

# A Comparative Analysis of Performance Characteristics of 2.2 kW 3 Phase Induction Motor using DAR and DCR Technology

S. Manoharan, N. Devarajan, M. Deivasahayam and G. Ranganathan

**Abstract -** This paper describes a comparison of the performance characteristics of a 2.2 kW induction motor with conventional Die-cast Aluminium Rotor (DAR) to that of a 2.2 kW induction motor with proposed Die-cast Copper Rotor (DCR). Both the motors are fabricated and its steady state characteristics are compared using MATLAB 7 software whose inputs are No-load and Blocked rotor tests obtained from the above motors. The actual load tests were also performed in the motors in accordance with IS 12615: 2004 standard.

**Index terms -** Induction motors, Die-Cast Copper rotor, Aluminium rotor, Motor efficiency, Energy efficient motor, High efficiency, International Standards, Energy savings.

## I. INTRODUCTION

Electric motors are used extensively in every sector of the economy. They perform a wide range of duties throughout the industrial, commercial, residential and agricultural sectors. Motor systems are the largest industrial loads, on average accounting for more than 70 % of all electricity consumption. Energy consumption of electric motor systems is an important economic and environmental issue. The sector wise breakup of electricity use in motor driven system in India is shown in Fig.1 [1].

According to [1], the broad segment wise market for a.c induction motor during the year 2002-03 in India was given in Fig. 2. Under this reference, annual purchase of alternating current (AC)/Direct Current (DC) motors of all ratings was estimated as 17/18 million units. Out of the total number of motors produced, Fractional HP motors account for over 85% of volume.

These small motors are used primarily in domestic appliances and are lightly and/or intermittently loaded. As a result there is little potential for cost-effective energy savings. DC motors have applications in the industrial sector. There are few DC motors in-service and most of them are being phased out in favour of AC motors with inverter drive systems. AC low-tension (or low voltage) motors are used by all end-user segments and represent the largest market, following fractional horsepower motors.

Manuscript received August 31, 2009.

S.Manoharan is with Department of Electrical and Electronics Engineering, Karpagam College of Engineering, Coimbatore, Tamilnadu, India (e-mail: manoish07@yahoo.co.in ).

N.Devarajan is with the Department of Electrical and Electronics Engineering, Government College of Technology, Coimbatore, India. (email: profdevarajan@yahoo.com)

M.Deivasahayam is with the Mehala Machine Works (India) Ltd, Coimbatore, India. (email:deiva\_sahayam@yahoo.com)

G.Ranganathan is a Consultant Engineer, Coimbatore. India. (email: grnathancbe@rediffmail.com)

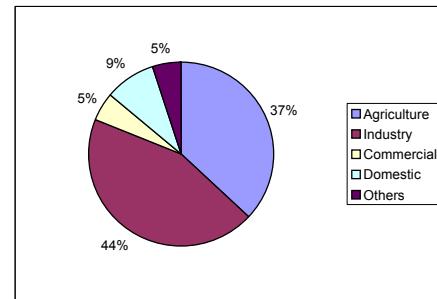


Fig. 1. Sector-wise break up of electricity consumption in motor driven systems

AC high-tension (high voltage) motors are used in the industrial sector and are designed for specific applications. AC low-tension motors can be further classified into squirrel cage and slip ring (wound rotor) motors. Slip ring motors are designed for specialized applications and are limited in number.

Squirrel cage induction motors are widely used and find applications in all segments of the industry. The greatest impact from motor efficiency improvements point of view is in the AC, low-tension, squirrel cage motor ranging in size between 0.75 kW to 37 kW. The demand for these motors has been growing at the rate of 3.8% per year. Motors larger than 37 kW tend to be more efficient and are often customer designed for the specific applications. Moreover, the numbers are also less. Hence the authors are concentrating to increase the efficiency of these low-tension motors, between the ranges 0.75 kW to 37 kW, which has major application in industries. The existing efficiency levels of these motors can be increased by 1.5-3% points by using DCR Technology. A lot of papers have been published for the past 10 years whose results are related with high rating, 4 pole motors and very few low rating (upto 5 Hp) 2-pole motors only [2,3].

The main objective of this paper is to compare the performance characteristics of a 2 pole 2.2 kW conventional DAR motor to that of a 2.2 kW proposed DCR induction motor. The efficiencies of the motors are determined using IS 12615: 2004 standard. The no-load and locked rotor tests are then used to determine the equivalent circuit parameters of each motor. The performance characteristics of the motors are then calculated by means of Matlab7 software.

## A. Experience with Energy Efficient Motor implementation – Literature Survey

In the year 1990, the US government stepped in and promulgated the ‘Energy Policy Act 1992’ which became

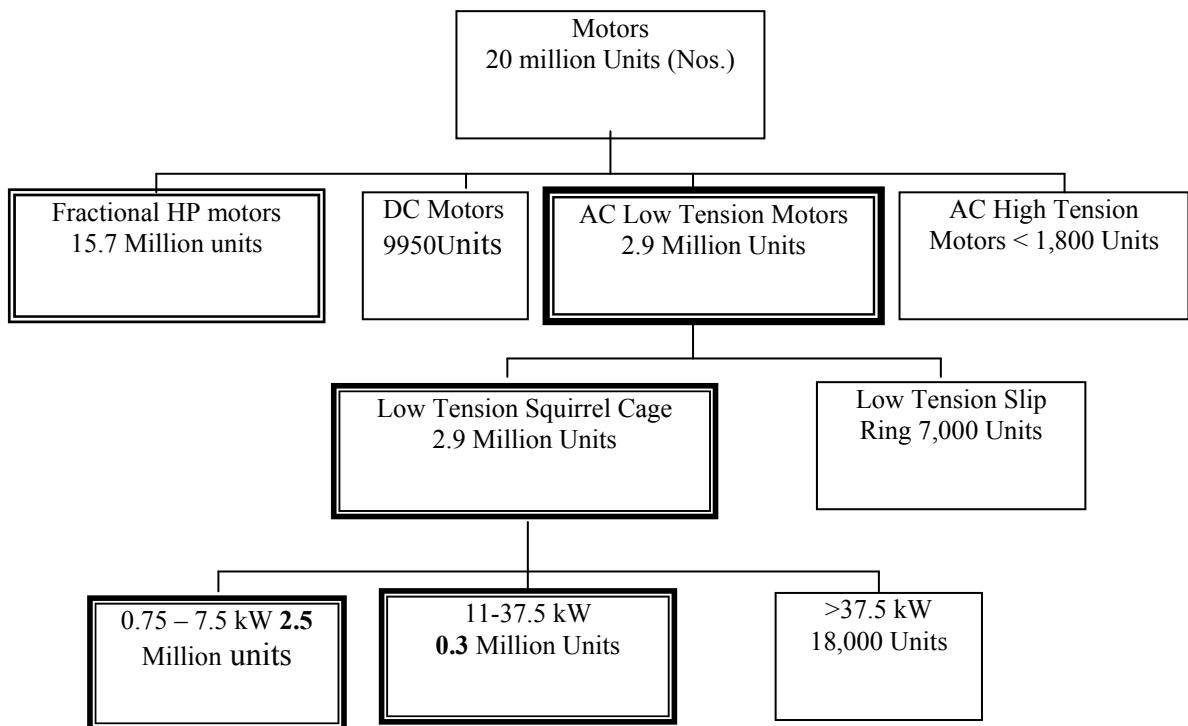


Fig. 2. Energy consumption of motors in India during the year 2002-03

effective in October 1997. The act covered the entire country and involved all stake holders- motor manufacturers, users, utilities and National Electric Manufacturer's Association (NEMA). The act specified mandatory efficiency standard and testing method for all motors sold in US from 1 to 200 HP. Authorized laboratory testing report was also made compulsory. There were no incentives for the mandatory standard, but motors with higher efficiency levels were eligible for the same.

The European Scheme to designate energy efficiency classes for low voltage AC motors has been in operation since 1999. It is based on a voluntary agreement between the European Commission and the European Committee of Manufacturers of Electrical Machines and Power Electronics (CEMEP) [4]. This Scheme classifies induction motors into three efficiency bands, from Eff3 (lowest) to Eff1 (highest). 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) [5].

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 standards & labeling program has brought about a regulation on Minimum Efficiency Performance Standards (MEPS) for energy intensive equipment including industrial motors.

On the motor manufacturers part, the Indian Electrical & Electronic Manufacturer's Association (IEEMA), which represents manufacturers with more than 50% share of the Indian Motor market had taken active measures in 1999 to

bring out a voluntary standard for Energy Efficient Motor (EEM) which is in line with Europe's CEMEP agreement (IEEMA 19), which was the fore-runner for the National Standard for EEM (IS 12615). Further, these manufacturers voluntarily eliminated low efficiency motors (EFF3) from their production range. There have been a number of initiatives undertaken 1999 on the demand end by the end user industries, supported by Energy Efficiency Advocates such as International Copper Promotion Council (India) popularly known as ICPCI to achieve energy savings by the use of energy efficient motors. These include selection of energy efficient motors in new purchases and projects, replacement of old inefficient motors on their economic merits and optimization of motor utilization to match the load. Many other Countries such as Canada, China, Mexico, Australia, and New Zealand have gone in for mandatory Minimum Energy performance Standards. These steps will require some time to completely assess their impact.

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.

## II. DIE CAST COPPER ROTORS

The basic losses in an induction motor consist of resistance losses in the stator winding and rotor cage, iron losses, friction and windage losses, and stray losses. The resistivities of copper and aluminium for circular mil, per

foot at 20°C are 10.37 Ω and 16.06 Ω 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. Therefore, by replacing the aluminium material in the rotor with copper, the overall efficiency of the machine gets increased. This idea leads to implementation of DCR technology.

It is well known that incorporation of copper for the rotor bars and end rings in place of aluminium would result in attractive improvements in motor energy efficiency. Since the electrical conductivity of this material is up to 60% higher than aluminum and hence, produce a more energy-efficient induction motor [6, 7, 8]. In addition, copper material has an ability to keep the efficiency constant over a broad range of loads, especially at low speeds and frequencies.

The manufacturing details for DCR are identical to DAR. The comparison of various Parameters between DCR and DAR are shown in Table I. DCR requires higher temperatures and pressures compared to DAR. The die life of DCR is also very short compared to aluminium counterpart [9, 10]. The challenges of die casting copper 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 reported in [11, 12]. A lot of studies have been done by Copper Development Association (CDA), USA and International Copper Association Ltd (ICA). They conclude 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 brings significant energy savings. Cooler running motor means longer motor life. Improved conductor bar and end ring consistency reduces maintenance cost [13]. The die-cast as a state-of-the-art technology makes an increase of rotor size each year due to the manufacturing advancements [14, 15]

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.

TABLE I: PARAMETER COMPARISON OF DCR MOTOR WITH DAR MOTOR

Parameters	Aluminium	Copper
Temperature	1200 F	2000 F
Shot pressure	2000 PSI	6500 PSI
Clamp pressure	2400 PSI	7800 PSI

### III. IS 12615: 2004 STANDARD

Several international standards exist for testing the efficiency of induction motors. The standards include:

IEEE 112, IEC 60034-2, CSA 390 and JEC 37. The standards differ mainly in their treatment of the stray losses in an induction machine [16, 17]. A detailed comparison of the different efficiency results between the standards was presented in [18]. The Indian standard IS 12615: 2004 was used in the research related to this paper. The IS 12615: 2004 standard uses the segregation of losses method to determine the efficiency of an induction motor as in the same way of reference international standard IEC 60034-2-1 [19]. The efficiency can be expressed in terms of output power ( $P_{out}$ ) and the sum of losses ( $\Sigma P_{losses}$ ), as:

$$\eta = \frac{P_{out}}{P_{in}} = \frac{P_{out}}{P_{out} + \Sigma P_{losses}}$$

Three tests are performed in order to determine the losses in an induction machine accurately. The tests and results associated with each are as follows:

#### a) Temperature Test

The motor is loaded and allowed to run until its temperature stabilizes. The temperature and winding resistances are recorded.

#### b) Load Test

The motor is loaded at six different loading points ranging from 25%-150% of rated load. The stator and rotor copper losses are calculated from this.

#### c) No-load Test

The motor is run at no-load with a varying supply voltage between 125% to 20% of rated voltage. The friction and windage and core losses are calculated from this.

Temperature correction (to 25°C) is done on the Stator and Rotor losses using the winding temperature and resistance from the temperature test. The stray load losses (SLL) are then found by subtracting all the calculated losses from the measured loss.

The loss segregation method is regarded as the most accurate method for calculating efficiency. This does of course depend on the accuracy of equipment. It also has the advantage of very high repeatability due to the temperature correction of the losses.

### IV. PERFORMANCE CHARACTERISTICS

In order to analyze the performance of an induction motor, first the conventional aluminium die cast material is placed in its rotor. After that, DCR is substituted in place of former one. A locked rotor test and a no-load test can be used to determine the equivalent circuit parameters of an induction machine [20]. So, these tests were performed on each of the motor and the test results are shown in Table II and III respectively. The equivalent circuit parameters for the DCR motor and the comparison with the DAR motor are shown in Table IV. Subsequently, the calculated equivalent circuit

parameters are fed in to MATLAB 7 software to determine the steady-state characteristic of the induction motor. From Table IV, it is observed that the value of no load resistance ( $R_0$ ) in the DCR motor is more than that of DAR motor. This is due to slot geometry which is designed for DAR motor. i.e., the slot design had not been optimized for copper.

The equivalent circuit model of an induction machine can be used to predict its performance characteristics. One such circuit is shown in Fig. 3. The variation (with output power) of its torque, current, input power factor, efficiency, etc. are determined using Matlab 7 software which is shown in Fig.4 (a-e).

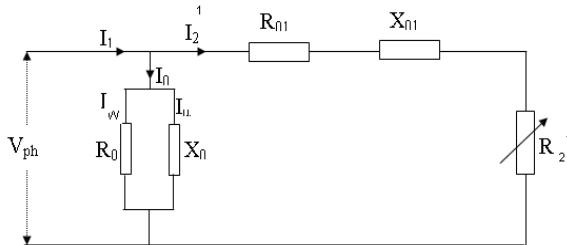


Fig. 3. Equivalent circuit of an induction motor

TABLE II: NO-LOAD TEST RESULTS FOR 2.2 kW (3-HP), 415V, 50 Hz, 2-POLE, 3-PHASE INDUCTION MOTOR

Parameters	DAR Motor	DCR Motor
No load voltage / ph	240V	240V
No load current / ph	2A	1.90A
No load power	220W	180W

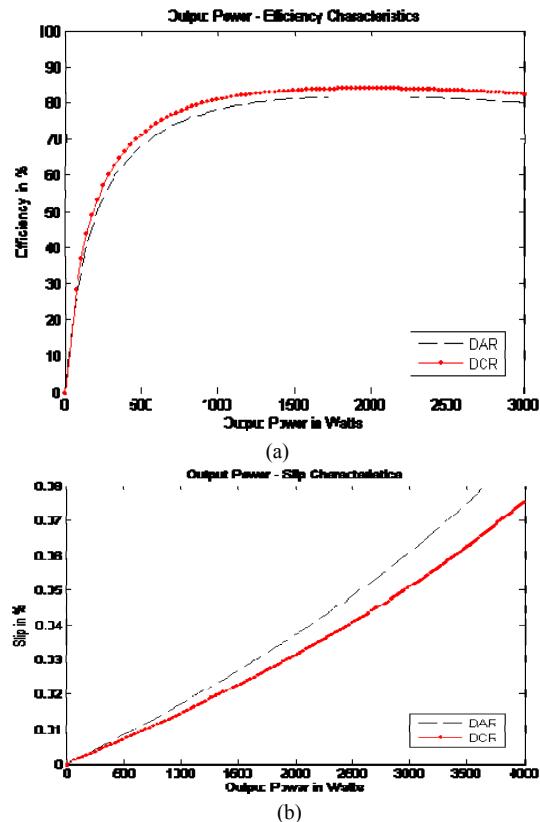
TABLE III: LOCKED ROTOR TEST RESULTS FOR 2.2 kW (3-HP), 415 V, 50 Hz, 2-POLE, 3-PHASE INDUCTION MOTOR

Parameters	DAR Motor	DCR Motor
L.R. voltage / phase	48.5V	47.3V
L.R. current / phase	4.6A	4.47A
L.R. power	410W	320W
Stator resistance per phase	2.73Ω	2.73Ω

TABLE IV: COMPARISON OF EQUIVALENT CIRCUIT PARAMETERS OF 2.2 KW (3-HP) DCR MOTOR WITH DAR MOTOR

Parameters	DAR Motor	DCR Motor
Iw (A)	0.30556	0.25
Iu (A)	1.9765	1.8835
I <sub>0</sub> (A)	0.30556 - 1.9765i	0.25 - 1.8835i
R <sub>0</sub> (Ω)	785.45	960
X <sub>0</sub> (Ω)	121.43	127.42
Z <sub>01</sub> (Ω)	10.543	10.592
R <sub>01</sub> (Ω)	6.4587	5.3384
X <sub>01</sub> (Ω)	8.3333	9.1478
R <sub>2</sub> (Ω)	3.7287	2.6084
R <sub>1</sub> (Ω)	2.73	2.73

The pictorial views of 3-Hp and 2-Hp copper die-cast rotors are shown in Fig 5. The experimental set up for conducting the full load test is shown in Fig. 6.



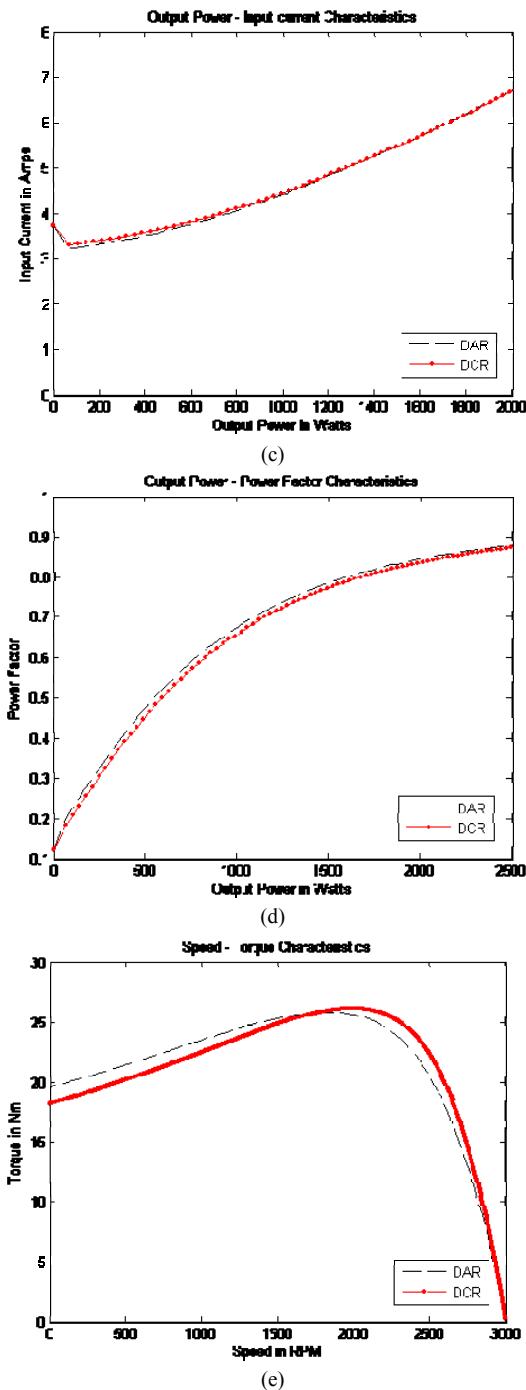


Fig. 4. Performance characteristics of a 2.2 kW (3-Hp) induction motor

## V. EXPERIMENTAL RESULTS

Results from tests obtained on two of the 2-pole motors of 3-phase, 2.2 kW (3-Hp), 415V, 50 Hz are shown in Table V. The important parameters responsible for the induction motor characteristics like Efficiency, Locked rotor Torque, Slip etc., are calculated from Matlab 7 software are compared from the tested results are shown in Table VI. Both the results are found almost tallying with each other.

As expected, the higher conductivity (copper) rotor material, the speed of DCR motor is increased slightly, the slip and input currents are reduced and the efficiency is increased. For the same output power, by merely replacing the DAR with DCR (without changing the other parameters), the efficiency of the motor is increased by nearly 2.6% points. It is observed that this increment in efficiency in DCR is due to the better conductivity of DCR. Starting

(locked rotor) Torque is reduced somewhat when copper is substituted for aluminium laminations with slots designed for aluminium. In applications where the lower starting torque is a problem, a modified design of the rotor slots offers the solution. The pull out (Breakdown) torque values are also reported in Table V. It is observed that the pull out torque in DCR is high. (i.e.) 365 % of the rated torque compared to 352 % of the rated torque for the same motor with DAR. From the mechanical characteristics shown in Fig.6, the DCR motor has the advantage of a higher torque at running speed. This characteristic of a DCR motor often finds very useful in applications such as centrifugal pumps, which need high torque at high speed. The p.f of the motor under various load conditions of both the DAR and DCR motors are nearly equal.

TABLE V: COMPARISON OF TESTED AND CALCULATED VALUES OF 3-HP DAR AND DCR MOTORS UNDER RATED CONDITIONS

Parameters	Results	DAR motor	DCR motor
Efficiency	Calculated	81.63	84.14
	Tested	81.58	84.18
Speed	Calculated	2875	2892
	Tested	2874	2918
Power factor	Calculated	0.84	0.84
	Tested	0.82	0.82
Input Power	Calculated	2654	2632
	Tested	2644	2620
Output power	Calculated	2199	2210
	Tested	2203	2203



Fig. 5. Pictorial views of fabricated 3-Hp and 2-Hp DCR



Fig. 6. Experimental setup of 3-Hp DCR Motor

TABLE VI: COMPARISON OF TEST RESULTS OF 2.2 kW (3-HP) DAR AND DCR MOTORS

Parameters	DAR			DCR		
	75%	100%	110%	75%	100%	110%
Voltage (Volts)	415	415	415	415	415	415
Current (Amps)	3.8	4.6	4.93	3.7	4.47	4.8
Input Power (Watts)	2040	2700	2990	1980	2620	2890
Speed (RPM)	2892	2874	2840	2931	2918	2902
Output Power (Watts)	1645	2203	2422	1656	2203	2425
Efficiency (%)	80.6	81.58	80.9	83.65	84.18	83.9
Power factor	0.74	0.82	0.84	0.76	0.82	0.84
Pull out torque (Break down) % of rated value	352		365			
LR Torque (% of full load Torque)	268		246			

## VII. CONCLUSION

This paper describes a comparative analysis of performance characteristics of 2.2 kW, 3-phase 2 pole TEFC induction motor using conventional DAR and proposed DCR technology. The results shows for the same output power, by merely replacing the DAR with DCR (without changing the other parameters), the efficiency of the motor is increased by nearly 2.6% points. If the rating of the machine is high, the incremental difference in efficiency of DCR motor is narrowed down. In today's rising power shortage, it is one of the solutions of energy efficiency initiative and energy conversion of the induction motor by using DCR technology. Apart from energy savings, the DCR motor also reduces the production of greenhouse gases and pushes down the total environmental cost of electricity generation. Therefore the adoption of these motors can give immense benefits to the user as well as the country and the global environment. If we concentrate the optimised designs for DCR motor with modified elements as slot designs and placement, the number of slots, stack height, gap length, shaft and bearing characteristics, stator winding configuration and frame size etc., then it is likely to render further enhancement of efficiency of the DCR motor.

## ACKNOWLEDGMENT

The authors would like to thank the management of Karpagam College of Engineering and M/s Megala Machine Works for their infrastructural and testing facilities provided to complete this research work.

## REFERENCES

- B.E. Kushare, K. K. Wagh, and S.Y. Kulkarni, "The complete guide to Energy Efficient motors", International Copper Promotion Council (India), Mumbai, 2003, pp. 18-20.
- Dale T. Peters, John G. Cowie, Edwin F. Brush Jr., "Advantages of the Copper Rotor Motor - Performance, Energy Savings and Environmental", in Copper, Dr. Jean-Marie Welter, Ed. USA: Wiley-VCH Verlag GmbH & Co. KgaA, 2006.
- E.E. Brush, Jr., D.T. Peters, J.G. Cowie, M. Doppelbauer and R. Kimmich, "Recent Advances in Development of the Die-cast Copper Rotor Motor", Proceedings of the International Conference on Electrical Machines, Crakow, Poland, 2004.
- John Malinowski, Jiri McCormick and Kevin Dunn, "Advances in construction techniques of AC induction motors preparation for super-premium efficiency levels", IEEE Transaction on Industry Applications, Vol.40, No.6, Nov/Dec 2004, pp. 206-211.
- F. Parasiliti, M. Villani, C. Paris, O. Walti, G. Songini, A. Novello and T. Rossi, "Three-Phase Induction Motor Efficiency Improvements with Die-Cast Copper Rotor Cage and Premium Steel", SPEEDAM 2004, Capri, June 16-18, pp. 3-4.
- M. Deivasahayam, "Energy Conservation through Efficiency Improvement in Squirrel Cage Induction Motors by Using Copper Die Cast Rotors", Proceedings of the International Conference on Energy Efficiency in Motor Driven Systems (EEMODS), Heidelberg, September 2005, pp. 92-101.
- John G. Cowie, David T. Brender and Dale T. Peters, "Die- Cast Copper Rotors for Improved Motor Performance", IEEE Pulp and Paper Conference, Charleston, SC, 2003.
- Copper Die-Cast Rotor Motor Project Report, International Copper Promotion Council (India), 2003, pp. 51-52.
- S. Manoharan, N. Devarajan, M. Deivasahayam and G. Ranganathan, "Review on Efficiency Improvement In Squirrel Cage Induction Motor By Using DCR Technology", Journal of Electrical Engineering, Vol. 60, No. 4, 2009, pp. 1-10.
- Brush E. F., Cowie J. G., Peters D. T., Van Son D. J., "Die-Cast Copper Motor Rotors: Motor Test Results, Copper Compared to Aluminum," in Energy Efficiency in Motor Driven Systems, F. Parasiliti, P. Bertoldi, Ed. New York: Springer, 2003, pp. 136-143.
- E. Chiricozzi, F. Parasiliti and M. Villani, "New Materials and Innovative Technologies to Improve the Efficiency of Three-phase Induction Motors - A Case Study", ICEM 2004, Cracow, Poland, September 2004.
- Dr. Rainer Kimmich , Martin Doppelbauer, James L. Kirtley, Dale T. Peters, John G. Cowie and Edwin F. Brush, "Performance Characteristics of Drive Motors Optimized for Die-cast Copper Cages," Energy Efficiency in Motor Driven systems (EEMODS) Conference Proceedings, Volume I, Heidelberg, Germany, September 1995, pp. 110-117.
- Copper Motor Rotor Technology Transfer Report, Available: <http://www.copper rotor motor.org>
- Dale.T.Peters, S.P. Midson, Walkington, W.G., Brush, E.F. Jr. and J.G Cowie, "Porosity Control in Copper Rotor die Castings," Transactions of the North American Die Casting Association Congress, Indianapolis, IN, 2003.
- S.Lie, Carlo Di Pietro, "Copper die cast efficiency improvement and economic consideration," IEEE transaction on energy conversion", vol. 10 no.3, Sep 1995, pp. 419-424.
- A. Boglietti, A. Cavagnino, M. Lazzari, and M. Pastorelli, "Induction motor efficiency measurements in accordance to IEEE 112-B, IEC 34-2 and JEC 37 International standards," in Conf. Rec. IEEE-IEMDC'03, Madison, WI, 2003, pp. 1599-1605.
- B. Renier, K. Hameyer, R. Belmans, Comparison of standards for determining efficiency of three phase induction motors" IEEE Transactions on Energy Conversion, Vol. 14, No. 3, September 1999.
- H.M.Mzungu, A.B. Sebitosi, M.A. Khan, "Comparison of standards for Determining Losses and efficiency of Three-phase induction motors", IEEE PES Power Africa 2007 Conference and Exposition, Johannesburg, South Africa, July 2007.
- Indian Standard (IS 9283:2004) - "Induction Motors -Energy Efficient, Three Phase Squirrel Cage -Specification", Bureau of Indian Standards, New Delhi, 2004.
- P.C. Sen, "Principle of Electrical Motors and Power Electronics", 2<sup>nd</sup> Ed. John Wiley & Sons, USA, 1999.

**Mr. S. Manoharan** took his B.E degree in Electrical and Electronics Engineering from Government College of Technology, Coimbatore in 1997 and later M.E degree in Electrical Machines from PSG College of Technology, Coimbatore in 2004. He is currently pursuing his doctoral work with Anna University Chennai in the area of Electrical Machines and drives. He has over 15 years of teaching experience. He is currently working as an Assistant Professor, Department of Electrical & Electronics

Engineering in Karpagam College of Engineering, Coimbatore, Tamilnadu. He has published research papers in both National and international journals of repute and presented papers in National and International Conferences. He has published more than half a dozen text books on Electrical and Electronics related fields. He is a life member of ISTE, SSI and member of IE (India) and IEEE.

**Dr. N. Devarajan**, Assistant Professor, EEE Department, Government College of Technology, Coimbatore. He received B.E (EEE) and M.E (Power Systems) from GCT Coimbatore in the year 1982 and 1989. He received Ph.D. in the area of Control Systems in the year 2000. He published 85 papers in the national and international conferences. He published 27 papers in international journals and 10 in national journals. Under his supervision currently 10 research scholars are working and 4 scholars completed their Ph.D. His areas of interests are control systems, electrical machines and power systems. He is member of system society of India, ISTE and FIE.

**Mr. M. Deivasahayam** received his B.E degree from P.S.G College of Technology, Coimbatore, in 1972. He has 35 years of experience in the field of Design, Erection and Commissioning of power plants with Government of India and abroad. He has published and presented papers in National & International Conferences. He is currently working as Joint Managing Director of Mehala Machines India Ltd., Coimbatore, India.

**Mr. G. Ranganathan** is a graduate in Electrical Engineering from P.S.G College of Technology, Coimbatore. He has 45 years of rich & varied experience in the fields of design, development, standardization & quality assurance of rotating electrical machines. He has been heading the Coimbatore unit of the erstwhile multinational GEC ALSTOM India Ltd. He is currently a consultant engineer of repute. He has contributed greatly in the design and development and energy efficiency improvements of asynchronous motors. He is the life member in various societies like IE (India) and Institute of Standards Engineers. His research papers have been published in National and international journals.