EEMODS '07

Energy Efficiency in Motor Driven Systems

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Conference Proceedings

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Volume II

Victor Zhou   Paolo Bertoldi Ed.

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Preface

Motor driven systems account for about 40% of global electricity demand, i.e. 7400TWh per year, and about 70% of the demand for industrial electricity. This is the single largest end-use of electricity. Not only this, but motor systems offer still today large efficiency improvement potential, calculated between 20% to 30%. This would significantly reduce greenhouse gas emissions at zero or even negative costs, as improvement measures in motor driven systems are generally economical.

Motor driven systems will therefore play a key role in bringing many countries on the road to meeting the Kyoto targets. If all the motor systems would be optimised energy cost savings would be US$100–146 billion per year. Yet energy efficiency investments are not yet priority in new plants or during refurbishments.

The fifth international conference on Energy Efficiency in Motor Driven Systems (EEMODS) was organised in Beijing (China) from 10 to 13 June 2007, to discuss the newest developments in this field of energy efficiency in motor driven systems.

This major international conference, which was previously been staged in Lisbon (1996), London (1999), Treviso (2002), and Heidelberg (2005) has been very successful in attracting an international and distinguished audience, representing a wide variety of stakeholders in the development, manufacturing and promotion of energy-efficient motor systems, including key policy makers, equipment manufacturers, academia, and end-users.

The EEMODS conferences have been very successful in attracting an international audience, representing a wide variety of stakeholders involved in policy implementation and development, and manufacturing and promotion of energy efficient motor systems.

The EEMODS conference has established itself as an influential and recognised international event where participants can discuss the latest developments and build international partnerships among stakeholders.

EEMODS'07 provided a forum to discuss and debate the latest developments in the impacts of electrical motor systems on energy and the environment, the policies and programmes adopted and planned, and the technical and commercial advances made in the dissemination and penetration of energy-efficient motor systems.

During the conference numerous studies on individual component (motors, pumps, compressors, fans) and on the consumption characterisation and the potential for improvement of energy efficiency of these systems have presented. Also policy actions in a variety of regions and countries have been presented. For motors, most of the OECD countries have adopted mandatory or voluntary efficiency requirements, classification systems and motor selection database. Other policy initiatives cover end-use equipment such as pumps, compressors, and fans. These initiatives tend to be of a voluntary nature and they include: information dissemination, best practice, voluntary agreement, audit schemes, and financial and fiscal incentives. More recently the attention of policy makers and programme designers has moved to the "systems" and to the numerous possibilities for improving efficiency and save energy in the systems design, operation and maintenance. Examples are the US Best Practice Programme and the European motor Challenge Programme.

In the opening plenary sessions representatives of policy making bodies in China, the US and the EU, as well of international organizations such as the International Energy Agency, the UNDP, and others gave an overview of the recent developments in the policy area.

96 papers were presented in the 3 concurrent sessions covering the following topics:
Compressed Air
Electrical Motors (technologies, policies, and test methods)
Fans and Fan Systems
Management Issues
Motor System Audit and Programs
Policies and International Issues
Power Electronics and Electrical Drives
Pumps and Pump Systems

This book contains the papers presented in the parallel sessions. It is hoped that its availability will enable a large audience to benefits from the presentations made in EEMODS'07. Potential readers who may benefit from this book include researchers, engineers, policymakers, energy agencies, electric utilities, and all those who can influence the design, selection, application and operation of electrical motor driven systems.

EEMODS'07 has been organised by the International Copper Association and hosted by the Energy Research Institute National Development and Reform Commission, with the scientific support of European Commission, DG Joint Research Centre.

Victor Zhou
Paolo Bertoldi

2007.10.1, Beijing

Motors

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Energetic Comparison between Induction Motors and Synchronous Reluctance Motors

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Abstract

Induction motors are widely used in both industrial and civil applications, but, if speed regulation is needed, some interesting alternatives are today available.
An alternative to induction motors is the transverse laminated synchronous reluctance (TLSyR) motor, that shows higher torque capability (in the same stator frame) and higher efficiency.
In this paper, two general purpose industrial induction motors (2.2 and 4kW, 4 poles, 380V, 50Hz) are compared with two TLSyR motors, built using the same stator frame of the induction motors.
The TLSyR motors are experimentally compared with the induction motors, showing an increment of the efficiency and an increment of the rated torque.

1 Introduction

Induction motors are the most world wide used motors in industrial and civil applications. The industrial process for the production of induction motors is a well known technology, the produced motors have a simple structure and show high robustness.

One of the most important features of induction motors is the possibility to supply the motor directly from the main. This feature is a strong advantage for induction motors, at least for low power applications and when speed regulation is not required.

Due to developments of power electronics, speed regulation of induction motors became an assessed technology. Thus, since speed regulation was affordable with low cost, more and more applications of induction motors drives with speed regulation appeared on the market.

Since speed regulation, with the consequent power electronics supply converter, is widely required, the possibility to change from induction motors to other types of electrical machines, like synchronous motors, can be investigated.

Permanent magnet synchronous motors show higher efficiency and torque density as compared to induction motors[1], however these advantages are traded off with the higher machine costs and difficulties for constant power operation.

Variable reluctance synchronous motors show the advantage of synchronous motors, such higher efficiency and torque density, and, due to the absence of permanent magnets, have low cost and the possibility to be controlled in the constant power region. Moreover, variable reluctance motors, due to the inherent rotor anisotropy, are suitable for zero speed sensorless control[2].

2 The transverse laminated synchronous reluctance motor

Several kind of synchronous reluctance motors have been presented and evaluated, even if several rotor structures with magnetic anisotropy can be designed, for industrial production the construction costs must be evaluated.

An interesting type of synchronous reluctance motor is the transverse laminated synchronous reluctance motor. It is constituted by:

- a stator that is a common three phase stator, like the induction motor.
- a rotor that is essentially composed by a purposely designed lamination, and skewed on the motor shaft like an induction motor.

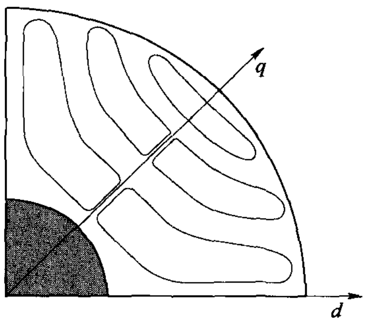

Figure 1 Rotor lamination of a transverse synchronous reluctance motor with the *d*, *q* reference

The reluctance anisotropy is obtained by the rotor lamination, as shown in figure 1 for a four pole motors. The *d* axis, direction with lower reluctance, and the *q* axis, direction with higher reluctance, can be seen by inspection.

High reluctance in the *q* axis direction is obtained by the presence of flux barrier obtained by cuts in the rotor lamination (three flux barriers for the lamination depicted in figure 1). Due to clear mechanical constraints internal and external rotor ribs are present.

The rotor ribs produce a reduction of the magnetic reluctance of the *q* axis, but they can be saturated by machine mmf.

The dimension of the rotor ribs must be the lowest allowed to overcome the centrifugal force on the rotor laminations, while the number of flux barrier is chosen for the torque ripple reduction, according to the number of stator slots[3].

The flux vs. current characteristics of a transverse laminated synchronous reluctance can be measured by a purposely developed tests[4].

In order to find the flux vs. current characteristics the motor must be supplied with a current controlled inverter, that fixes the i_d and i_q values, while the rotor position is measured by a shaft transducer.

The fluxes are then computed from the measured motor supply voltages. The main problems related to this measurement are: the definition of motor speed chosen for the test, the compensation of resistive voltage drop in the stator windings and the compensation of iron losses.

Figure 2 and figure 3 show the flux vs. currents characteristics of the two transverse laminated synchronous reluctance motors employed for the energetic comparison, in order to identify the motors the TLSyR motor to be compared with the induction motor with a rated power of 2.2kW is named TLSyRM 2.2 (the second motor is consequently named TLSyRM 4).

Some comments can be evidenced for both motors:

- the $\lambda_d = \lambda_d(i_d, i_q)$ characteristics is highly non linear due to the saturation of the rotor iron.

- the $\lambda_q = \lambda_q(i_d, i_q)$ characteristics is nearly linear, except for low currents around the zero when the rotor ribs need to be saturated.
- both flux vs. current characteristics are affected by magnetic cross coupling.

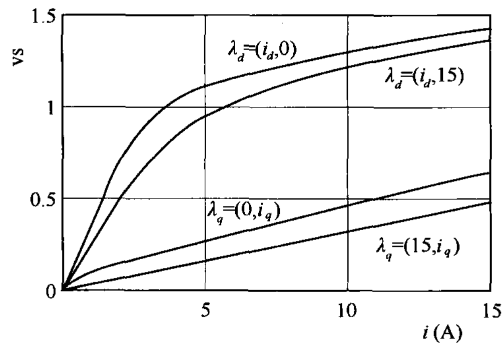

Figure 2 Motor TLSyRM 2.2, measured flux vs. current characteristics $\lambda_d = \lambda_d(i_d, i_q)$ and $\lambda_q = \lambda_q(i_d, i_q)$, peak values

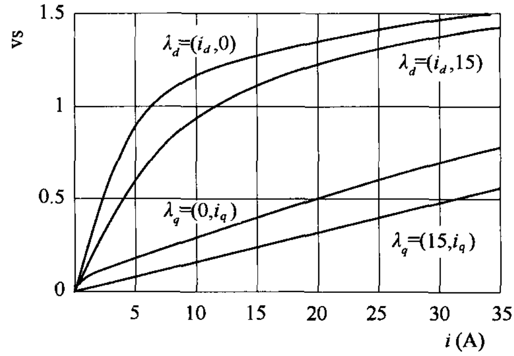

Figure 3 Motor TLSyRM 4 , measured flux vs. current characteristics $\lambda_d = \lambda_d(i_d, i_q)$ and $\lambda_q = \lambda_q(i_d, i_q)$, peak values

From the magnetic characteristics the maximum torque over current locus can be computed (maximum Nm/A locus). The output torque of a synchronous reluctance motor can be evaluated by the relationship:

$$T = 3/2\, p(\lambda_d\, i_q - \lambda_q\, i_d) \tag{1}$$

Where p is the pole pair number.

If a supply current of constant amplitude is moved from the d axis (where the output torque is zero) to the q axis (where the output torque is again zero) a maximum of the output torque for the assigned supply current is found (figures 4 and 5).

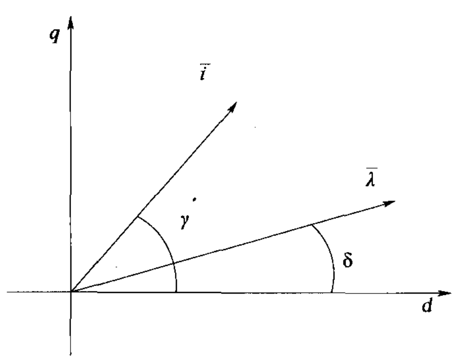

Figure 4 Current and flux vectors in the d,q reference frame

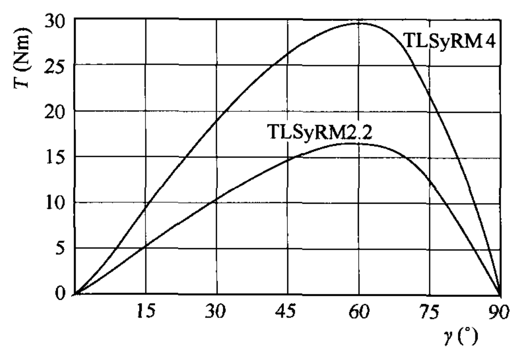

Figure 5 Constant current torque vs. γ characteristic. Current amplitudes 8 A for motor TLSyRM 2.2 and 14 A for motor TLSyRM 4

The value of γ angle which corresponds to the maximum output torque can be experimentally measured, or computed from the magnetic characteristic by the machine magnetic model. Figure 6 and figure 7 respectively shows the max Nm/A loci, computed by the magnetic model, and used for the control algorithm.

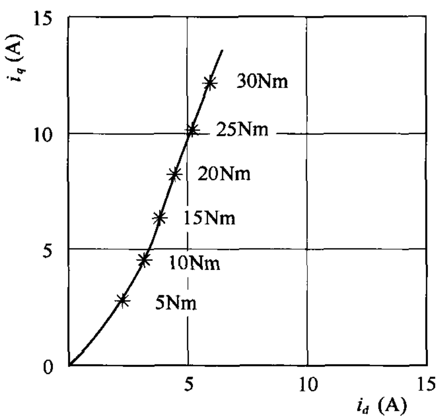

Figure 6 Motor TLSyRM 2.2: maximum torque locus for constant current amplitude (max Nm/A) in the *d*, *q* plane (peak values)

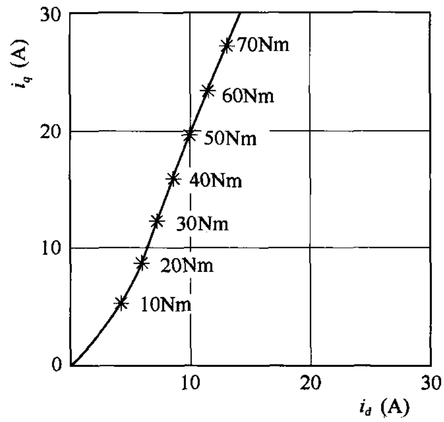

Figure 7 Motor TLSyRM 4: maximum torque locus for constant current amplitude (max Nm/A) in the *d*, *q* plane (peak values)

3 Construction of transverse laminated synchronous reluctance motors

The induction motors employed in this activity are "off the shelf" induction motors for general purpose use. They are not designed for high efficiency applications and have been designed independently of this comparison with synchronous reluctance motors.

The synchronous reluctance motors are made by simple substitution of the induction motor rotor. This means that, starting from the dimensional data of the induction motor, the reluctance rotor was designed in order to optimise its performance. It has to be pointed out again that the two stators was not optimised for the use with variable reluctance rotors. Since the two inductions motors have the same air gap diameter (outer stator lamination diameters 165mm), but different stack lengths (70mm and 120mm) only one variable reluctance rotor lamination was designed. The mechanical air gap was kept constant for all the motors.

4 Test bench set up

The motor comparison is made by experimental evaluation of load test.

A test bench equipped with torque and speed transducers was employed and a dc generator was used as brake.

During the test all the motors have been supplied by the same inverter that is a VSI inverter, equipped with IGBT modules, switching frequency of 10kHz. The dc voltage bus was supplied by a front-end diode bridge connected to a 380V, 50Hz main.

The control is digital with a DSP microprocessor whose algorithm was adapted to induction and synchronous reluctance motors by changing some routines.

The induction motors were supplied following the constant voltage/frequency law, choosing the voltage supply value from the nameplate data, while the synchronous reluctance motors were supplied by controlling the i_d and i_q currents and fixing the reference values on the max Nm/A