High efficiency motors: Standards and Solutions

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International Copper Association
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High efficiency motor Standard
Motors

Motor is widely used and account for a large share in industrial electricity consumption
In China, they consume about 70% industrial electricity, which is about 40% of the country’s total electricity. The energy performance of these motors has an enormous impact on the total electricity consumed.
# Energy Efficiency standard

<table>
<thead>
<tr>
<th></th>
<th>IEC 60034-30</th>
<th>US</th>
<th>EU (past)</th>
<th>China GB18613-2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Super premium efficiency</td>
<td>IE4</td>
<td>NEMA Premium Plus</td>
<td>-</td>
<td>Grade 1</td>
</tr>
<tr>
<td>Premium efficiency</td>
<td>IE3</td>
<td>NEMA Premium</td>
<td>-</td>
<td>Grade 2</td>
</tr>
<tr>
<td>High efficiency</td>
<td>IE2</td>
<td>EPAAct</td>
<td>Eff1</td>
<td>Grade 3</td>
</tr>
<tr>
<td>Standard efficiency</td>
<td>IE1</td>
<td>-</td>
<td>Eff2</td>
<td></td>
</tr>
<tr>
<td>Below standard efficiency</td>
<td></td>
<td></td>
<td>Eff3</td>
<td></td>
</tr>
</tbody>
</table>
Energy efficiency standard of Motors

Motor Efficiency Standard

Mandatory:
Minimum Energy Performance Standard (MEPS)

Voluntary:
Top Runner Program
## Global Mandatory Standard

<table>
<thead>
<tr>
<th>Efficiency Levels</th>
<th>IEC 60034-30-1</th>
<th>Minimum Energy Performance Standard (MEPS)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Super Premium Efficiency</strong></td>
<td>IE4</td>
<td></td>
</tr>
</tbody>
</table>
| **Premium Efficiency**      | IE3            | Canada (< 150 kW)                                                                                                      
|                             |                | EU (2015>7.5 kW, 2017>0.75KW)                                                                                          
|                             |                | Mexico (0.75-375 kW)                                                                                                   |
|                             |                | USA (0.75-375 kW), effective 2016.6.1                                                                                                                 |
|                             |                | South Korea 2015-2017                                                                                                  |
| **High Efficiency**         | IE2            | Argentina                                                                                                              |
|                             |                | Australia                                                                                                              |
|                             |                | Brazil                                                                                                                  |
|                             |                | Canada (150 kW-375KW)                                                                                                  |
|                             |                | China                                                                                                                   |
|                             |                | European Union (EU 28)                                                                                                 |
|                             |                | Mexico (> 150 kW)                                                                                                       |
|                             |                | South Korea                                                                                                            |
|                             |                | New Zealand                                                                                                            |
|                             |                | Switzerland                                                                                                             |
|                             |                | Turkey                                                                                                                  |
| **Standard Efficiency**     | IE1            | Costa Rica                                                                                                             |
|                             |                | Israel                                                                                                                  |
|                             |                | Taiwan                                                                                                                  |
Global trend of MEPS

- Each country increasing develop National Motor MEPS
- Developing Nations creating new MEPS
- No Global MEPS Program
- MEPS greatly help to increase market share of high efficiency motors

Source: IHS 2014
As one of the operation of The Energy Conservation Law, the Top runner program was applied to industrial induction motors from 2015 in Japan.

Japanese Energy Conservation Law was established in 1979, against oil crisis.

Unlike MEPS set the minimum efficiency for the market, Top Runner set the highest efficiency level in the market as the objective.

The motor manufacturers & importer should report to Ministry of Economy, Trade and Industry (METI) the average efficiency during each fiscal year.

China is planning to conduct the similar Top Runner Program for motors.
2 High efficiency motor solution
High Efficiency Motor Solutions

<table>
<thead>
<tr>
<th>IE class</th>
<th>Induction design</th>
</tr>
</thead>
<tbody>
<tr>
<td>IE2</td>
<td>Induction design</td>
</tr>
<tr>
<td>IE3</td>
<td>PM, SR, PMSR, DOL SR, DOL PM</td>
</tr>
<tr>
<td>IE4</td>
<td>PM, SR, PMSR, DOL SR, DOL PM</td>
</tr>
<tr>
<td>IE5</td>
<td>PM - Permanent (NdFeB) magnet motors, SR - Synchronous Reluctance (SynRM), PMSR - Permanent Magnets assisted SR (SynRM²), DOL SR - Direct on line SynRM (DOL SynRM), DOL PM - Direct on line PM</td>
</tr>
</tbody>
</table>

PM – Permanent (NdFeB) magnet motors  
SR – Synchronous Reluctance (SynRM)  
PMSR – Permanent Magnets assisted SR (SynRM²)  
DOL SR - Direct on line SynRM (DOL SynRM)  
DOL PM – Direct on line PM
# High Efficiency Motor Solutions

![Motor Diagrams](IPMView.png)

<table>
<thead>
<tr>
<th></th>
<th>Permanent Magnet</th>
<th>Induction</th>
<th>Switched Reluctance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rotor</strong></td>
<td>- Interior PM</td>
<td>- Aluminum Bars</td>
<td>Only steel laminations</td>
</tr>
<tr>
<td></td>
<td>- Surface PM</td>
<td>- Copper Bars</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(PM’s usually rare earth)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Stator</strong></td>
<td>- Distributed Wind</td>
<td>Distributed Wind</td>
<td>Concentrated Wind</td>
</tr>
<tr>
<td></td>
<td>- Concentrated Wind</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1 coil/tooth)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: David Fulton, Construction and Functional Differences, SAE 2011 Powertrain Electric Motors Symposium
Permanent Magnet Motor

Pros

- Higher energy density
- Flatter efficiency curve compared with Induction motors

Cons

- Difficult to design: electromagnetic (performance)
- Mechanical (integrity & strength)
- Manufacturing difficulties
- Demagnetizing of magnets
- Higher cost
Switched Reluctance Motor

Pros
- Construction simpler and robust
- No PM or AL/Cu in rotor
- Concentrated winding without end turn length which use less copper wire
- Even more flatter efficiency curve than PM motors, which means it can work in a larger range

Cons
- Noise, torque ripple which is inherent and can’t be eliminated
- Small air gap is needed for high energy density
Induction Motor

Pros
- Simpler and Rugged structure
- Lower material and sensor
- Higher power density without torque ripple and noise
- Mature control technology
- Stability and reliability

Cons
- Comparative lower efficiency
- Not a broad range for high efficiency
Structure of different types of motors

China AC Motor Market, New Built (kW), 2013

- **High Voltage Motor**: 2.8%
- **Small & Medium Induction Motor**: 73.9%
- **Lower Voltage Large Motor**: 1.8%
- **PM Motor**: 0.1%
- **Reluctance Motor**: 21.4%

**High voltage Motor**: >6kV
**Small & Medium Motor**: 0.75 – 375 kW
# Types of loss of induction of motors

<table>
<thead>
<tr>
<th>Type</th>
<th>Proportion (%)</th>
<th>Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper Loss</td>
<td>35-45</td>
<td>Size of stator conductor; coefficient of winding resistance</td>
</tr>
<tr>
<td>Rotor Loss</td>
<td>20-25</td>
<td>Size of the rotor cage; coefficient of conducting bar</td>
</tr>
<tr>
<td>Stray load loss</td>
<td>10-15</td>
<td>Manufacturing process; slot combination; air gap size</td>
</tr>
<tr>
<td>Iron Loss</td>
<td>20-25</td>
<td>Magnetic conductivity of iron core material; loss coefficient</td>
</tr>
<tr>
<td>Mechanical Loss</td>
<td>5-10</td>
<td>Efficiency of fan; loss of bearing</td>
</tr>
</tbody>
</table>
Methods to reduce loss and improve efficiency

- Increase effective materials and reduce winding loss and iron loss;
- Adopt better magnetic materials and processes to reduce iron loss;
- Reduce fan and fluid loss;
- Reduce stray loss through design and process improvements;
- Improve casting process and reduce rotor loss;
- Apply computer optimization design and reduce loss and improve efficiency;
Copper Rotor Motor
Copper Rotor Motor

With Copper Rotor:

- Improve Efficiency
- Lower Temperature
- Reduce Motor Size
- Less Weight
- Anti Corrosion
Increase motor efficiency

2.2 kW, 4 Poles, 50Hz motor

Al rotor -> Copper rotor

Efficiency:  83%-> 86.5%

IE2 -> IE3

The smaller motors are, the more efficiency improvement by using copper rotors.
Nan Yang Motor developed IE5 efficiency induction motor;
It is the highest efficiency induction motor ever reported in the world;
Attended the global competition for high efficiency motor held by SEAD, the initiative of Clean Energy Ministerial.

<table>
<thead>
<tr>
<th>Type</th>
<th>Entry Efficiency for Competition</th>
<th>Real Efficiency</th>
<th>Weighted Average Efficiency</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>YZTE4-112M-4P 4kW 415V 50Hz</td>
<td>91.20%</td>
<td>91.37%</td>
<td>91.16%</td>
<td>Australia</td>
</tr>
<tr>
<td>YZTE4-160M-4P 11kW 415V 50Hz</td>
<td>93.50%</td>
<td>93.99%</td>
<td>93.30%</td>
<td>Australia</td>
</tr>
<tr>
<td>NSPE184T-4P 5HP 460V 60Hz</td>
<td>91.10%</td>
<td>91.90%</td>
<td>91.22%</td>
<td>North America</td>
</tr>
<tr>
<td>NSPE254T-4P 15HP 460V 60Hz</td>
<td>93.60%</td>
<td>93.62%</td>
<td>93.95%</td>
<td>North America</td>
</tr>
</tbody>
</table>
Increase motor efficiency

**North American Regional Winners**

- **5 HP Induction (60 Hz)**
  - Nanyang Explosion Protection Group Co. Ltd.
  - 91.1% efficiency at full load
  - **NSPE184T**

- **15 HP Induction (60 Hz)**
  - Nanyang Explosion Protection Group Co. Ltd.
  - 93.6% efficiency at full load
  - **NSPE254T**
The copper rotor IE5 induction motors were awarded the Global Efficiency Medal which was issued officially during the Clean Energy Ministerial in May, 2015.
Increase motor efficiency

IE class

IE2
Induction design

IE3
Induction design

IE4
Induction design

IE5
PM, PMSR, DOL SR, DOL PM
Induction design
Induction design

PM – Permanent (NdFeB) magnet motors
SR – Synchronous Reluctance (SynRM)
PMSR – Permanent Magnets assisted SR (SynRM²)
DOL SR - Direct on line SynRM (DOL SynRM)
DOL PM – Direct on line PM
Reduce motor physical size & cost

### Cu Vs. Al for 75KW-2 Motor

<table>
<thead>
<tr>
<th>225M3-2 75kW</th>
<th>Efficiency (%)</th>
<th>Frame Size</th>
<th>Cu Density(kg/kW)</th>
<th>Steel in Stator (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper Rotor</td>
<td>94.91%</td>
<td>225</td>
<td>0.98</td>
<td>300</td>
</tr>
<tr>
<td>Al Rotor</td>
<td>93.8%</td>
<td>280</td>
<td>0.62</td>
<td>375</td>
</tr>
</tbody>
</table>

- **Higher Efficiency**
- **Less Material**
- **More Compact**

With Copper Rotor - High Energy Density
Increase installed motor efficiency

Efficiency improvement opportunity exits in installed motors to improve energy efficiency by replacing the current Al rotor with Cu rotors.

2.2 kW, 4 Poles, 50Hz motor
Al rotor -> Copper rotor
Efficiency: 83%-> 86.5%*
IE2 -> IE3

<table>
<thead>
<tr>
<th></th>
<th>Cost</th>
<th>Difficulty</th>
<th>Reliability</th>
<th>Skill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Re-winding</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Change Lamination</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Change Rotor</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>
Simulation results of Y-series motor with power of 0.55 KW - 22 KW including 2, 4, 6 pole motors for efficiency improvement.
3 High efficiency motor case study
## Rebuilt Motor Case Study

<table>
<thead>
<tr>
<th>7.5 kW 4 Poles Motor</th>
<th>11 kW 4 Poles Motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency Grade: IE1 -&gt; IE3</td>
<td>Efficiency Grade: IE1 -&gt; IE3</td>
</tr>
</tbody>
</table>

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![Motor Image](image-url)
Economical analysis by taking 7.5 KW motor as an example:

- The price of new Y-series 7.5KW motor is RMB 1,900;
- The price of copper rotor of 7.5 KW motor is RMB 750;
- The price of new IE3 7.5 KW motor is RMB 3,500 – 4,000;
- The cost to replace rotor is RMB 250 (Excluding shaft and bearing);
- The cost is only RMB 1,000 to refurbish an old motor to a IE3 motors without even count in the old AL rotor value;
- The motor efficiency could be improved by 3.4%, from 87% to 90.4%;
- The electricity consumption could be decreased from 34,483KWh to 33,186KWh, which means 1,297 KWh, valued RMB 1,297. (Assumed that the annual working time is 4,000 hours);
- The pay back period is 0.77 years, which is much less than changing motors;
High efficiency motor case study

The 30kW-6 IE4 motor was tested in the Sheng Li Oil field
High efficiency motor case study

The first trial is to replace the existing IE2 motors
The replaced motor efficiency was 91.5%
CMR IE4 motor efficiency is 94.3%
The nominal efficiency improvement is 2.8%
The IE2 motors consumed 4.569 kW·h/h on average, or 109.66 kW·h per day.

The IE4 CMR motors consumed 4.22 kW·h/h on average, or 101.28 kW·h per day.

The actual energy saving is therefore 7.64% \(\frac{(109.66-101.28)}{101.28}\), much higher than the 2.8% nominal efficiency improvement.

The average working load for this motor installation is lower than 40%.

The annual energy saving valued RMB 1,540.

The pay back period is less than 3 years.
4 Discussion
Discussion about Singapore Standard

Whether or not Singapore need energy standard for motors?

If yes, what kind of standard is needed?
Thank you for your attention!

Email: daniel.liang@copperalliance.asia