KERI

한국전기연구원

Technologies Feasibility Studies for Super(IE4) and Ultra Premium(IE5) Efficiency Motor

October 7-10. 2018

*Dr. DOHYUN KANG, *Dr. PILWAN HAN, *Dr. YONDO CHUN
**BYUNGHUI KANG(KR)
*Electric Motor Research Center
Electric Propulsion Research Division
Korea Electrotechnology Research Institute(KERI)
E-Mail : dhkang@keri.re.kr
** Hyosung Corporation

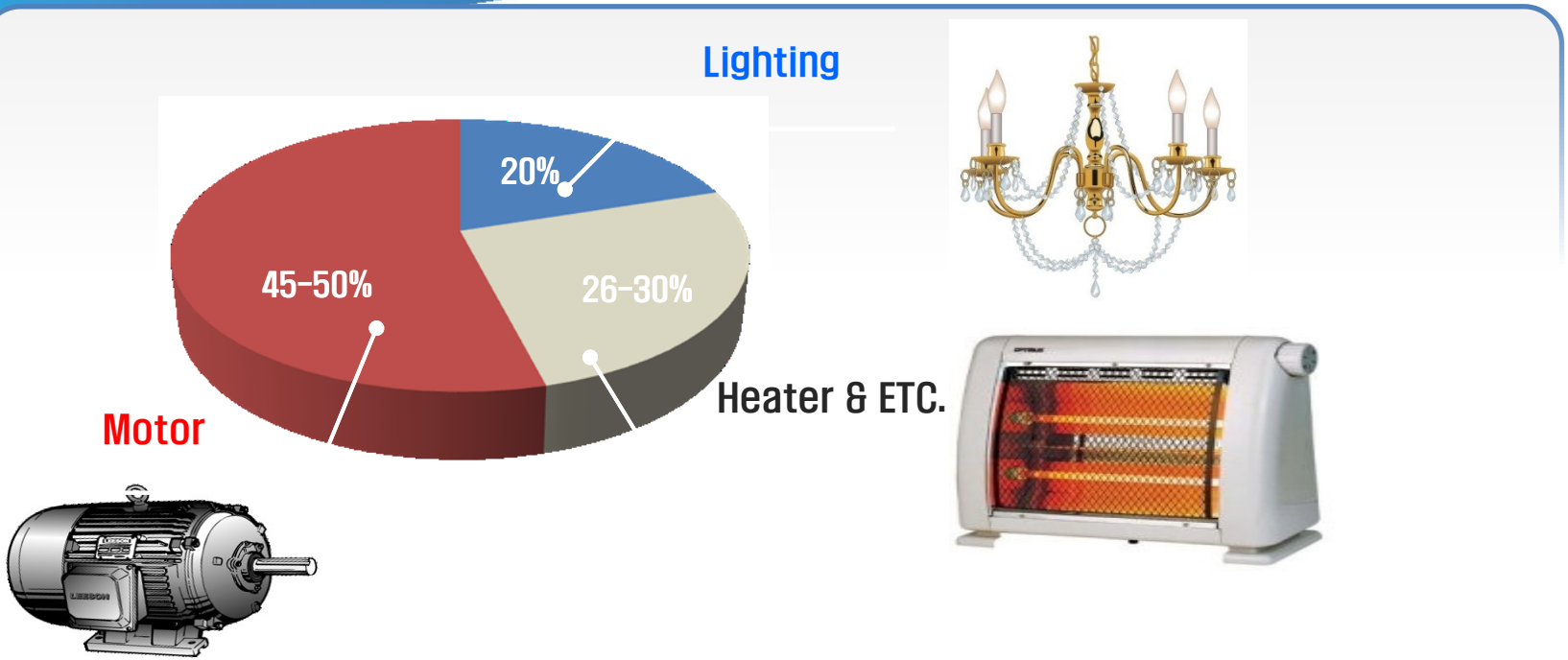
Outline

1. Global Energy Consumption by Motor
2. Motor Technology Development
3. CIGRE
4. CIGRE WG(Working Group) A1.47
5. WG A1.47 activities: Questionnaire
6. WG A1.47 activities: Survey findings
7. Conclusion

Ref. 1 : International co-work suggestion

Ref. 2 : Old motor status in Swiss Industry

1. Global Energy Consumption by Motor



Motor consumes

- 45% of electric energy
- 15% of all primary energy (oil, coal, gas, nuclear, hydroelectric, ---etc)

Power Station Facilities in the World : 8,000GW in 2030

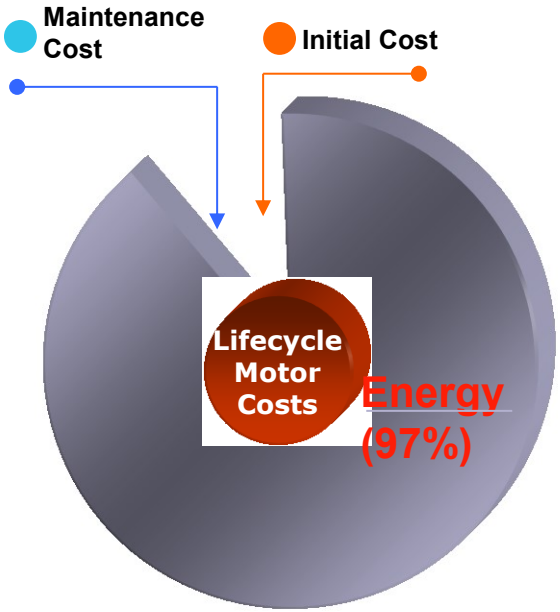
Power Station Facilities for motor in the World:4,320GW in 2030

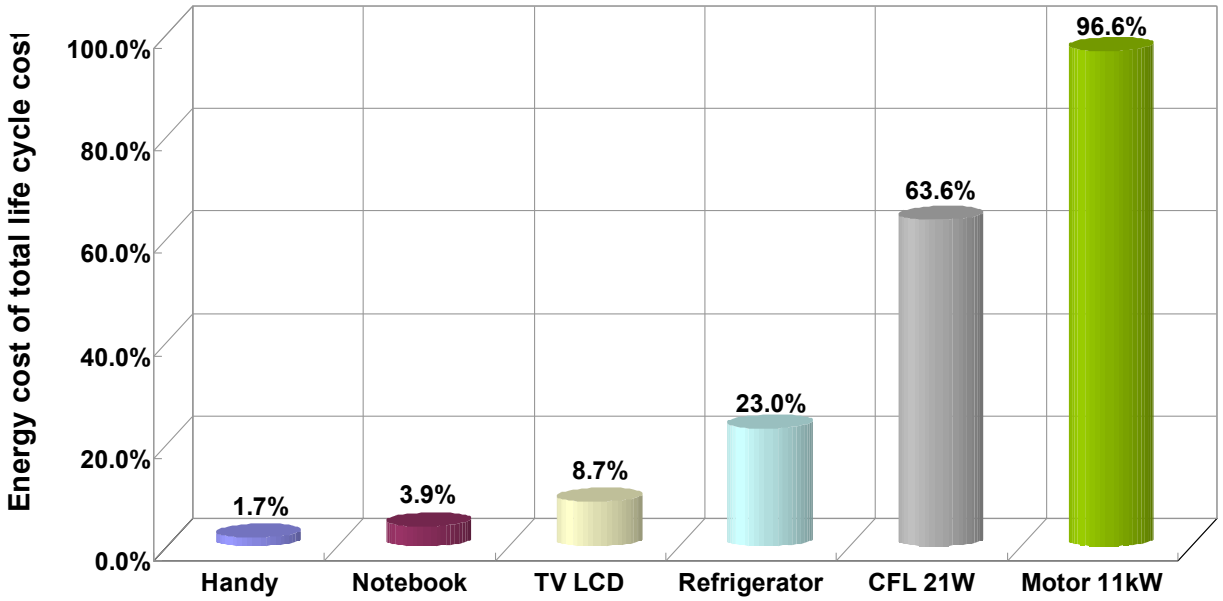
Save 108 nuclear reactors by 3% higher motor efficiency

(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

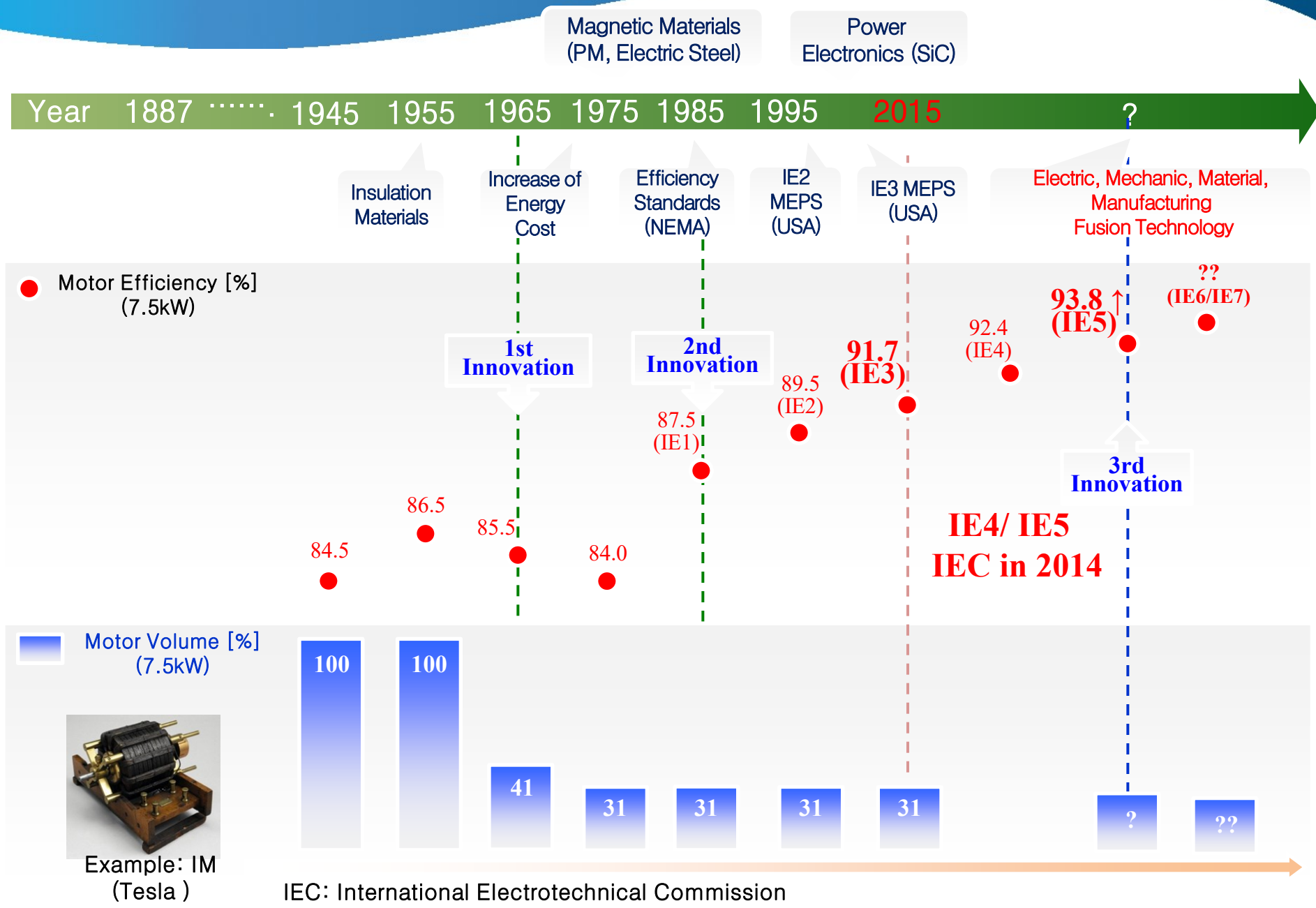
1. Global Energy Consumption by Motor

❖ Energy Cost for Total Life Cycle Costs



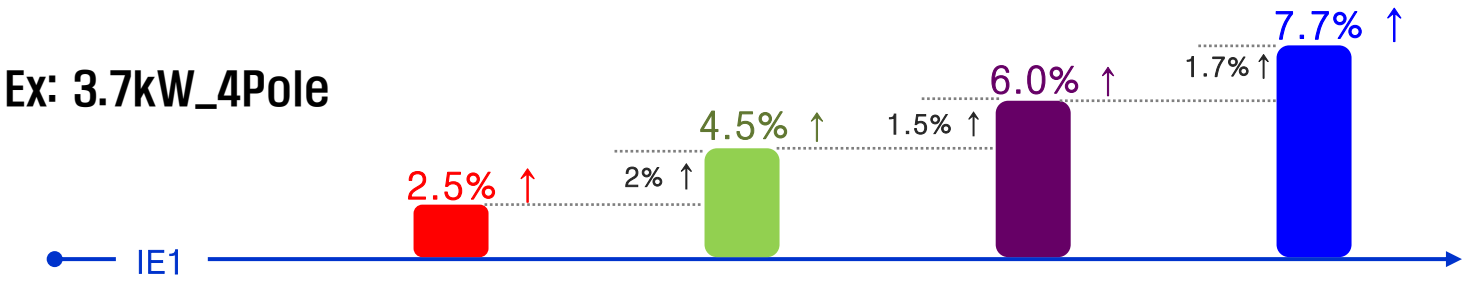


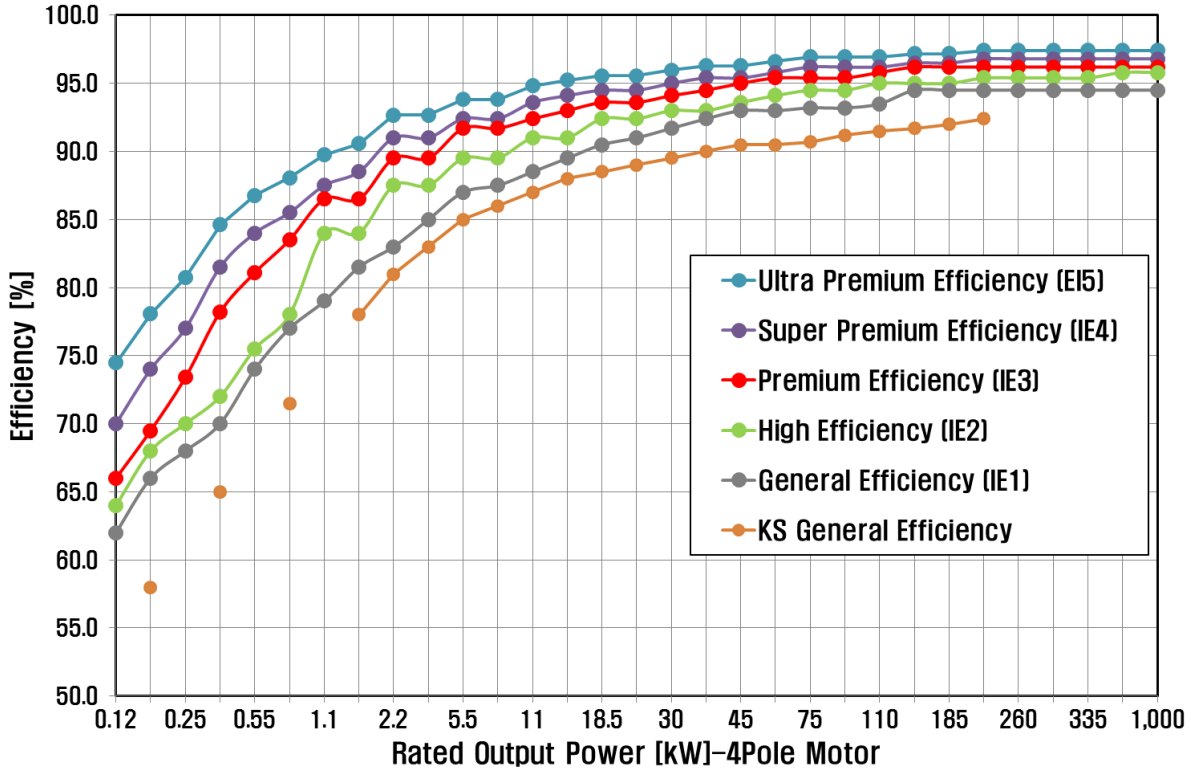
2. Motor Technology Development



2. Motor Technology Development

Standard (IE1)	High (IE2)	Premium (IE3)	Super Premium (IE4)	Ultra Premium (IE5)





3. CIGRE

❖ What is CIGRE?

- CIGRE (Conference Int. Grandes Reseaux Electriques: http://www.cigre.org/ International Council of Large Electric Systems) founded in1921(97 years)
- An international non-profit association to exchange knowledge, share best practices for improving electric power systems of today and tomorrow
- 16 studies committees in CIGRE from A1 to D2

A1 Rotating Electrical Machines
A2 Transformers
A3 High Voltage Equipment
B1 Insulated Cables
B2 Overhead lines
B3 Substations
B4 HVDC and Power Electronic
B5 Protection and Automation
C1 System Development and Economics
C2 System Operation and Control
C3 System Environmental Performance
C4 System Technical Performance
C5 Electricity Markets and Regulation
C6 Distribution Systems and Dispersed Generation
D1 Materials and Emerging Test Techniques
D2 Information Systems and Telecommunications

3. CIGRE

❖ What is CIGRE?

- Working Groups (WGs) performs the studies of technical issue in accordance with the Terms of Reference (ToRs) previously approved by the TC Chairman.
- Today there are more than 230 active WGs in CIGRE with some 3500 international Experts.

- Technical Brochure(Report) are the purpose of Working Group

-27 active working groups in SC A1 rotating electrical machines

4. CIGRE WG(Working Group) A1.47

-IEC 60034-30-1 (in March 2014)
IE4/IE5 class motor (line operated AC motors)is newly included
IE5 class losses should be 80% of IE4 motors

-WG A1.47 "Technological Feasibility Studies for Super(IE4) and Ultra-Premium(IE5) Efficiency Motors" was approved on November 03 2014 by technical committee

-WG A1.47 shall focus on
Designs: new motor topologies and optimization
Materials: magnetic materials, conductors, PM, insulation
Productions: die-casting, coil fill factor, manucaturing(cutting)
Loss reduction for IE4/IE5 motor: to be IE4/IE5 motor
Provisional mile-stone : IE4/IE5 motor mass production and mandatory

-WG A1.47 Technical Brochure(Report) published on June 2018
https://e-cigre.org/publication/729-technological-feasibility-studies-for-super-and-ultra-premium-efficient-motors

4. CIGRE WG(Working Group) A1.47

-WG A1.47 Technical Brochure(Report) published on May 2018

https://e-cigre.org/publication/729-technological-feasibility-studies-for-super-and-ultra-premium-efficient-motors

Order Publications

Reference: **729**

Type:
TECHNICAL BROCHURES

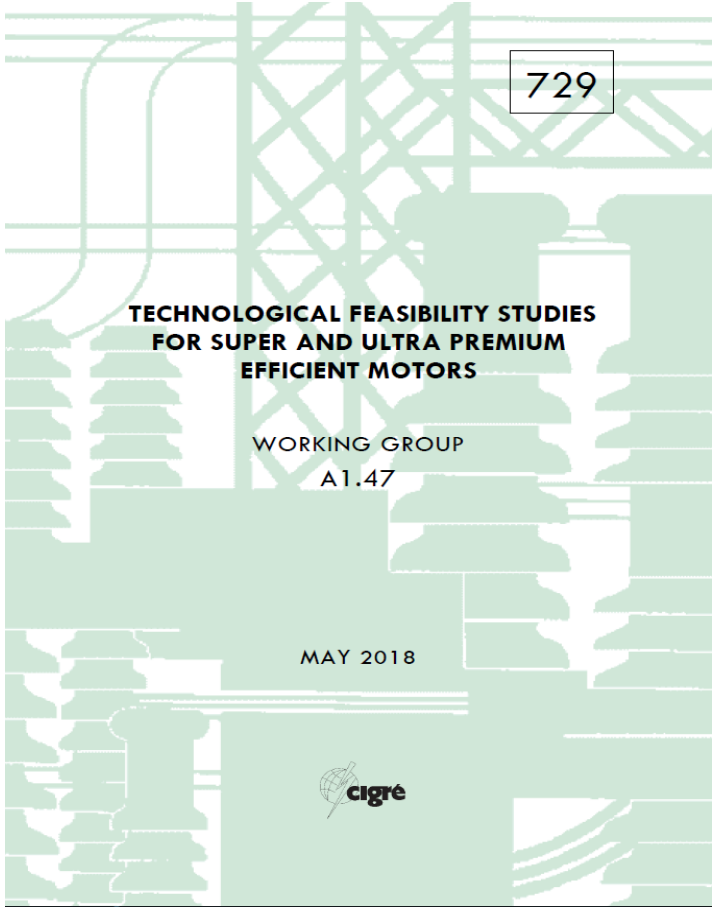
Title:
Technological feasibility studies for super and ultra premium efficient motors

Abstracts

Three main efficiency gains is possible in Super(IE4) and Ultra Premium Efficient (IE5) motors through improvements in materials, manufacturing and motor design. It's the intention of these technological feasibility studies for super and ultra-premium efficient motors to provide information about the feasible motor types, qualitative / quantitative loss reduction methods and loss estimation. Finally, the time to set the IE4 and IE5 classes as mass production of motors and mandatory motor requirements is proposed.

File Size: 3,3 MB
Pages NB: 134

Study Committee : A1
WG (TF): WG A1.47
Year: 2018



4. CIGRE WG(Working Group) A1.47

-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	DoHyun 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
	17	USA	John Petro	Affiliation: Independent consultant
Contributor	18	Brazil	Carlos Ogawa	Affiliation: WEG
	19	Finland	Juha Pyrhonen	Affiliation: LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
	20	USA	Emmanuel Agamloh	Affiliation: ADVANCED ENERGY

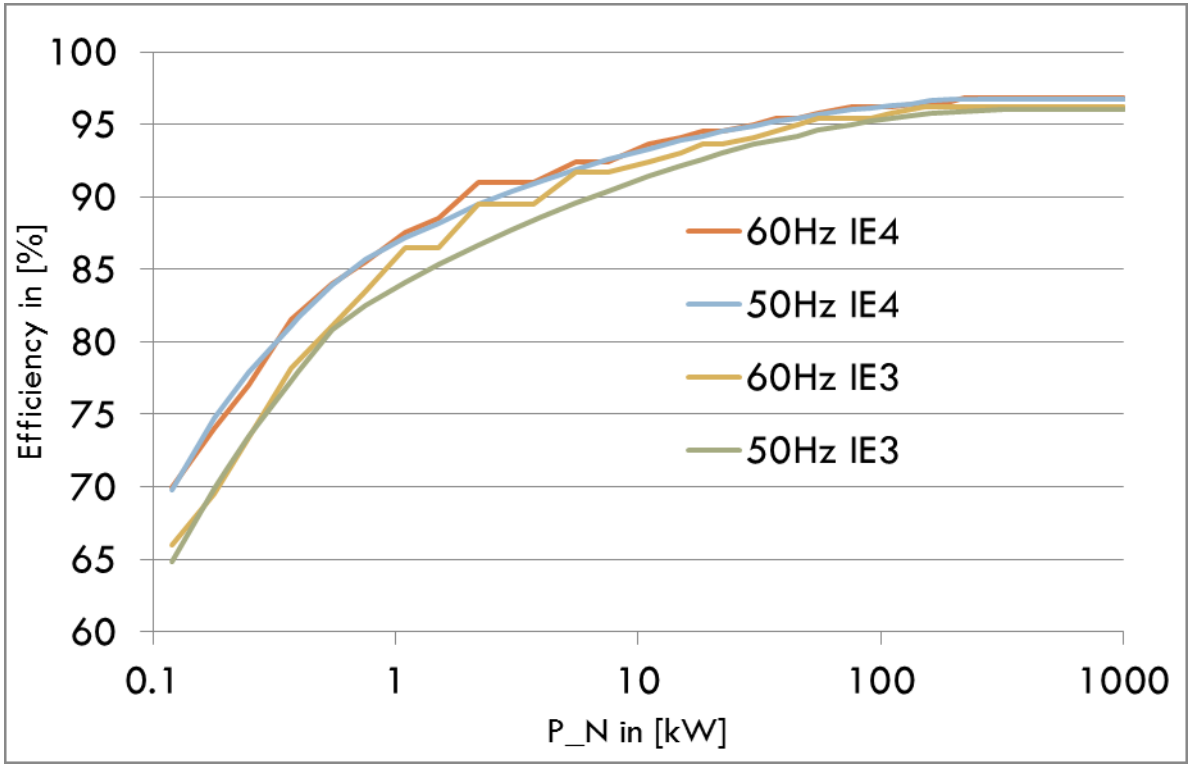
5. WG A1.47 activities: Questionnaire

1 Frequency(50 or 60 Hz)
2 Motor type for IE4 and IE5
  - Cage induction motor
  - Synchronous reluctance motor with a starting cage
  - Permanent-magnet motor with a starting cage
  - Synchronous motor with a field winding and starting cage
  - Some other type of motor
3 Motor Size and Efficiency according IEC
  - Small/medium/large-size (0.75/37/250 kW motor.)
  - Efficiency according to small/medium/large-size
4 Loss reduction by materials, production, design
  - Qualitative/Quantitative evaluation
5 Loss estimates for the IE3, IE4 and IE5 motors
  - 0.75/37/250 kW motor with 4 pole
6 Time schedule for mass production and mandatory

6. WG A1.47 activities: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



6. WG A1.47 activities:Survey findings

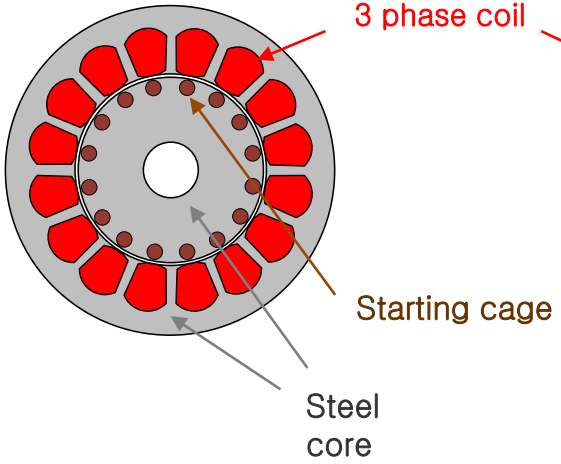
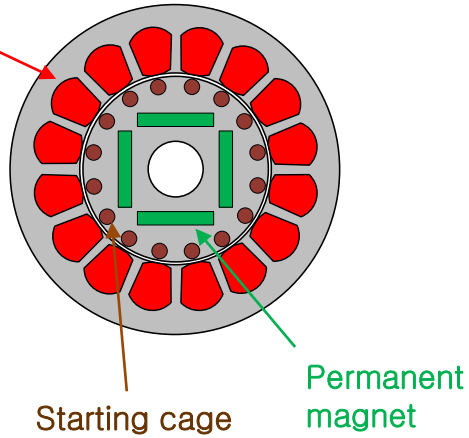
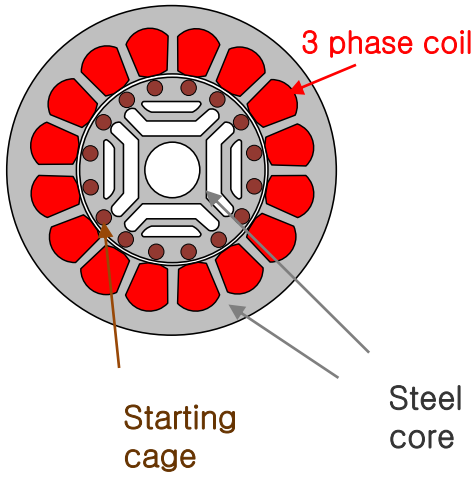
2) Classification of motor size for survey

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

5. WG A1.47 activities: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			

4) Feasible motor types for 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

5) Feasible motor types for 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

6. WG A1.47 activities:Survey findings

6)Quantitative Evaluation for loss reduction by material

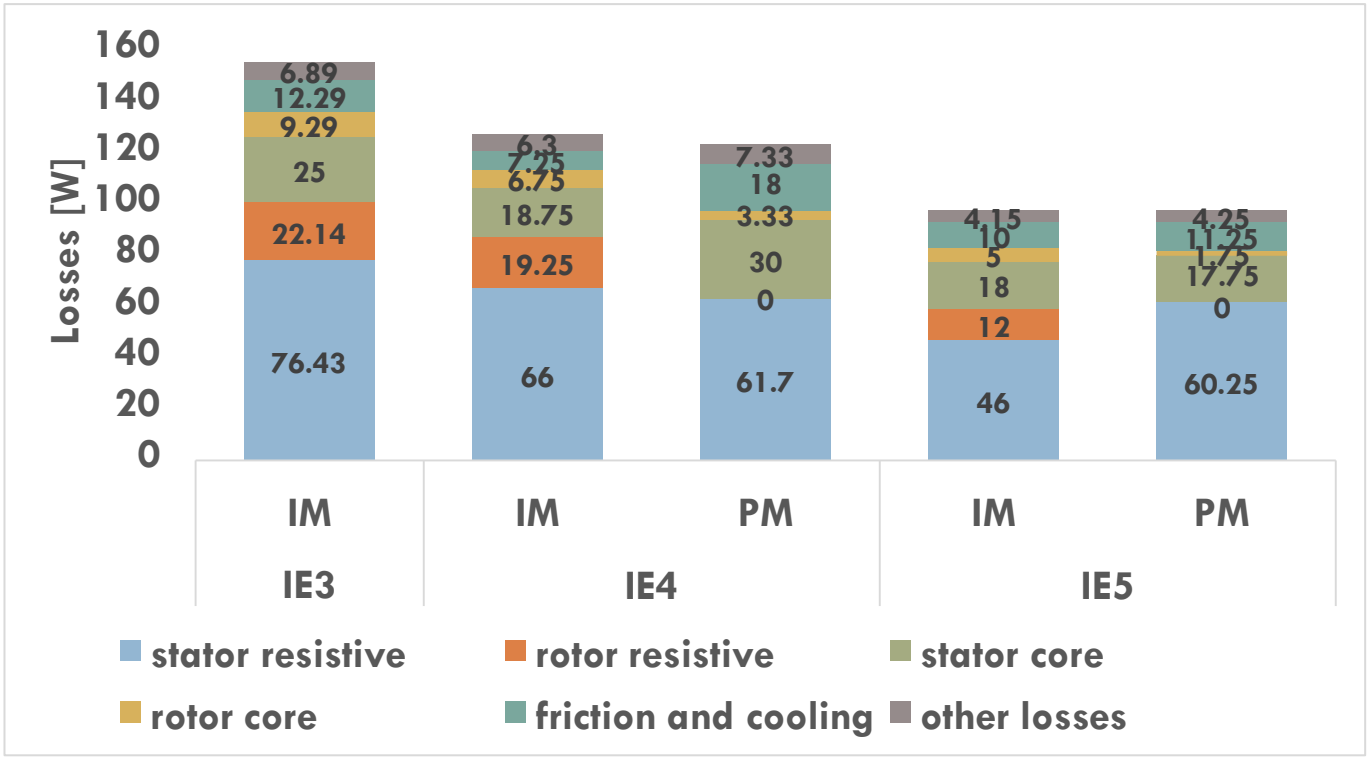
Material	Change in the loss	Available year	Reference and Remark
nano-crystalline core materials	-Core losses at B=1.7 T are reduced fr om 100% (Si-steel highest-graded ori ented) to 30-50% (nano-crystalline core).	2025 - 2030	
amorphous core Materials	- Iron losses are substantially reduced. For H = 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 dielec trics 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 m agnets 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 m agnets without rare-ea rth 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

7) Quantitative Evaluation for loss reduction by production tech

Production Tech.	Change in the loss	Available 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 through the production process (self bonding, emboss 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, W17/50=2.0 W/kg (Si-steel B)	now	The laminations should be prefabricated to 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 supply; would be much large reduction at higher frequencies.	now	Would have a higher loss reduction in inverter-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 with a material of good thermal conductivity	-from 100% to 90-98% in resistive stator losses	now	Already available for motor for air conditioning
better fan efficiency	-from 100% to 80-90% in the friction losses	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	

6. WG A1.47 activities:Survey findings

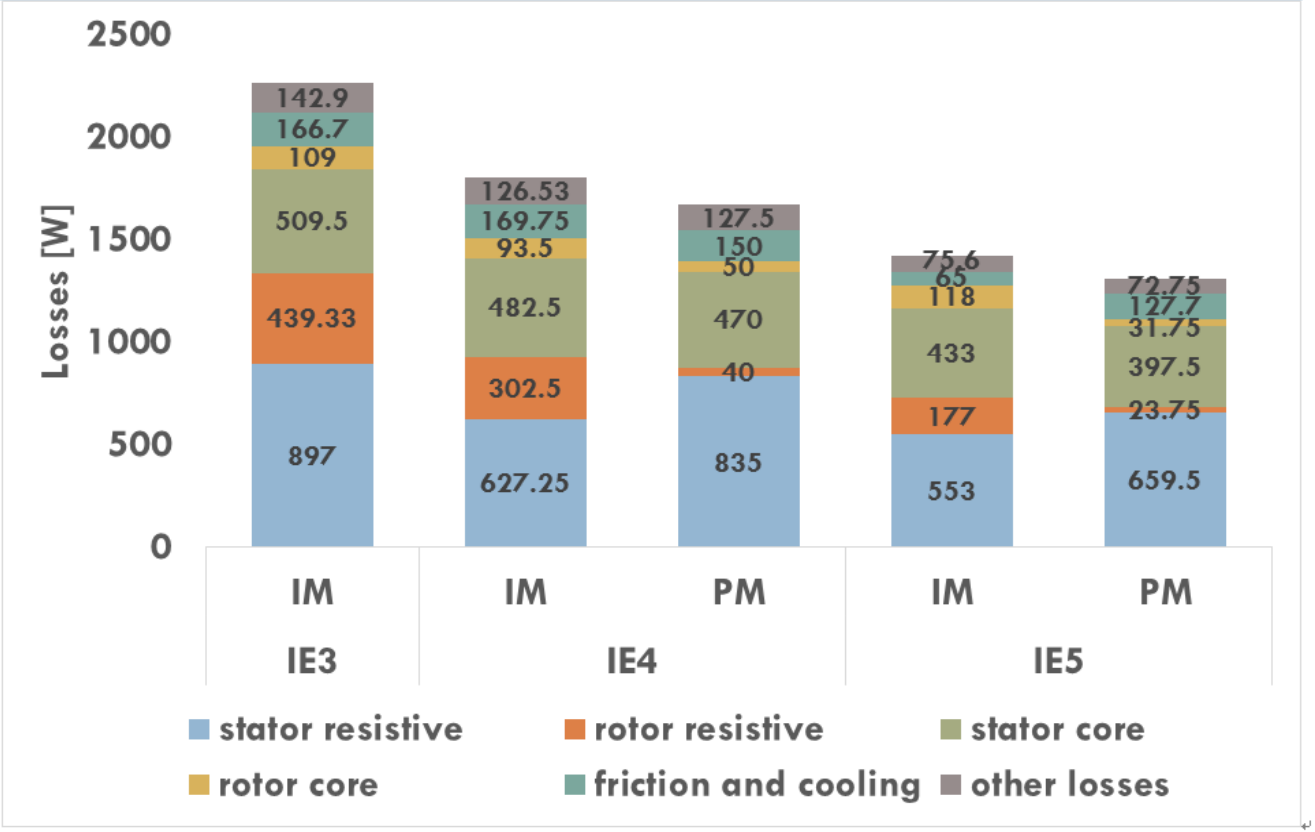
8) Loss calculation
-0.75kW



6. WG A1.47 activities:Survey findings

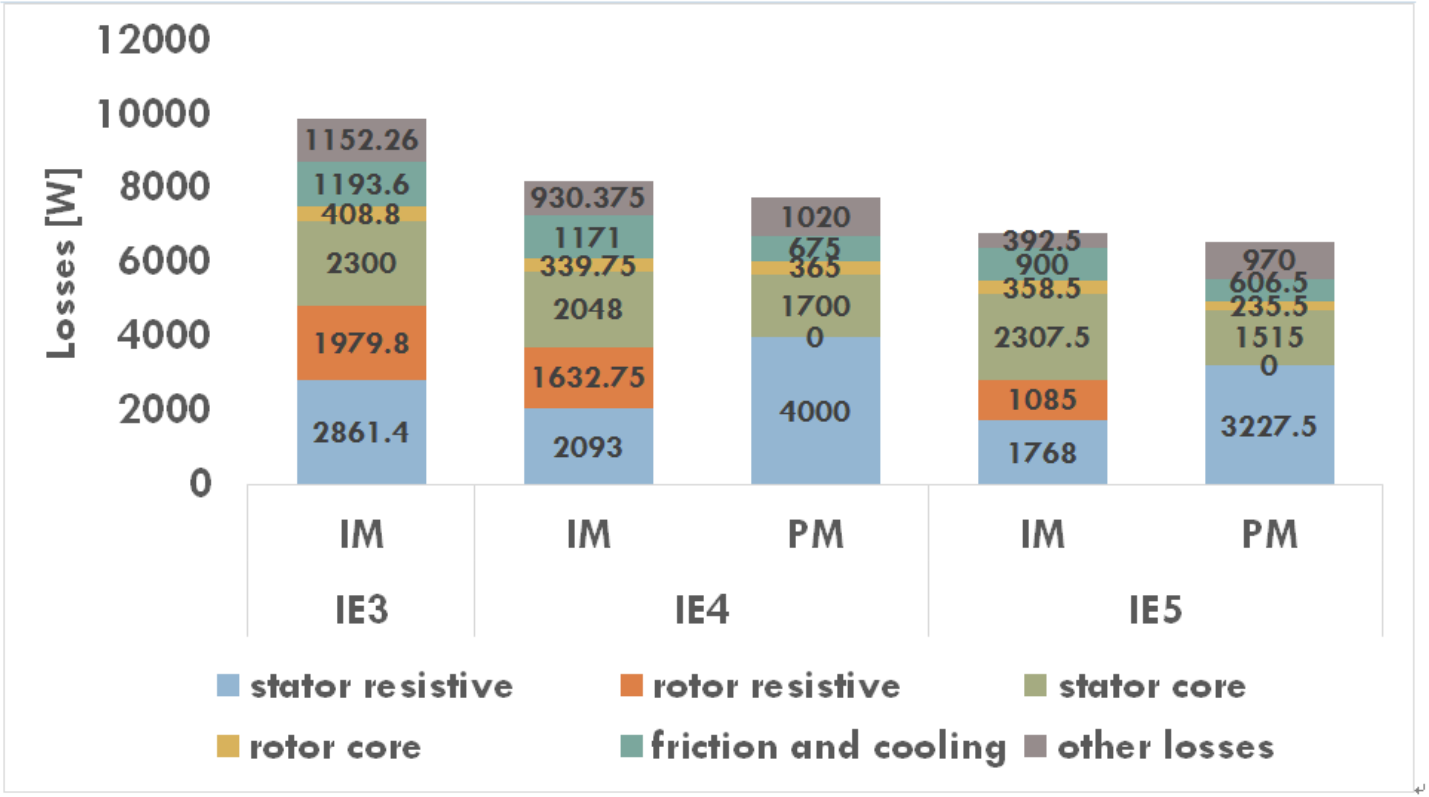
8) Loss calculation

-37kW



8) Loss calculation

-250kW



6. WG A1.47 activities:Survey findings

9) 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

7. 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

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

Thanks a lot

Question and Discussion

DO-HYUN KANG WG A1.47 Convener
dhkang@keri.re.kr

I would like to thank

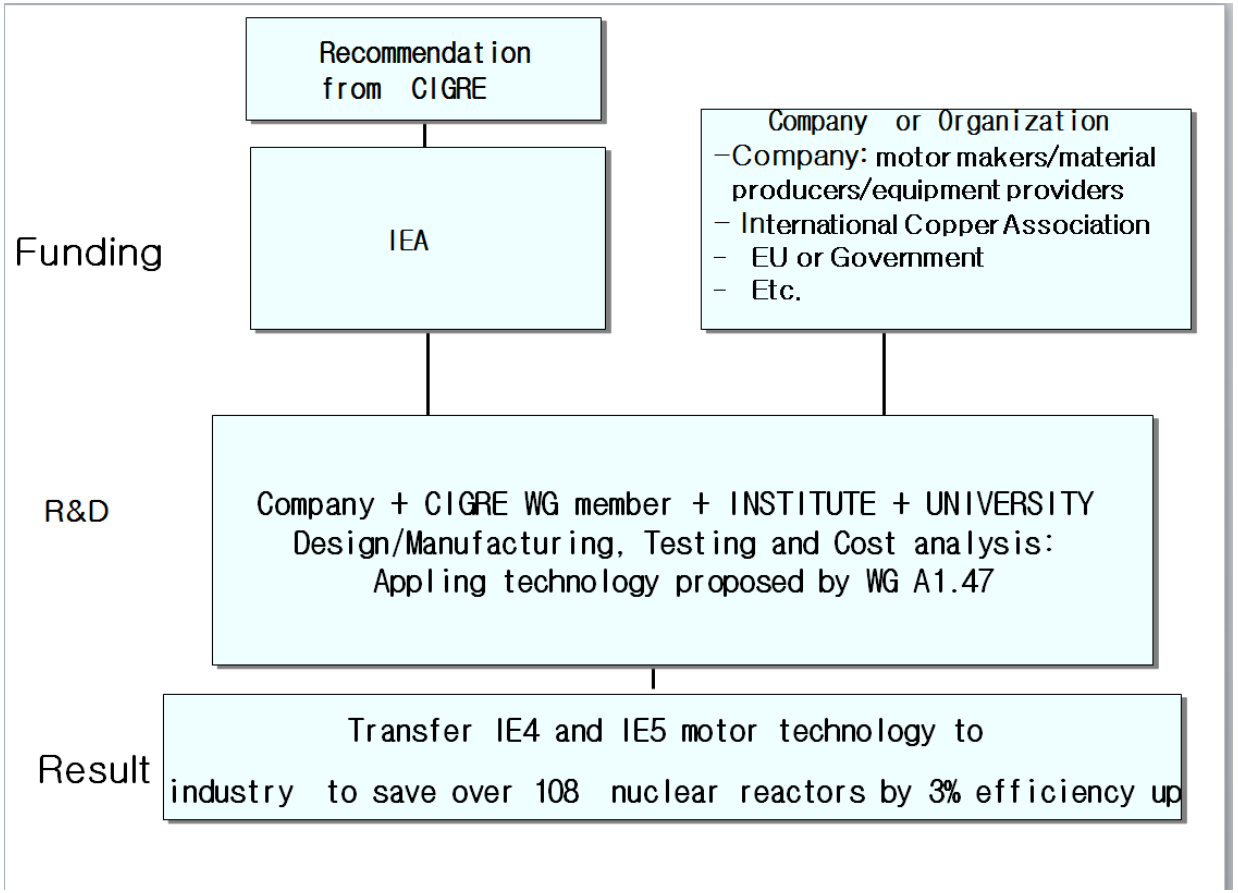
Mr. Byung Hui Kang(KR) of Hyosung Corporation: as secretary

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 Industry

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 Industry

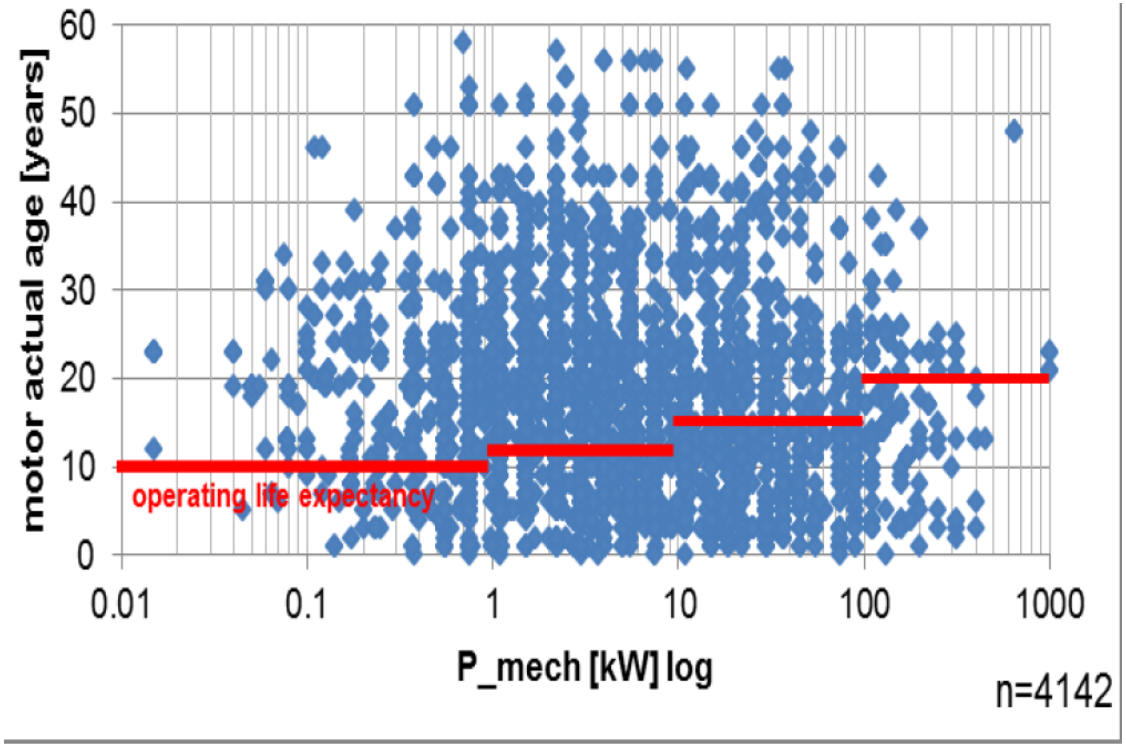


Table 3 Expected motor lifetime

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)