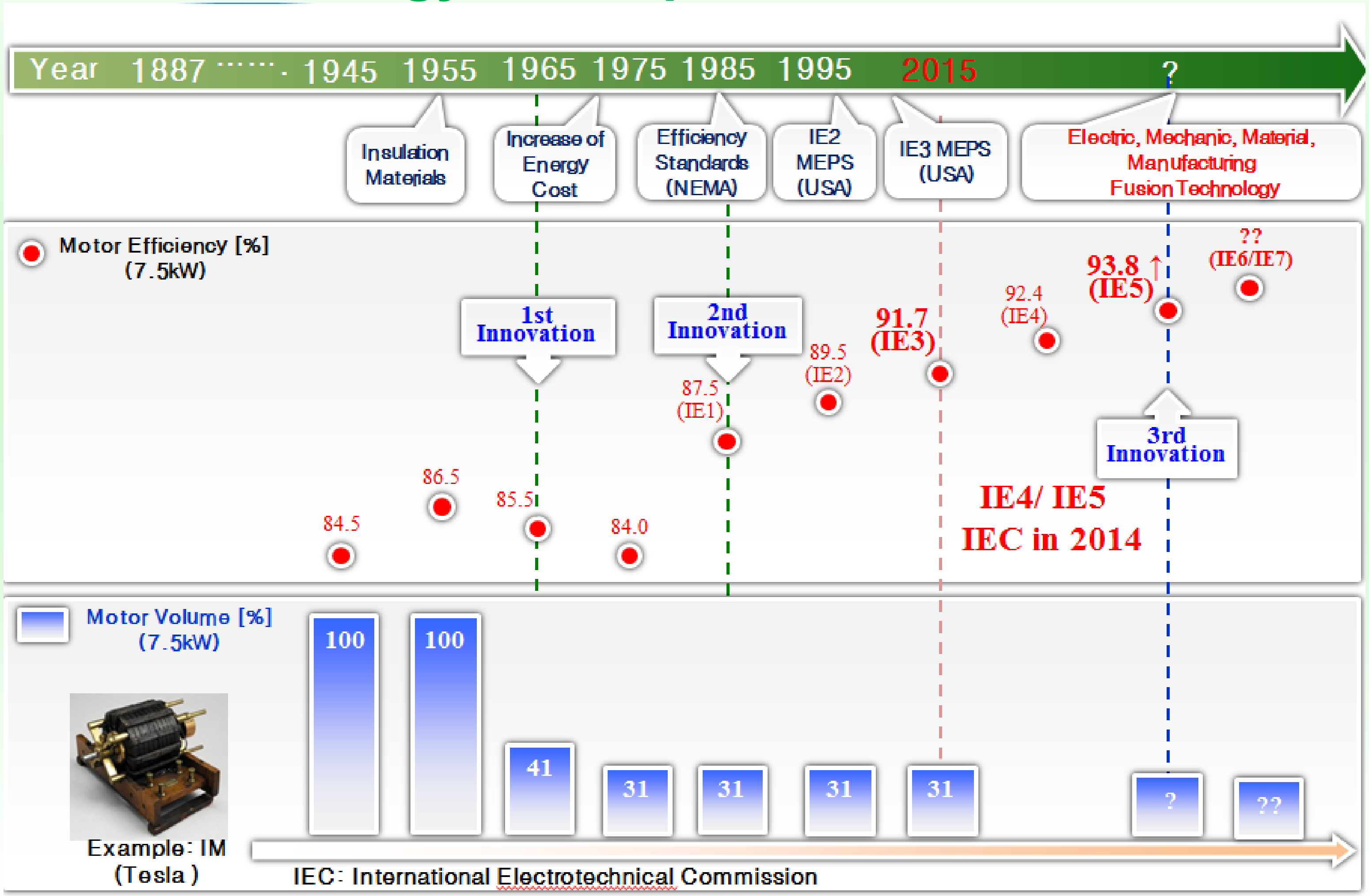
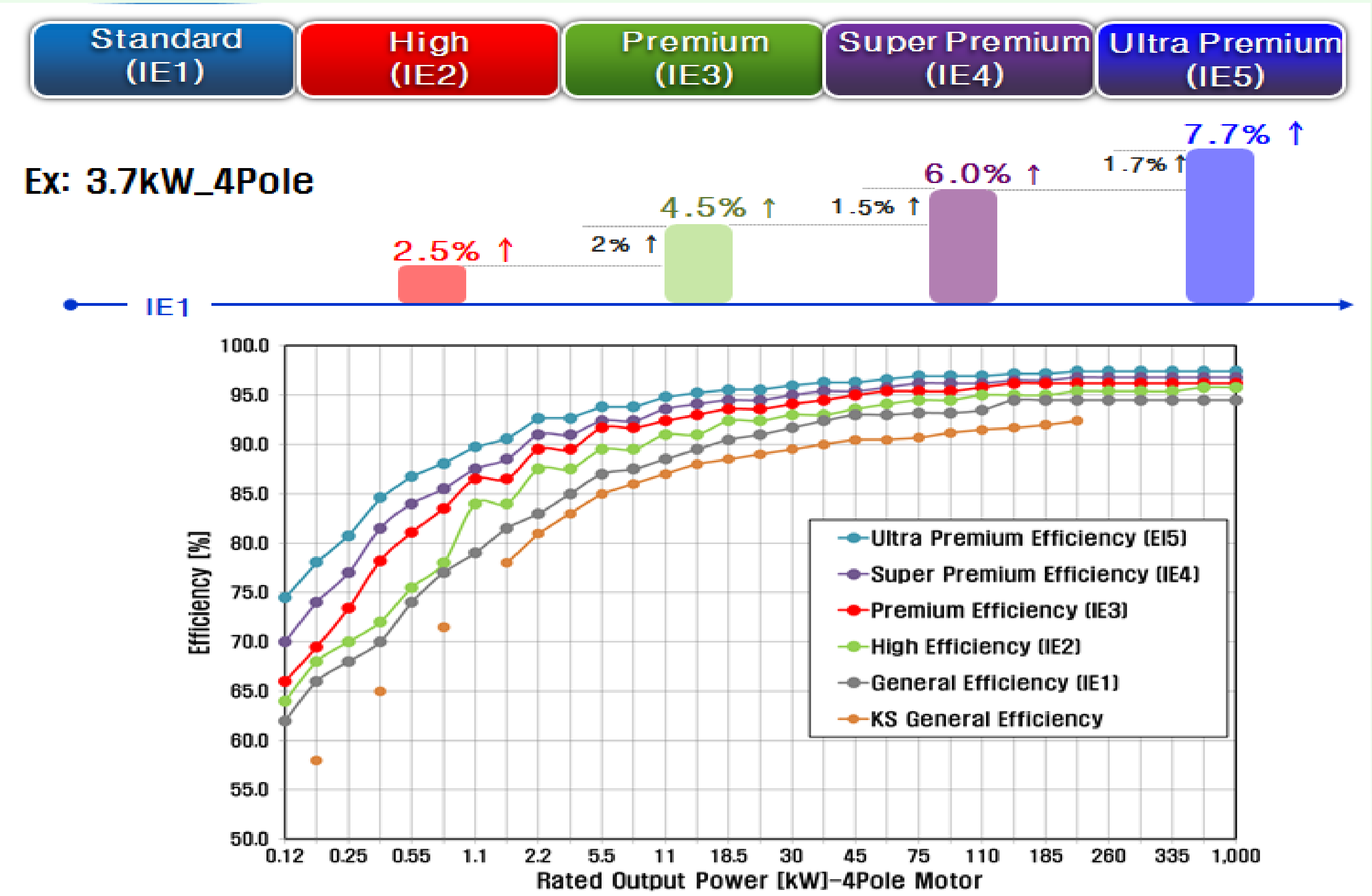
Contributor	18	Brazil	Carlos Ogawa	Affiliation: WEG
	19	Finland	Juha Pyrhonen	Affiliation: LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
	20	USA	Emmanuel Agamloh	Affiliation: ADVANCED ENERGY

2. Motor technology development : Efficiency and Volume



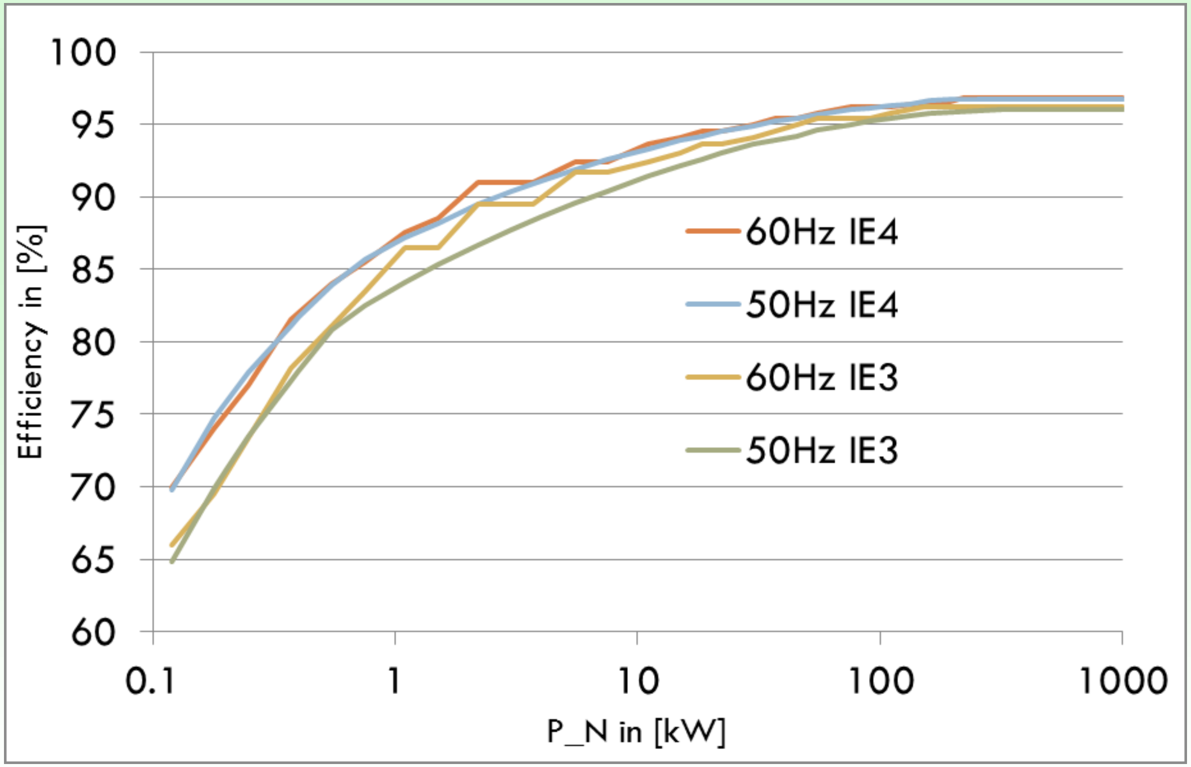
2. Motor technology development :Efficiency according to power



3. Survey findings

1) frequency

- 2/3 of the world population is using 50Hz and 1/3 is using 60Hz.
- 60Hz the medium size rating motors: about 1% higher efficiency



3. Survey findings

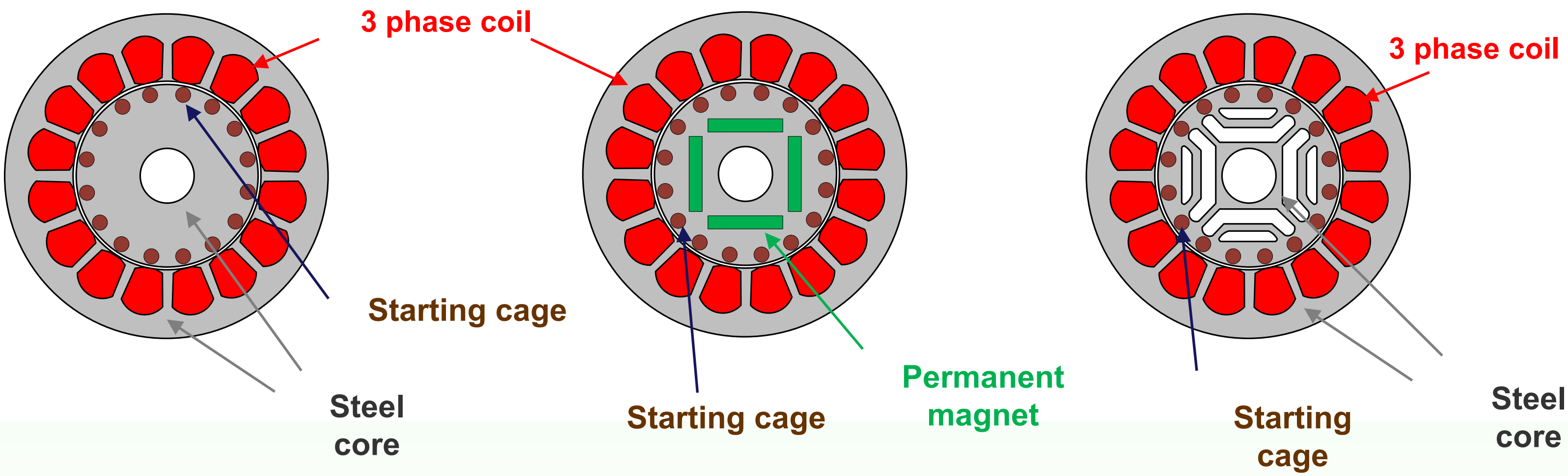
2) Classification of motor size for survey

Classification	Rated power
Small motor	0.12 – 3.7 kW
Medium-size motor	3.7 – 55 kW
Large motor	55 – 1000 kW

Power	Freq.	IE3 efficiency (%)	IE4 efficiency (%)
0.75 kW	50 Hz	82.5	85.7
	60 Hz	83.5	85.5
37 kW	50 Hz	93.9	95.2
	60 Hz	94.5	95.4
250 kW	50 Hz	96.0	96.7
	60 Hz	96.2	96.8

3. Survey findings

3) Motor types

Types	IM (Cage induction motor)	PM-SC (Permanent-magnet motor with a starting cage)	SRM-SC Synchronous reluctance motor with a starting cage
Structure			

3. Survey findings

4) Feasible motor types

- IE4

	Small	Medium	Large
IM	○	□	□
SRM-SC	○	□	△
PM-SC	○	○	△

○ → already available □ → feasible
△ → feasible with issues X → not possible

IM:	Cage induction motor
SRM-SC:	Synchronous reluctance motor with a starting cage
PM-SC:	Permanent-magnet motor with a starting cage

3. Survey findings

4) Feasible motor types

- IE5

	Small	Medium	Large
IM	X	X	△
SRM-SC	□	△	X
PM-SC	□	□	△

o→ already available □ → feasible
△ → feasible with issues X → not possible

IM: Cage induction motor
SRM-SC: Synchronous reluctance motor with a starting cage
PM-SC: Permanent-magnet motor with a starting cage

3. Survey findings

6) Quantitative Evaluation for loss reduction by material

Material	Change in the loss	Available year	Reference and Remark
nano-crystalline core materials	-Core losses at B=1.7 T are reduced from 100% (Si-steel highest-graded oriented) to 30-50% (nano-crystalline core).	2025 – 2030	
amorphous core materials	- Iron losses are substantially reduced. For H = 100 A/m B = 0.95 T (18 W/kg) for Silicon Steel (IE3) to 1.26 T (1.5 W/kg) for amorphous iron alloy (IE4)	2020-2025	2025 for small motors, 2030 for medium size motors and 2035 for large motors (IE4 class). For IE5 class five years more.
nano-enhanced dielectrics for winding insulation	-from 100% to 90-95% in dielectric losses.	now-2025	It is used to reduce partial discharge . Binder with CNT/CMT will improve the thermal conductivity and breakdown voltage
carbon nanotubes for higher conductivity of windings	-from 100% to 50 – 30 % in winding resistive losses	2035	carbon nanotubes' conductivity is 2 – 3 … times higher than that of Cu
Superconductors	-from 100% to 0% in winding resistive losses	2050	Superconductors resistivity is 0 but they probably require a complicated cooling system
stronger permanent magnets with rare-earth metals	- from 100% to 0% in rotor bar losses because of synchronous speed. - from 100% to 80% in stator resistive losses by reducing stator current	2020	The price of rare-earth minerals will be unstable. -In general PMAC motor losses are 10-20% lower than IE3 motors
stronger permanent magnets without rare-earth metals e.g. Core - Shell Magnet	- from 100% to 0% in rotor bar losses because of synchronous speed.	2025	-Manufacturing process needs to be developed. -Rare-earth free permanent magnets, e.g. exchange coupled nanocomposite magnets with (BH)max higher than 30 MGOe

3. Survey findings

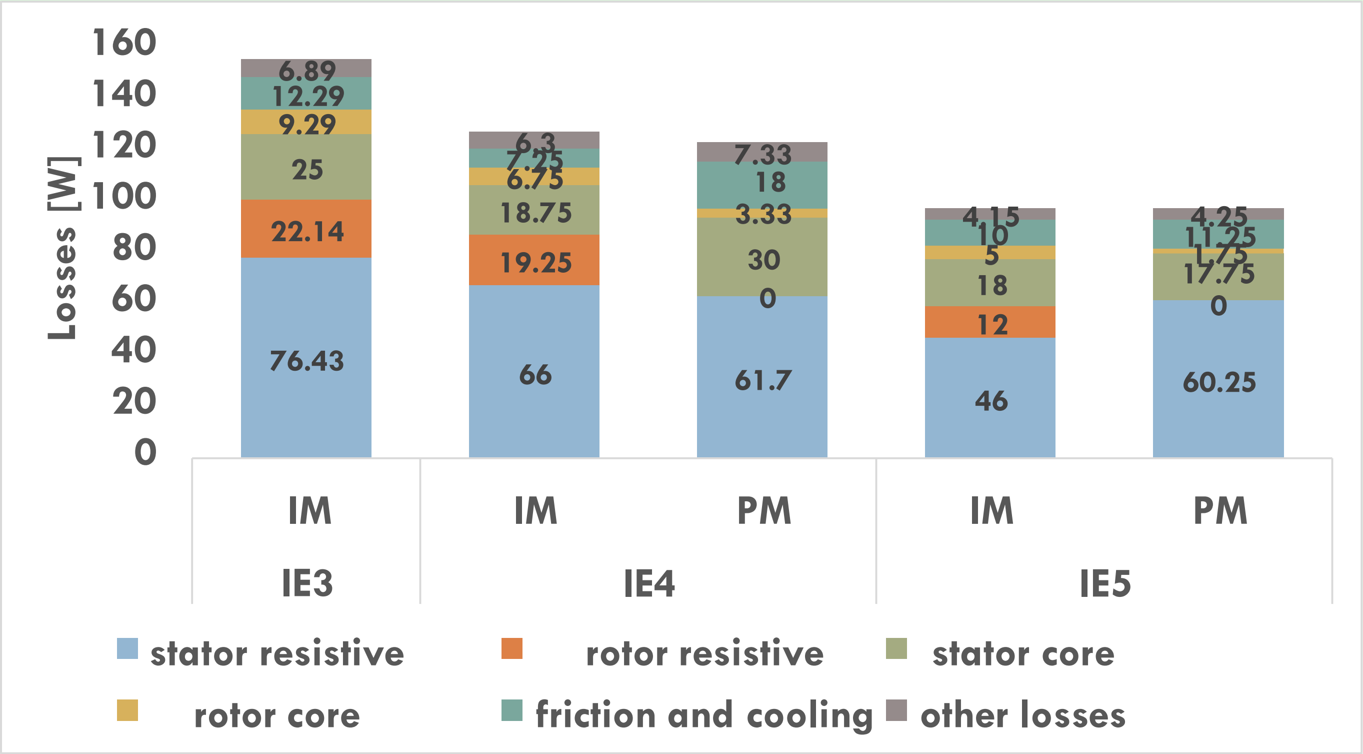
7) Quantitative Evaluation for loss reduction by production tech.

Production Tech.	Change in the loss	Avail able year	Reference and Remark
higher space factor of stator winding	-from 100% to 79-93% in stator winding resistive losses. -filling factor from 0.55-0.65 to 0.7.	now – 2020	
maintaining good quality of core sheets throu gh the production process (self bonding, emb oss free and annealing)	-from 100% (Si-steel A) to 75% (Si-steel B) -from Bs=1.9 T, W17/50=2.3 W/kg(Si-steel A) to Bs=1.84 T, W1 7/50=2.0 W/kg (Si-steel B)	now	The laminations should be prefabricated t o their correct geometry, be annealed and thereafter insulated.
eliminating circulating currents in the parallel strands of stator winding	- from 100% to 94-98% in stator resistive losses at 60 Hz suppl y; would be much large reduction at higher frequencies.	now	Would have a higher loss reduction in inv erter-fed motors
casted copper cage	-from 100% (Al) to 63% (Cu) in rotor resistive losses. -changing resistive from 2.75 to 1.73 [μΩ•㎝]	now	Already available in the market for small motors
Potting, e.g. encapsulating the end-winding wi th a material of good thermal conductivity	-from 100% to 90-98% in resistive stator losses	now	Already available for motor for air conditi oning
better fan efficiency	-from 100% to 80-90% in the friction losse	now	bi-directional special aerodynamic fan
reducing friction losses by better bearings	-from 100% to 98% of total losses	now	
motor size up	-from 100% to 70-95% in winding resistive and iron losses	now	-It depends on the standards to re-define power/frame ratio
dimensional optimization of the motor	-from 100% to 98% in the total losses by slots/teeth	now	
Heat treatment stator & rotor pack	-from 100% to 85% in stator & rotor pack losses	2020	

3. Survey findings

8) Loss calculation

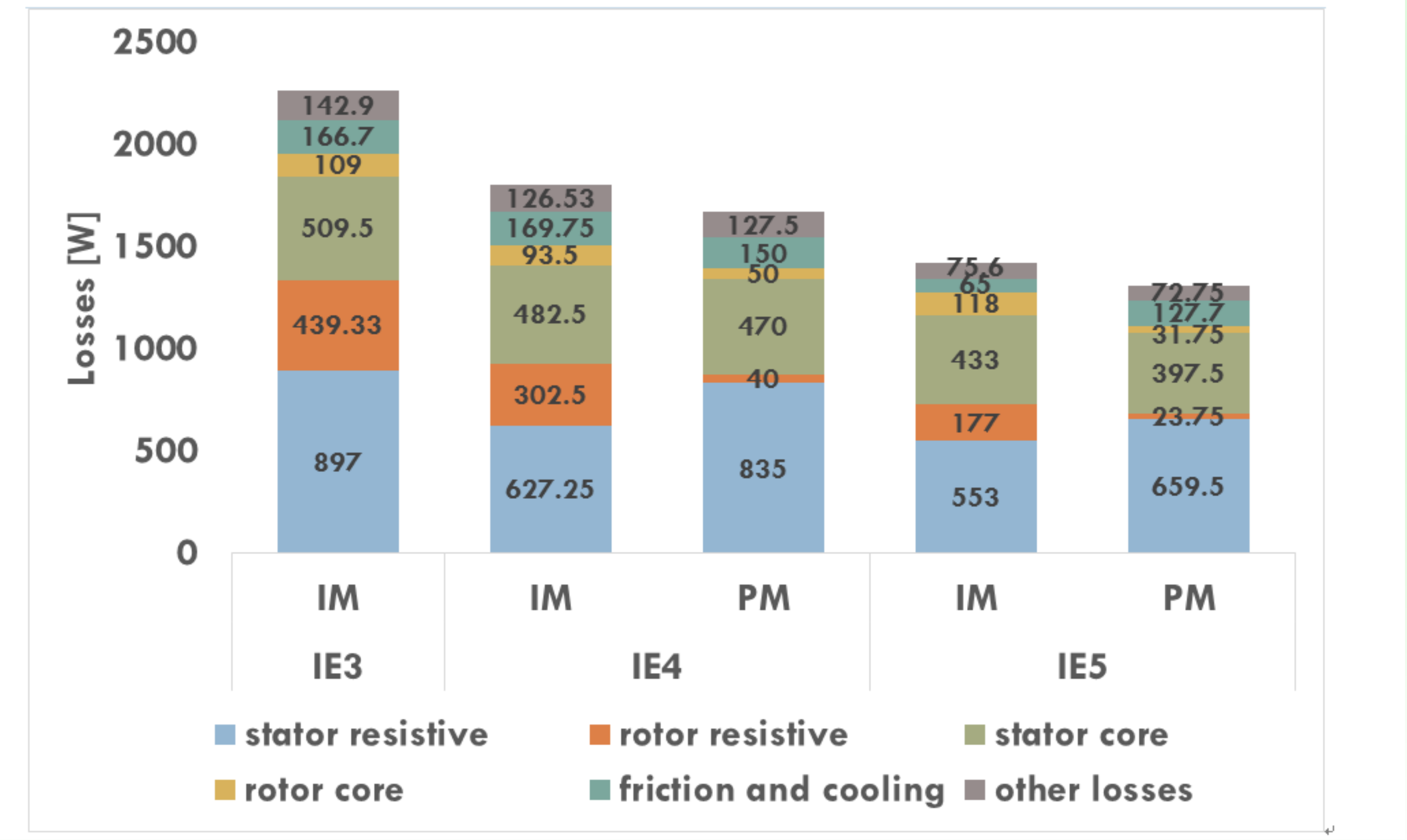
-0.75kW



3. Survey findings

8) Loss calculation

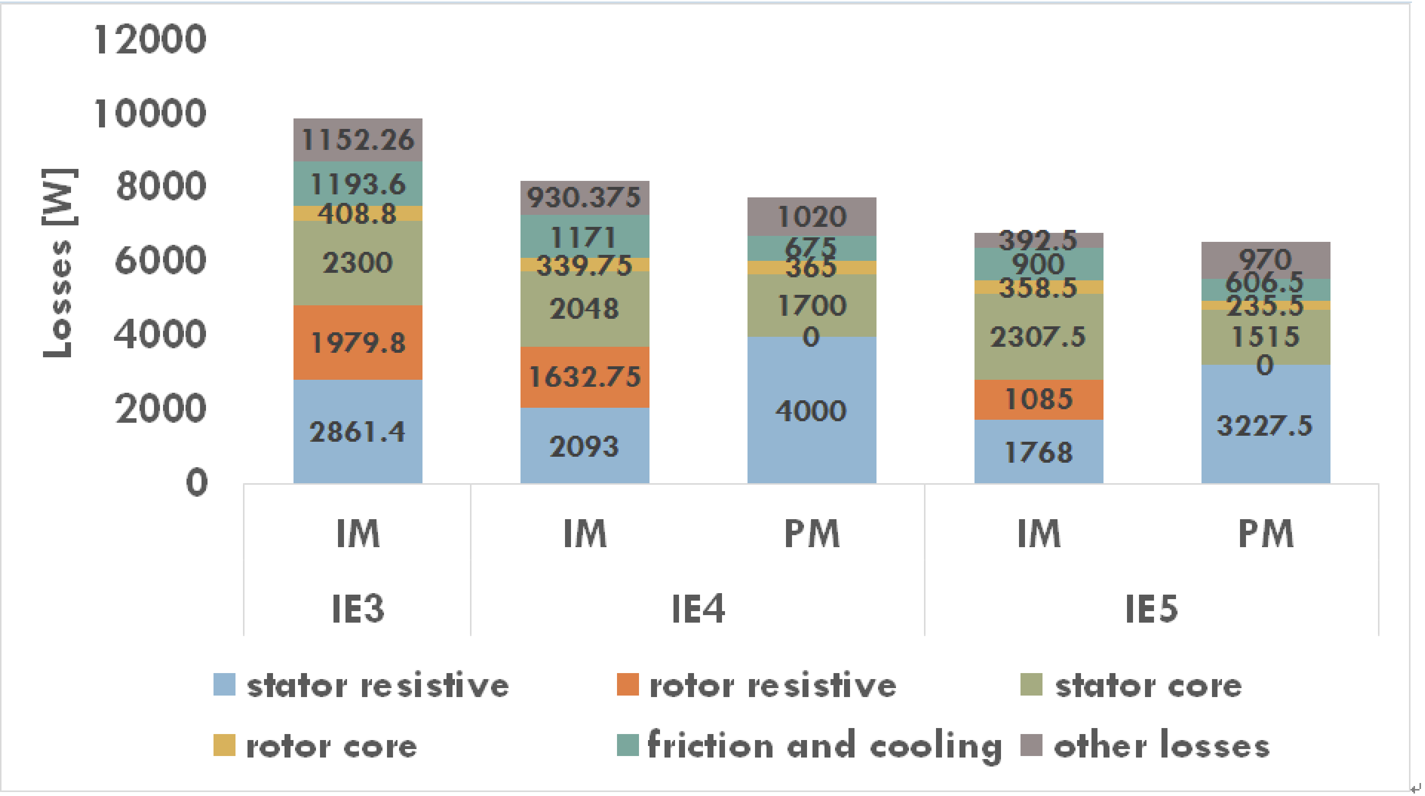
-37kW



3. Survey findings

8) Loss calculation

-250kW



3. Survey findings

10) Time table for mas production and setting mandatory

- Mass production

IE class	Small motors	Medium-size motors	Large motors
Year for mass production of IE4 motors	2023	2023	2025
Year for mass production of IE5 motors	2031	2032	2036

IE4: middle of 2020s / IE5: middle of 2030s

-Setting mandatory

IE class	Small motors	Medium-size motors	Large motors
Year for setting IE4 mandatory	2030	2029	2030
Year for setting IE5 mandatory	2038	2037	2038

IE4: beginning of 2030s / IE5: end of 2030s

4. Conclusion

1)Time forIE4 and IE5: influenced by the action of manufacturers, governments, the international political response to climate change

2)IE4 and IE5 sooner than we thought(no more atomic energy/more EV)

3)Save about 108 nuclear reactors and about 378 TWh per year (30.2 billion US$) by 3% efficiency up in 2030

4)International co-work (with motor makers/material producers/equipment providers /institutes/universities) to verify technical feasibility of IE4 and IE5 and for cost analysis by funding from IEA or ???

5)56% of motors are old than expected life time in Swiss
-Save 252 nuclear reactors by 7% efficiency up
- Pay-back 4-5 years

6)We (WG members /3 contributors) are very proud of joining WG A1.47.

Thanks a lot

Question and Discussion

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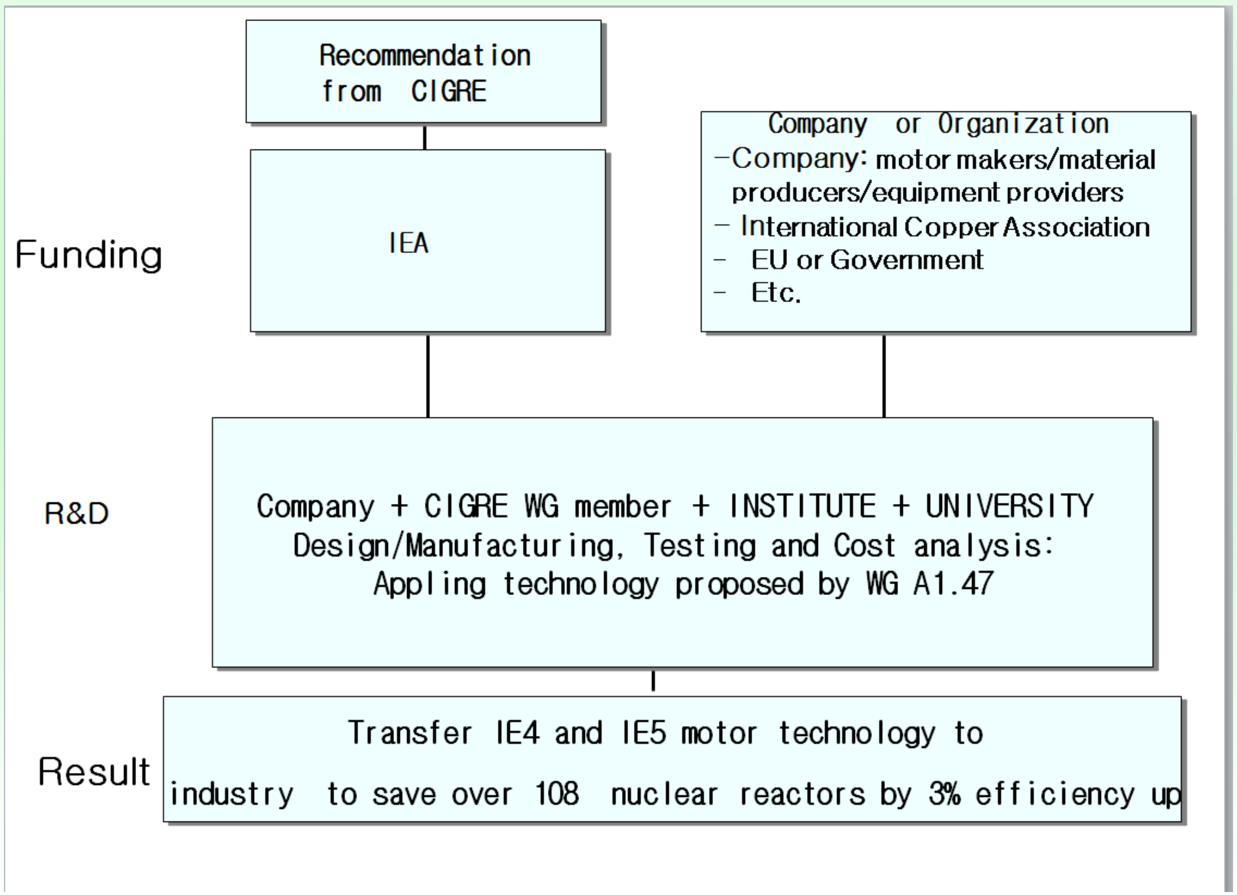
I would like to thank

Mr. Byung Hui Kang(KR) of Hyosung Corporation: as secretary
Prof. Antero Arkkio (FI) of Aalto University who has given a great contribution to make the questionnaire form,
Prof. Erli Ferreira Figueiredo of Rio de Janeiro State Uni. who has given a great contribution to this WG and
Mr. Tobias Schmalen (DE) of University of Applied Sciences Trier who has given a great contribution to writing Technical Brochure.

Ref. 1 : International co-work suggestion



Ref. 1 : International co-work suggestion

a) Work scope

- The 1st 3 years is mainly based on planning and calculation work

- The 2nd 3 years is mainly based on building motors, testing and cost analysis

b) Funding amount

- The 1st 3 years: total ???? US$ (???% from IEA, ????% from others)

- The 2nd 3 years: total ???? US$ (???% from IEA, ????% from others)

Ref. 2 : Old motor status in Swiss: Application

Application	Number		Energy consumption		Rated power per motor		Age	Operation	Equipped with VSD	
			total	per motor*	average	maximum	per motor*	per motor*		
	[no.]	[%]	[GWh/a]	[MWh/a]	[kW]	[kW]	[a]	[h/a]	[no.]	[%]
Fans	1044	25%	65.5	63	18	1000	16	5455	311	38%
Pumps	1590	38%	43.2	27	13	315	16	4275	279	34%
Rotating machines	672	16%	29.9	44	35	4050	22	2883	63	8%
Cooling compressors	124	3%	21.5	174	64	450	17	4283	17	2%
Air compressors	109	3%	22.0	202	74	315	15	4064	25	3%
Other	251	6%	8.4	33	25	2870	18	4491	60	7%
Conveyors	352	8%	5.4	15	6	160	19	4232	66	8%
All motors	**4142**	**100%**	**195.9**	**47**	**21**	**4050**	**17**	**4351**	**821**	**20%**

*average

By Swiss Agency for Efficient Energy Use (S.A.F.E.) in 2014

Ref. 2 : Old motor status in Swiss : business

No.	Core business	Electricity consumption	Motors on motor list	Motors tested on-site
		[GWh/a]	[no.]	[no.]
1	Dairy	40.2	294	23
2	Energy solutions	38.4	652	33
3	Waste incineration	38.2	277	14
4	Chocolate	35.4	540	25
5	Dairy	19.7	223	-
6	Chemical industry	16.9	96	-
7	Water supply	15.3	163	-
8	Industrial adhesives	12.4	381	-
9	Plastic material	11.9	10	-
10	Medical products	11.8	186	-
11	Rolled aluminum	11.4	108	-
12	Chalk production	10.0	74	-
13	Bioorganic products	7.8	381	-
14	Meat processing	5.9	42	9
15	Vegetable oils	4.9	208	-
16	Chocolate	3.5	325	-
17	Confectionary	2.8	42	-
18	Yeast production	2.3	140	-
Total		**288.8**	**4142**	**104**

S.A.F.E. 2013

4142 motors on the motor list consume 196 GWh electricity per year.(70%)

Ref. 2 : Old motor status in Swiss: motor age

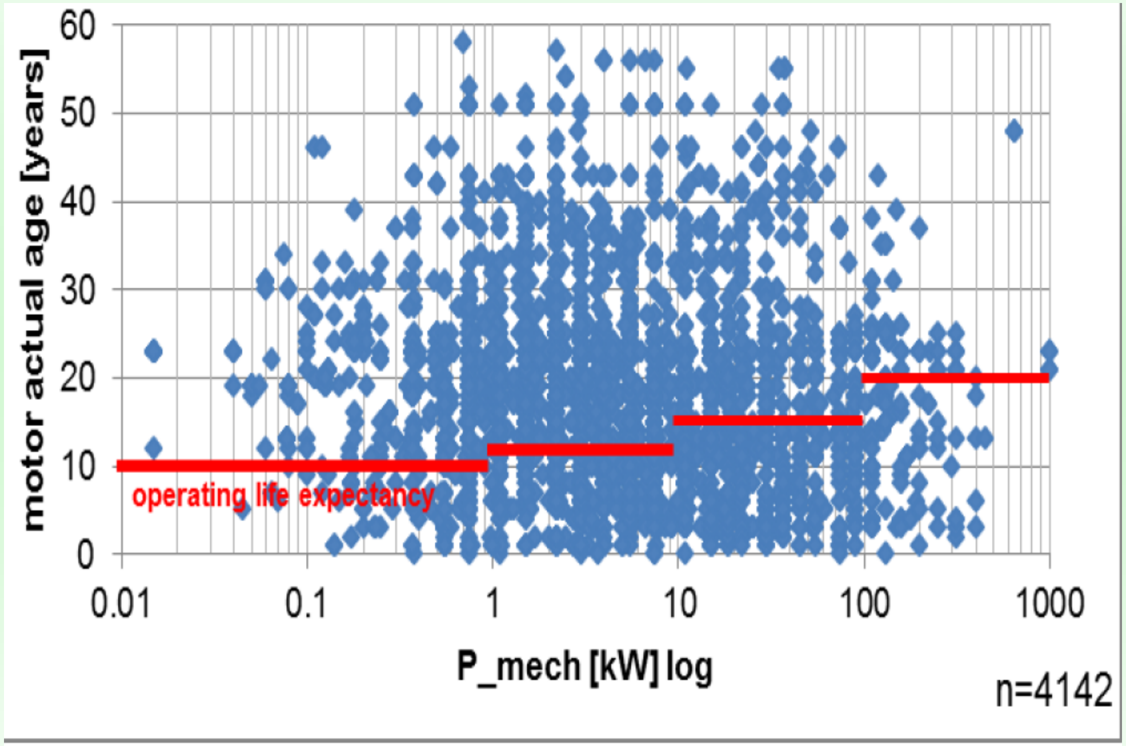


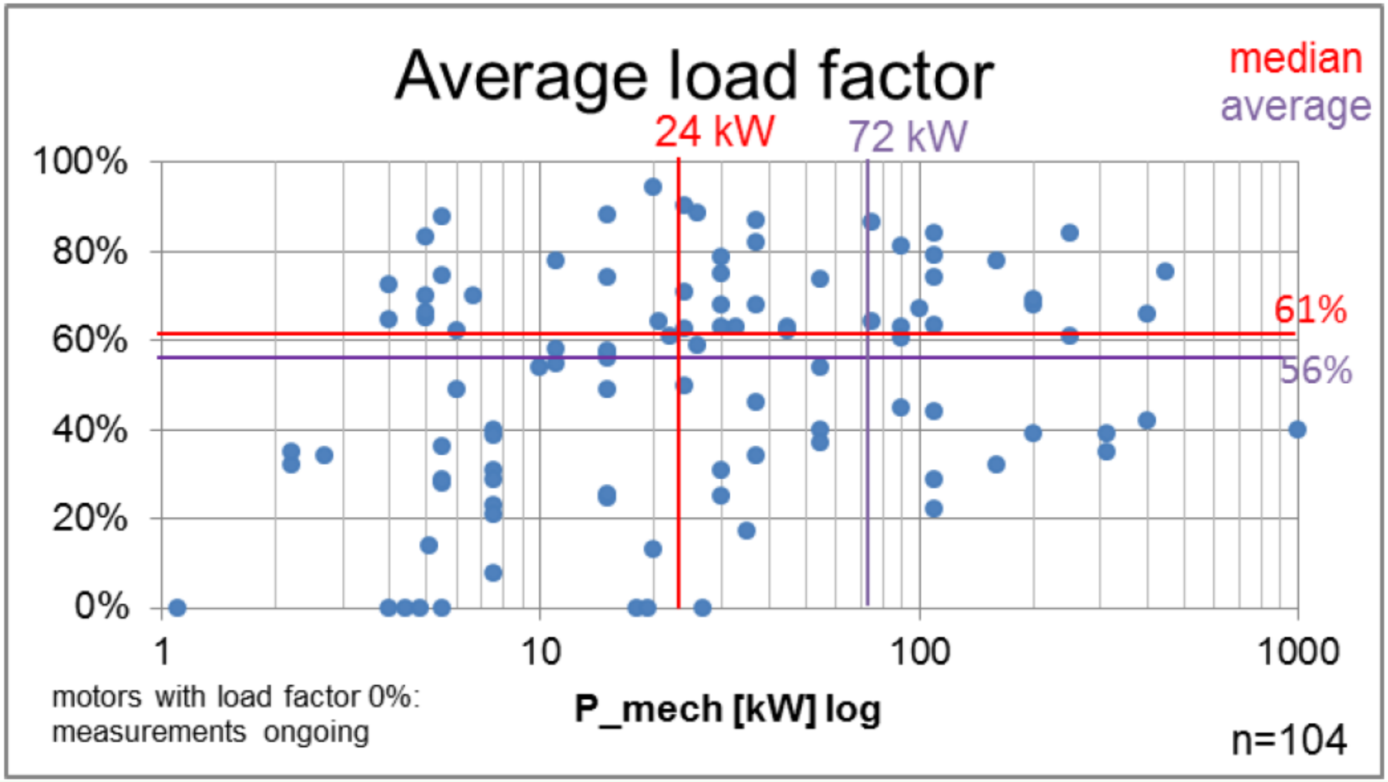
Table 3 Expected motor lifetime

Output power	Expected lifetime (years)
below 1 kW	10
1 kW - 10 kW	12
10 kW - 100 kW	15
100 kW - 1000 kW	20

Source: [3]

-56% of motors are old than expected life time (max 64 years old)

Ref. 2 : Old motor status in Swiss: over size motor



-39 motors(39/104=37.5%) has load factor less then 50% (heavily oversized)