CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION

Induction motors account for approximately 50% of the overall electricity use in industrialized countries. In the agricultural and commercial sectors also, power consumption by ac motors is quite substantial. On an average, the energy consumed by a motor during its life cycle is 60-100 times the initial cost of the motor. Therefore efficiency of the motor is of paramount importance both during selection and operation. High electrical conductivity of copper in the rotor structure of a squirrel cage induction motor can achieve a reduction in overall energy losses of around 11%-19% and a consequent increase in energy efficiency. This chapter reviews the comparison of various rotor construction techniques, implementation of Die-cast Copper Rotor Motor, Efficiency improvement, Energy saving potential, adoption of DCR Technology in India and the comparisons of various efficiency standards. The needs and tasks regarding the technology are also discussed.

2.2 LOSSES IN AN INDUCTION MOTOR

The electric motor has a long history of development since its invention by Nicola Tesla in 1888, with earlier effort aimed at improving power and torque at reduced cost. The need for higher efficiency became apparent during the late 1970’s and by the early 1980’s. At last, one British manufacturer started to market a premium range of motors with improved efficiency. Now the trend is towards the design and manufacturing of motors with a small improved efficiency at a small extra cost (Chiricozzi et al 1997).
It is needless to state that, this extra cost could be realized in the savings in the operating cost.

Since, efficiency being the ratio of the amount of work produced i.e., output power to the amount of energy consumed i.e. input power, the Induction motor losses are the difference between input and output powers, and can be classified into five categories (Boglietti et al 2003).

1. Iron losses: magnetic losses in the core laminations, hysteresis, and eddy current losses, labeled as $P_c$.

2. Stator $I^2R$ resistance losses: current losses in the stator windings, $P_s$.

3. Rotor $I^2R$ resistance losses: current losses in the rotor bars and end rings, $P_r$.

4. Windage and friction losses: mechanical drag in bearings and cooling fans, $P_w$.

5. Stray load losses: mainly iron and joule losses, also called additional load losses, increasing with load and result from a multitude of sources, such as surface and slot conditions, leakage flux, etc. They are normally difficult to measure and calculate, $P_l$.

Relative proportion of five loss components of an induction motor is dependent on the motor size. Taking the 4-pole motor as an example, loss distribution is shown in Figure 2.1 (Austin H. Bonnett 1999). Accordingly, engineers from SIEMENS provide the typical loss distribution, shown in Figure 2.1 in their recent research work concerning the next generation motors and the areas for improvements of the efficiencies are shown in Figure 2.2 (Fuchslichs et al 2008). Furthermore, they analyzed all the different factors and evaluated their influences to motor performance and different dependencies between each other. The individual factors have to be
carefully investigated due to the inter dependence with each other. Sometimes
an increase obtained from on one such factor may not contribute to a resultant
improvement in efficiency. In addition, the cost and commercial impact have
to be considered.

Figure 2.1 Loss distribution for a 4-pole induction motor

Figure 2.2 Impact of the possible areas for improving the motor performance
For improving the efficiency of an induction motor, various attempts are made to reduce the Watt losses in the motors and this study has been taken up primarily to reduce rotor copper loss using DCR technology.

2.3 ROTOR CONSTRUCTIONAL METHODS

2.3.1 Induction Motors with CFR

In the early days, ‘copper bars’ were used as rotor conductors which were inserted into rotor slots and brazed to the copper end rings to form the squirrel cage rotor. Such fabricated copper rotor construction is dating back to the 1920’s (Finley et al 2001).

The fabricated copper bar rotor is constructed utilizing the following steps:

1. Stack rotor punchings on a stacking mandrel.
2. Hold punchings together along with end heads. Clamp assembly together.
3. Insert shaft into hot core, lock core in place without welding.
4. Insert bars.
6. Braze end connectors to bars.
7. Turn and balance rotor assembly.

Some of the conditions to be satisfied to assure that the highest quality and reliability is obtained when manufacturing CFR are:

- Consistent clamp pressure applied uniformly to laminations will minimize the thermal sensitivity of the rotor assembly.
While the clamp pressure should be consistent, it should not be excessive. Excessive clamp pressure increases the core losses.

- The end connectors should be induction brazed to the bars. In addition, the temperatures of both the end connectors and bars should be continually monitored throughout the brazing process. Induction brazing, results in much more consistent temperature distribution than with flame brazing. Additionally, it heats the end connector, which in turn heats the bars. This will minimize the amount of heat that the rotor core will have to absorb. Both of these mechanisms will minimize the amount of residual stresses present in the end connectors, bars, or braze joint. In addition, the rotor will exhibit less thermal sensitivity than a flame-brazed rotor.

- A loose rotor bar is the number one cause of CFR failure. Because during starting period, the rotor bars oscillate at

  \[
  \text{Rotor Bar Vibration Frequency} = 2 \times \% \text{ Slip} \times \text{Line Freq.}
  \]

  The rotor bars vibrate as a consequence of high current forces (Bredthauer et al 1994).

- End heads must be designed in such a way that they exert constant clamping force. Even if the lamination clamping portion of the end head is axially displaced, it will exert a constant clamping force on the rotor punchings. The rotor will grow thermally, if the end heads are overly rigid and they will exert too much clamping force, resulting in increased core losses.
**2.3.2 Induction Motors with DAR**

As squirrel cage motors started dominating the Industrial scene, Research and Development got on to eliminate or minimize the rotor problems of the brazed construction. Then, as a technology improvement and enabling mass and defect free production at lower cost, the die cast Aluminium rotors got developed totally eliminating bars insertion, end rings brazing and so on. This successful development was readily adopted all over and today it dominates the entire world of LT squirrel cage induction motors.

The aluminium rotor is constructed utilizing the following steps:

1. Stack rotor punchings on a stacking mandrel.
2. Insert punching / mandrel stack in end connector mold.
3. Die cast (i.e., inject aluminium) rotor.
4. Insert shaft into hot rotor core.
5. Turn and balance rotor assembly.

The basic process has been unchanged since its inception. Till 1970, Squirrel cage induction motors up to 250 HP were designed with Aluminum Die-cast rotor having laminated steel as the core material. After 1970, as the cost of electricity went up, it became more expensive to use less efficient motors (Hartung 1994 and Lie et al 1995). It has been illustrated...
that significant improvement in motor efficiency can be achieved by substituting Aluminum with Copper (Paris et al 2003).

2.3.3 Induction Motors with DCR

The resistivities of copper and aluminium for circular mil, per foot at 20°C are 10.37Ω and 16.06Ω respectively. Hence, for the same current requirement, the substitution of copper for aluminium results in \((16.06 - 10.37)/16.06 = 35.4\%\) reduction in resistance loss (John S. Hsu et al., 2000). The overall efficiency of the machine gets increased by replacing the aluminium material in the rotor with copper. This idea leads to implementation of DCR technology. A DCR construction does not differ significantly from DAR construction. The DCR imposed manufacturing challenges that have been only recently met.

In essence the manufacturing details for DCR are identical to DAR. The increased temperatures and pressures required to die cast copper as shown in Table 2.1. It shows that, DCR requires higher temperatures and pressures, compared to DAR’s.

**Table 2.1 Parameters comparison of DAR with DCR**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Aluminium</th>
<th>Copper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>1200 F</td>
<td>2000 F</td>
</tr>
<tr>
<td>Shot pressure</td>
<td>2000 PSI</td>
<td>6500 PSI</td>
</tr>
<tr>
<td>Clamp pressure</td>
<td>2400 PSI</td>
<td>7800 PSI</td>
</tr>
</tbody>
</table>

A large number of literatures have been published in the past few years on the benefits from the performance of the induction motor by using copper as the conductive material in the rotor (Dale T. Peters et al 2002a, John G. Cowie et al 2003). These researches consistently show that the higher
electrical conductivity of copper compared to aluminum results in higher electrical energy efficiency of the machine by reduction in rotor $I^2R$ losses and often through reduced stray load and windage and friction losses as well. More efficient machine necessarily has lower slip and thus runs at a slightly higher speed. But, when copper is simply substituted for aluminum, starting or locked rotor torque is reduced and starting currents are higher. This can be a problem in many applications. Recently, efforts to improve the starting characteristics of the motor and to generally accommodate the design to better utilize the high conductivity copper in the squirrel cage have been undertaken (Kirtley et al 2004).

The DCR is constructed utilizing the following steps:

1. Stack rotor punching on a stacking mandrel
2. Insert punching /mandrel stack in end connector mold
3. Die cast (i.e., inject copper) rotor
4. Insert shaft into hot rotor core
5. Machining the rotor in order to remove the ingates resulting from the injection of mould material.
6. Perfect balancing of the rotor assembly.

Therefore, it is well known that the incorporation of copper for the rotor bars and end rings in the place of aluminium would result in attractive improvements of motor efficiency (Dale T. Peter et al 2003a). In addition to increase in efficiency, the copper adjusts with much more stability to changing loads, especially at low speeds and at low frequencies. The temperature rise in the rotor is very less which has the advantage of fewer repairs and re-windings. So, the life of the motor is increased and the
maintenance cost is decreased. Due to the above advantages the DCR is preferred over a CFR.

2.3.4 Comparisons of All Types of Rotor Constructions

A study was carried out, to present four different rotor constructions (Die-cast Aluminum “DAR”, Die-cast Copper “DCR”, Fabricated Aluminum bar “AFR” and Copper Fabricated Rotor “CFR”) concerning their manufacturing process and properties, rotor stress, electrical performance, rotor bar heat capacity and so on. The study summarized the different facets and provided a comparison shown in Table 2.2, where the comparison is relative one, with a lower number indicating an advantage (Craggs 1976 and Finley et al 2001).

Table 2.2 Various Facets Comparison for Different Rotor Construction

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>DAR</th>
<th>AFR</th>
<th>DCR</th>
<th>CFR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Efficiency</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Design Flexibility</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Size</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Tooling/Capital</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>High Inertia/ Multiple Restart</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

The fabrication costs are more than Die-cast technology due to the labor-cost. The Die-cast as a state-of-the-art technology makes an increase of rotor size each year due to the manufacturing advancements. The previous challenges of die casting copper, which has higher temperatures and pressures compared with die casting aluminum, have been solved with the development
of a die casting process using nickel-base alloy die inserts operated at elevated temperature. Substantial progress in understanding and managing the porosity problem, characteristic of high-pressure die-casting has also been pointed out (Dale T. Peters et al 2002b and 2003b). The integrity and reliability of DCR is just as good as in DAR. The primary reason why DCR’s are not common place yet, is because it requires specialized equipment (investment) and know-how in this field.

Active development of the Die-cast copper rotor motor begun in 1997 has now resulted in a growing market with about 2,50,000 units in service and is still growing at a rapid rate. The DCR technology has been a significant effort of the world copper industry through the International Copper Association Ltd (ICA) managed by the Copper Development Association (CDA). The DCR project has been conducted jointly with die casters, motor manufacturers in all major motor markets worldwide and academia. A sizeable data bank of motor performance test results exists now, illustrating the several advantages of using the DCR.

2.4 EFFICIENCY OF DCR MOTOR


An economic comparison between aluminum and copper squirrel cages was also made in the previous literatures (Poloujadoff et al 1995). They concluded that when the initial cost is considered, the initial price of copper cages is higher by 15%, but the savings in operating losses is seven or eight times the increase in price. The use of DCR is one method enabling motor efficiency to be increased as much as 1.5 % - 3 % above what is currently
possible using Die-cast aluminium rotor with out changing any other parameters. These efficiency increases are expected to be higher on small motors, decreasing 0.55% on larger designs.

Significant efficiency improvements could be attributed to adding more copper to the windings, upgrading the laminations to premium-grade low-loss steel, enhanced lamination designs, precision airgap between rotor and stator, and reducing fan and other losses in the motor. Furthermore, engineers from Baldor reviewed, design and production techniques, which are required to fulfill the NEMA Premium efficiency standard, and introduced new research being done to further improve efficiency level, including better lamination steel slot designs and Die-cast copper rotors (John Malinowski et al 2004). The efficiency level is upgraded mainly by reduction in stray load loss and core loss as well as, some reduction in windage and friction losses. It has been proved that DCR, together with optimized laminations could greatly help to achieve higher efficiency economically (Koo et al 2007). A feature to be noted is that, a reduction windage loss, which is normally accomplished by reducing the external fan diameter, will greatly improve the efficiency of the motor. Meanwhile the tradeoff is temperature rise in the winding, which will lead to some increase in the stator resistance loss. Therefore, the designers should always keep in mind to find a balance among the diverse losses so that the overall motor performance is optimized.

2.4.1 Problems in DCR Technology and Solutions

The manufacturing details for DCR are identical to DAR. The melting point for aluminum alloys is in the 676°C (1250 F) range. The material used for the rotor’s die-casting mold is often H-13 tool steel, which is not highly stressed at these temperatures. Die life can be in the thousands of rotors depending on die complexity. Copper melts at 1083°C (1982 F). This high melting temperature results in failure of conventional die steels by
thermal fatigue of the surface ("heat checking") in less than 100 shots (Parasiliti et al 2004). The solutions to tooling issues related to die-casting of copper have been identified and the tool life can be considered acceptable now (Dale T. Peters et al 1999 and Sakhuja et al 2004). THT Presses, Inc has demonstrated economical means to die cast copper utilizing equipment, developed specifically for Copper Rotors Cast Vertically task (Dale T. Peters et al 2002c and 2002d). The details about the THT approach are discussed. The DCR is now being employed by several manufacturers as a cost-effective way to achieve EPAct and Eff1 efficiency levels or to reach or exceed NEMA Premium levels (Thieman et al 2007). SEW Eurodrive and Siemens AG in Germany, in particular, have made extensive investments to optimally design the motor while copper in the rotor. The comparison or test for different power ratings of motors (Most of these motors are SEW’s DT/DTE and DV/DVE series) have been discussed, together with some summaries about the achievement and optimal designs (Brush et al 2003; Kimmich et al 2005; Stark et al 2005 and Kirtley et al 2007). Consequently, from the studies above, it appears that the process of die casting copper rotors can be reliable and robust. The motor total energy losses could be reduced by 15%~23%. Further improvements in process and rotor design such as optimization of the steel laminations and slot shape should extend copper’s lead in efficiency over aluminum. (Update: Copper motor rotor (2001), Copper Development Assoc., New York NY).

The cost of DCR is higher by about 15 % as compared to the motors of existing efficiency levels when replacing aluminium by copper die casting without any other change. But the extra cost may prove to be nominal. A copper rotor in a 15 HP motor could result in a 1.2% efficiency gain and difference in retail list price of $10 to $12 per motor. For a $ 900 to $1,500 motor, the payback may be measured in months. In order to offset the cost of the DCR following solutions are identified.
• Development of dedicated motor design and configurations of laminations optimized for DCR’s.

• Identifying and sourcing of appropriate electrical steel for the core packs.

• For motors with DCR’s there is a need for a more perfect technology of melting and die-casting. Then only mass-production of rotors at an affordable cost is possible.

2.4.2 Advantages of DCR Technology

CDA-USA and ICA conducted many studies on the advantages of DCR Technology. They came to a conclusion that improved efficiency at a small increase in cost or alternatively reduced cost for the prevailing efficiency levels, reduced temperature rise during operation, reduced manufacturing cost and reduced weight could be achieved when applying Die-cast copper instead of aluminum. Improving motor efficiency will bring significant energy savings and improved conductor bar and end ring consistency reduces the maintenance cost. Cooler running motor means longer motor life (www.copper-motor-rotor.org).

2.4.3 Technical Issues

2.4.3.1 Starting torque

The copper rotor motor has the advantage of high torque at running speed and its starting torque is lower than in aluminium rotor motors (85 Nm instead of 90 Nm in a 5.5 kW motor), which is beneficial for gearbox life. In applications where lower starting torque is a problem, a modified design of the rotor slot offers a solution. It is found that the measured inter-bar resistance is lower in DCR than in cast aluminium rotors. This leads to a
reduced pull-out torque and increased stray-load losses (Alexander Stening et al 2008). For a continuous rated motor this cannot be a problem.

2.4.3.2 Higher start-up current

The higher conductivity of copper, i.e. its lower electrical resistance, will result in a slightly higher start-up current as the slot area remains the same. (7.0 times the nominal current for a 7.5 kW copper rotor motor, instead of 6.0 times for its aluminum counterpart). Soft starter can be used to avoid that this higher current aspects of the electricity system. Also, since motors are increasingly being driven by inverters, inrush and starting currents become less of an issue (Chiricozzi et al 2004).

2.4.3.3 Rotor inertia

The higher rotor weight increases rotor inertia. This improves the motor's efficiency, but can be a problem in certain applications - for example, motor's that frequently switch direction at high speed. A survey among manufacturers, users, researchers, engineers and members of associations, revealed that the copper rotor motor has now become an accepted technology (82%). A majority assess the technology ready for mass production (74%). Higher efficiency (42%), lower heat production (24%) and reduced cost (11%) are seen as major advantages. The main application domain is for industrial low voltage induction motors of 1 up to 100 kW, but the technology also has potential for fractional kW motors (De Keuleneer 2006).

2.5 HISTORY OF MOTOR EFFICIENCY STANDARDS

During the year 1992, Congress passed the Energy Policy Act (EPAct), which granted the USA Department of Energy (DOE), the authority to set minimum efficiency standards for certain classes of electric motors. EPAct rules for motors became effective from Oct. 24, 1997. EPAct did not
create new efficiency performance levels but rather established a minimum efficiency level in US. Upgrading motors from pre-EPAct level to EPAct efficiency levels increases motor efficiency by 2.3%. In 1994, NEMA issued definitions for “energy efficient” motors. These motors must have nominal efficiencies meeting or exceeding NEMA MGI. EPAct covers general-purpose motors rated from 1 to 200 HP; 2-, 4- and 6-pole (3600, 1800 and 1200 rpm), horizontal, T-frame, single speed, continuous duty, 230V, 460V or 230/460V, NEMA Designs A and B. Efficiencies of these so-called "EPAct motors" are from one to four percentage points higher than the previous "standard-efficiency" motors.

NEMA revised MGI-1993 to include the specification of a design E motor and they were specified to satisfy the International Electro technical Committee (IEC) standards. These standards allow motors to be designed for higher efficiency with lower restrictions on torque and starting current than design B motors (NEMA standard publishing 1993).

In the year 1996, the Consortium for Energy Efficiency (CEE) launched its Premium Efficiency Motors Initiative. Motors meeting the CEE standards are designated as “CEE Premium Efficiency” which is 0.8-4% more efficient than EPAct motors.

The European Union (EU) and Committee of European Manufacturers of Electrical Machines and Power Electronics (CEMEP) have developed a motor efficiency classification scheme for motors during the year June 2000. Motors covered by this agreement are defined as totally enclosed fan ventilated (IP 54 or IP 55) three phase A.C. squirrel cage induction motors in the range of 1.1 to 90 kW, with 2- or 4-poles, rated for 400 V-line, 50 Hz, S1, Duty Class, in standard design. Motors sold in Europe had an efficiency marking, designated as EFF1 for their best efficiency, and EFF2 for standard efficiency. There is a lower EFF3 level family of motors that the EU is
discouraging from being manufactured. Motor efficiency of EFF1 is comparable to that of U.S. EPAct efficiency values (Bertoldi et al 2000). This agreement should stimulate the Manufacturers in the development of new ranges of high efficiency motors that requires an accurate motor design, the adoption of new materials (e.g. premium steel) and Innovative technologies (e.g. copper rotor cage die-casting) (Parasiliti et al 2002).

As a replica to the US position, the International Electrotechnical Commission (IEC) proposed a standard referring to the energy efficiency classes for electric motors (Tudorache et al 2009). By this standard IEC intends to keep only the old Eff2 (IE1) and Eff1 (IE2) energy efficiency classes (giving up the standard class Eff3) and to add another two classes with even higher efficiencies, i.e., Premium Efficiency (IE3) and Super Premium Efficiency (IE4). The replacement of standard electric motors with IE2 or even higher energy efficiency class machines could entail important energy savings (up to more than 3% of the total electric energy consumed worldwide) and significant reduction of greenhouse gas emissions (Stanciu et al 2005).

The Government of India has already taken some important steps to introduce policy measures in the form of the Energy Conservation Act 2001 to encourage the use of Energy Efficient products. The Act has notified 15 Industry sectors under the schedule of Energy Intensive Industries. To compliment the market transformation, a standard and labeling program has brought about a regulation on Minimum Efficiency Performance Standards (MEPS) for energy intensive equipment including, industrial motors.

Based on the CEMEP classifications, the Indian Electrical and Electronics Manufacturers Association (IEEMA) developed IEEMA-19:2000. This formed the basis for the development of IS: 129615-2004 for Energy Efficient Motors by the Bureau of Indian Standards. Table 2.3 shows the
comparison of efficiency levels as per different standards for a few 3 phase / 4 pole ratings.

On the Design and Development front, different measures are being explored to achieve higher efficiencies in the motors in a cost effective way. The International Copper Association along with the Common Fund for Commodities and the United Nations Development Programme (UNDP), the United Nations Development Programme - Global Environment Facility (UNDP-GEF), is setting up an Enabling Technology Center (ETC) primarily to commercialize the DCR technology useful for building cost effective High Efficiency Motors.

In May 2001, NEMA announced a new motor efficiency standard- NEMA Premium™ efficiency. These motors are required to have 20% lower losses than EPAct motors. NEMA Premium™ applies to single-speed, polyphase, 1 to 500 HP, 2-, 4-, and 6-pole (3600, 1800 and 1200 rpm) squirrel cage induction motors, NEMA Designs A or B, 600V or less, (5 kV or less for medium voltage motors), and continuous rated. In the month of June 2001, NEMA and CEE agreed to align the NEMA Premium™ and the CEE Premium EfficiencySM efficiency levels to co-promote the standard.

After NEMA released the General Specification for Consultants, Industrial and Municipal: NEMA Premium® Efficiency Electric Motors (600 Volts or Less) in 2003, most of the major motor manufacturers put more and more effort to meet or even to exceed the NEMA Premium® Efficiency requirements. The intent of this specification is to outline the minimum requirements for three-phase AC induction motors labeled with “Premium®” applied to municipal and industrial applications for operation on voltages 600 volts or less, rated 500 horsepower or less, operating more than 2000 hours per year at greater than 75 percent of full load.
Table 2.3 Comparison of Efficiency Levels as per Different Standards for a few 3 Phase / 4 Pole Ratings

<table>
<thead>
<tr>
<th>Rating (kW)</th>
<th>EPAct</th>
<th>IEEE 841.2004</th>
<th>CEMEP / IEMA – 19/ BIS 12615</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>EFF1</td>
</tr>
<tr>
<td>0.75</td>
<td>82.5</td>
<td>84.0</td>
<td>82.5</td>
</tr>
<tr>
<td>1.1</td>
<td>84.0</td>
<td>85.5</td>
<td>83.8</td>
</tr>
<tr>
<td>3.7</td>
<td>87.5</td>
<td>-</td>
<td>88.3</td>
</tr>
<tr>
<td>7.5</td>
<td>89.5</td>
<td>90.2</td>
<td>90.1</td>
</tr>
</tbody>
</table>

The efficiency values of the same rating machine, when tested using the different standard conventions, can vary by several percentage points, which is shown in Figure 2.3.

While efficiency values for NEMA Premium™ has been indicated in the Table 2.3, the forgoing discussions however will be dealing only with motors up to EFF1 level. A mention has been made at the end of this chapter on Premium efficiency of a few leading international manufacturers who utilized DCR, besides other improvements.

2.5.1 International Standards for Motor Efficiency Assessment

It is critical that, motor efficiency comparisons to be made using a uniform product testing methodology. There is no single standard efficiency testing method that is used throughout the industry. The most common standards are:

- IEEE 112 -1984 (United States)
- IEC 34-2 International Electro technical Commission (Europe)
- JEC - 37 (Japanese Electro technical Committee)
- BS - 269 (British)
- C-390 (Canadian Standards Association)
- ANSI C50.20 same as IEEE 112 (United States)
- IS 12615 – 2004 read with IS 4889 – 1968 (India)

The common practice for testing of motor’s in the 1 to 125-HP size range is to measure the motor power output directly with a dynamometer. The standards for testing of motor efficiency differ primarily in their treatment of stray load losses (Mzungu et al 2007). The Canadian Standards Association (CSA) methodology and IEEE 112 - Test Method B determine the stray load loss through an indirect process by measuring mechanical output (IEEE Std 112-1996, ‘Standard Test Procedure for Polyphase Induction Motors and Generators). The IEC standard assumes stray load losses to be fixed at 0.5 percent of input, while the JEC standard assumes there are no stray load losses (Anibal T. de Almeida et al 2002 and Boglietti et al 2004).

**Table 2.4 Efficiency Results of a given Motors using Various Testing Standards**

<table>
<thead>
<tr>
<th>Standard</th>
<th>Full Load Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7.5 HP</td>
</tr>
<tr>
<td>Canadian (CSA C390)</td>
<td>80.3</td>
</tr>
<tr>
<td>United States (IEEE – 112, Test Method B)</td>
<td>80.3</td>
</tr>
<tr>
<td>International (IEC – 34.2)</td>
<td>82.3</td>
</tr>
<tr>
<td>British (BS – 269)</td>
<td>82.3</td>
</tr>
<tr>
<td>Japanese (JEC – 37)</td>
<td>85.0</td>
</tr>
</tbody>
</table>

The efficiency of a motor, when tested using the different standard conventions, can vary by several percentage points. Table 2.4 shows a full load efficiency test results of 7.5 HP and 20 HP motors using different international standards.
Although the IEC method is easy to use, it overestimates efficiencies by up to 2% for motors smaller than 10 kW and underestimates them slightly for motors larger than 700 kW. The IEEE is more accurate, but is not perfect either, because it relies on the accuracy of the torque transducer.

Emerging technologies push the efficiency into new heights. However, so far there is no formal standard available concerning the so-called “Super Premium Efficiency” level. Besides, many different energy efficiency standards for cage induction motors are already in use with new classes currently being developed, which make it difficult for manufacturers to design motors for a global market and for customers to understand differences and similarities of standards in different countries. Hence, IEC has proposed a project regarding new international motor efficiency classification system IEC 60034-30 that can eventually include the new Super Premium efficiency level. IEC 60034-30 (Ed. 1.0) states efficiencies respectively, for both 50Hz and 60Hz and integrates different well-known efficiency standards with its own Energy Efficiency Classes as IE4, IE3, IE2 and IE1, shown in Table 2.5.

Table 2.5  Integration of different global standards according to IEC 60034-30

<table>
<thead>
<tr>
<th>Efficiency Levels</th>
<th>IEC60034-30 (Ed. 1.0)</th>
<th>Corresponding to other standards</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>50Hz</td>
</tr>
<tr>
<td>Super Premium Efficiency</td>
<td>IE4</td>
<td>Around 15% reduced losses based on IE3</td>
</tr>
<tr>
<td>Premium Efficiency</td>
<td>IE3</td>
<td>15% - 20% reduced losses based on IE2</td>
</tr>
<tr>
<td>High Efficiency</td>
<td>IE2</td>
<td>CEMEP –EU eff1</td>
</tr>
<tr>
<td>Standard Efficiency</td>
<td>IE1</td>
<td>CEMEP –EU eff2</td>
</tr>
</tbody>
</table>
As shown below in Figure 2.3, it is observed that IE4 identifies the motor efficiency approximately from 88% to 97% compared with IE3’s 84% to 96% in the same output power scope (Conard U. Brunner 2007). One aspect needs to be clearly pointed out is that these advanced motors for IE4 usually require power electronics (frequency converters) to operate, and since grid frequency and the number of poles of converter-fed machines are not directly related to speed these motors are typically rated for a speed range and classified by torque rather than power, as described in IEC 60034-30 Ed. 1.0 draft.

![Figure 2.3 Different efficiency levels comparison by CEMEP](image)

Figure 2.3 Different efficiency levels comparison by CEMEP

As one can see in Figure 2.3, there is approximately 1% difference between IE1 and eff2, also between IE2 and eff1, which is due to the fact that in the new testing standard, the additional (stray) load losses are determined from a test, whereas in CEMEP they were considered as flat 0.5% of input power and that is why the curve is called “Devalued curve”. In the latest edition of IEC 60034-30 (2008-04-30), the IE4 efficiency class could be defined by reducing the losses by 15% relative to IE3. Then, the efficiency for different output power rating could be calculated as:
\[ P_{\text{loss IE3}} = \frac{P_{\text{Rated output}}}{\eta_{\text{IE3}}} - P_{\text{Rated output}} \]

\[ P_{\text{loss IE4}} = (1 - 15\%) \cdot P_{\text{loss IE3}} \]

\[ \eta_{\text{IE4}} = \frac{P_{\text{Rated output}}}{P_{\text{Rated output}} + P_{\text{loss IE4}}} \times 100\% \]

(2.1)

A more detailed comparison is shown in Figure 2.4. The draft standard also indicates that other technologies than cage-induction motors will be required for IE4 and the scope of IEC 60034-30 would be revised consequently.

Figure 2.4  IE3 (Premium) and IE4 (Super Premium) efficiency levels comparison Vs. rated output power (according to IEC 60034-30, \( \approx 15\% \) lower losses subtracted from IE3).
In order to eliminate the scruples such as, premium efficiency gained by compromise, other performance characteristics and the motor reliability, a study was made based on similar enough motors and operation conditions to compare the construction, performance and reliability for Pre-EPAct, EPAct and Premium Efficient motors (Austin, H. Bonnett et al, 2008).

2.6 MARKET RESEARCH - AN OVERVIEW

By going through various motor manufacturers’ product catalogs as shown in Table 2.6, a conclusion could be made that leading manufacturers are aiming to obtain even higher efficiency than NEMA Premium®. Baldor seems to be striving to achieve the Super Premium Efficiency level, as one could understand by taking a look at their Premium motors’ name, which is Super-E® Premium Efficient Motor. The Baldor’s Super-E® motors meet or exceed the efficiency levels defined by NEMA Premium®, however, there is still some distance to the Super Premium Efficiency (IE4) requirement for larger power rating. Baldor achieves the higher efficiency levels by a more focused motor design, paying particular attention to the active materials, whereas SEW and Siemens are already in the front-line. Leroy-Somer has been making PM motors to replace the induction motors for some areas.

SEW-Eurodrive has been active in an extended effort to design the motor to optimally use copper in the rotor to upgrade their DT/DV series to DTE/DVE. Ultra Efficient TEFC motor of Siemens has the highlight feature of a Copper Rotor (Siemens exclusive, leading-edge, DCR design), thus Siemens motors have industry-leading efficiencies, as shown in Figure 2.5. From Figure 2.5 it is seen that the efficiency levels are beyond NEMA Premium level (Fuchsloch et al 2007).
Table 2.6  High efficiency motors from competitor companies in the market

<table>
<thead>
<tr>
<th>Company</th>
<th>Country</th>
<th>Name for the Highest Efficiency</th>
<th>Efficiency level</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.O.Smith</td>
<td>US</td>
<td>E-Plus 3</td>
<td>EPAct standards</td>
</tr>
<tr>
<td>Baldor</td>
<td>US</td>
<td>Super-E Premium Efficiency</td>
<td>NEMA Premium</td>
</tr>
<tr>
<td>Brook Crompton</td>
<td>UK</td>
<td>WK Premium efficiency motor</td>
<td>EFF1</td>
</tr>
<tr>
<td>Emerson</td>
<td>US</td>
<td>NEMA Premium efficient motor</td>
<td>NEMA Premium</td>
</tr>
<tr>
<td>GE</td>
<td>US</td>
<td>XSD Ultra NEMA Premium efficiency TEFC</td>
<td>NEMA Premium</td>
</tr>
<tr>
<td>HYOSUNG</td>
<td>KR</td>
<td>Premium high efficiency motor</td>
<td>NEMA Premium</td>
</tr>
<tr>
<td>LEESON</td>
<td>US</td>
<td>Premium efficiency WATTSAVER</td>
<td>NEMA Premium</td>
</tr>
<tr>
<td>Rockwell</td>
<td>US</td>
<td>N/A</td>
<td>NEMA Premium</td>
</tr>
<tr>
<td>SEW-eurodrive</td>
<td>DE</td>
<td>DTE/DVE</td>
<td>Exceed NEMA Premium</td>
</tr>
<tr>
<td>Siemens</td>
<td>DE</td>
<td>Ultra Efficient (GP100/100A)</td>
<td>Exceed NEMA Premium</td>
</tr>
<tr>
<td>Sterling Electric</td>
<td>US</td>
<td>N/A</td>
<td>NEMA Premium</td>
</tr>
<tr>
<td>TECO</td>
<td>CA/US</td>
<td>Global XPE series</td>
<td>NEMA Premium</td>
</tr>
<tr>
<td>TOSHIBA</td>
<td>US</td>
<td>Premium FC-EQPIII XT</td>
<td>NEMA Premium</td>
</tr>
<tr>
<td>WEG</td>
<td>US</td>
<td>NEMA Premium Rolled Steel motor</td>
<td>NEMA Premium</td>
</tr>
</tbody>
</table>
A comparison could be made to understand the market products efficiency level with reference to ABB (test method: IEC2007), Siemens and SEW- Eurodrive premium efficiency motors (test method unknown). Due to the limitation of the data availability, the comparison only cover 4 poles motor for a general impression, where the IE3 and IE4 levels are also stated, in Figure 2.6. As we can see from the figure, Siemens’ motors have four points of power rating, where the efficiencies exceed the IE4 level.

![Siemens Ultra Efficient Motor and its efficiency compared with Premium Efficiency (IE3)](image)

**Figure 2.5 Siemens Ultra Efficient Motor and its efficiency compared with Premium Efficiency (IE3)**

The output power ratings are 1kW, 1.5 kW, 3 kW and a comparison could be made to understand the market products efficiency level with reference to ABB (test method: IEC2007), Siemens and SEW-Eurodrive premium efficiency motors (test method unknown). Due to the limitation of the data availability, the comparison only covers 4-pole motor for a general impression, where the IE3 and IE4 levels are also stated, as shown in Figure 2.6. SEW motor fulfills IE3 at low power range (1.1kW~11kW), and at output ratings higher than 15 kW, the efficiencies are slightly lower than IE4. The ABB motor M4BP series meet IE3, but all of them are less efficient than SEW and Siemens motor. The reason could be the use of copper rotor for both SEW and Siemens motor, which also indicates the efficiency improvement potential of ABB motor if the DCR concept, is applied.
Currently only the large manufacturer’s produce EE motors. To meet EFF1 standard, manufacturer’s generally employ a range of improvements in material’s, manufacturing method’s and quality control that collectively reduce the motor’s losses and boost its operating efficiency to the required standard. The improvements include specialized steel alloys in stator laminations, greater copper content in the stator windings and core, improved resins and varnishing practices, better temperature control in the baking/curing process and overall improved attention to quality control.

As the cost of energy goes up, the trade off of the cost for some technologies, which were thought to be expensive, will be compensated by the energy saving. At the same time as new motor technologies develop, high efficiency motors will go beyond the typical standard asynchronous squirrel cage AC induction motors.

Figure 2.6 Efficiency Vs. output power comparison between ABB, Siemens and SEW motors.
2.7 INDIAN SCENARIO FOR ADOPTION OF DCR MOTOR

India, the world’s second largest emerging energy market (after China), faces a chronic energy shortage say up to 20% during peak periods while energy use is growing multifold. The problem is especially felt in rural areas, where 63% of households do not have any electricity at all. One step towards meeting this need was taken by the International Copper Promotion Council India (IPCPI), which is supported in part by a grant from an arm of the Small Scale Industries Development Bank of India and funded by the USAID Eco Project. The Council tested copper rotors in motor’s used for pumping water, one of the country’s leading agricultural uses for electricity.

2.7.1 ICPCI Project at Coimbatore Motors and Pumps Cluster

Coimbatore, popularly known as Manchester of South India, is situated in the western part of the state of Tamil Nadu. It is well known for its textile industries and has excellent potential for industrial growth. An Indian company in Coimbatore, has developed Asia’s first ever-copper rotor in motor’s to help conserve energy. After two years extensive research, during the year 2002, the Tirupur based company succeeded in developing a copper Die-cast rotor motor to replace aluminium cast rotor. Mehala Machines India Ltd, based in Coimbatore has replaced aluminium rotors with copper as the other good conductors.

In order to test the reliability of Indian made Die-cast Copper Rotors and confirm the gains and performance in various other important parameters, a project was conceived and carried out in Coimbatore Motors and Pumps cluster by International Copper Promotion Council (India) – ICPCI during the year 2003. Small Industries Development Bank of India (SIDBI) and Technology Bureau for Small Enterprises (TBSE) provided Motors and Pumps cluster by ICPCI. Small Industries Development Bank of
India (SIDBI) and Technology Bureau for Small Enterprises (TBSE) provided assistance for the same.

Nexant Inc. (USA) helped in developing the concept and in formulating the various dimensions, schedules and so on for the project. Institutions like Coimbatore District Small Scale Industries Association (CODISSIA) and The Southern India Engineering Manufacturers' Association (SIEMA) played active roles in helping the industry grow and prosper with the help of institutions like SIDBI and National Small Industries Corporation Ltd. (NSIC). The facilities like Testing Center called Small Industries Testing and Research Center (SITARC) established by the cluster members has rendered testing support.

Ratings and types of motors that were chosen covered industrial sector, agricultural sector as well as domestic applications. The samples include single and three phase types of a.c. motors as well as, ratings and types presently used in both Die-cast aluminum rotors and Copper Bar rotors. The ten Die-cast copper rotors, for the eight ratings of motors chosen were sourced from an Indian manufacturer, based on the drawings and the supply of rotor stampings by the various manufacturers, participating in the project. These were assembled into motors and then were assembled with the conventional type of rotors used by them for performing comparative tests. These tests were carried out in the respective factories and some samples from each of the ratings were subjected to exhaustive tests at SITARC. Field tests were also conducted later to confirm performance and reliability under actual field conditions.

Based on experimental tests, the average improvement in efficiency variation of the motors between the ratings 0.5 HP – 5 HP with Die-cast copper rotors in comparison with Die-cast Aluminium rotors, a rise in efficiency of 2.5 to 3.0 % points is achieved.