Energy Efficiency & Energy Savings

Efficiency improvements of electrical drives – contribute to improvement of environmental conditions

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Abstract

The electricity sector plays an important role in the EU-25 energy sector, with electricity generation accounting for about 36 % of total primary energy use and more than 30 % of man-made CO_2 emissions.
Actions must be taken to reduce the growth in electricity demand in the domestic, commercial and industrial sectors. All the activities must be economically viable and achieve proper energy savings. The costs of efficiency improvements must be paid back in a few years time by the electricity saved.
The paper describes measures to improve the efficiency of electric motors, transformers and actions to forster the penetration of more energy efficient drives.

Keywords: Efficiency, electrical motor, losses, transformer.

1. Introduction

A look on the electricity distribution system reveals that a vital component is the transformer beside the electrical motors and the power electronics for variable-speed drives. Focus will be on novel and improved materials but also on novel designs by using finite element analysis for electrical energy converters. Table I shows the four possible design areas.

Table I: Design areas

Materials / Design approach	Classical materials	Novel or improved materials
Classical, proven designs	O	OO
New design features	OO	OOO

A drive system is composed of a number of subsystems such as:
- transformer
- power electronics and control

- electrical motor
- load (e.g. fan, pump, compressor).

Big energy savings can be achieved by studying the complete system, and in particular through the implementation of variable-speed drives. In this paper the focus will be on the transformer and the variety of electric motors.

2. Transformers

There are two kinds of costs in the life span of a transformer. One is the purchase price paid by the users and the other is the cost of energy lost from the transformer over its active life due to the iron and copper losses. The total cost of ownership, or “total owning cost” (TOC) of a transformer is the sum of both. Recent improvements in amorphous metal casting technology have allowed the production of amorphous metal ribbon with better surface smoothness and therefore the lamination factor is high e.g. 90 % when optimally processed. Amorphous metal ribbon has typically a thickness of 0.025 mm compared to the silicon steel with 0.23 mm when used for distribution transformers. Amorphous metal used in the construction of distribution transformers is limited to an operating induction of about 1.35 to 1.4 T because of its lower saturation induction and the location of the typical knee on the magnetising curve. Because of the low iron losses the transformers made from amorphous alloys have an improved efficiency as shown in table II.

Table II: Efficiency comparison of transformers

Type / Application	Domain refined silicon steel, stacked	Amorphous metal, wound
Three phase (50 Hz, 150 kVA)		
25 % load	99.0 %	99.5 %
100 % load	99.1 %	99.3 %
Single phase (60 Hz, 37.5 kVA)		
25 % load	98.8 %	99.5 %
100 % load	99.0 %	99.1 %

The no-load losses are also reduced to less than 50 % compared with silicon steel [1, 2].

3. Electric motors

About 90 % of the total motor electricity consumption is done with ac three-phase induction motors in the power range from 0.75 kW to 750 kW. This was the starting point why in Europe during 2000 motor manufacturers belonging to CEMEP (European Committee of Manufacturers of Electrical Machinery and Power Electronics), signed a voluntary agreement to designate the efficiency classes of electric motor. Three efficiency classes were defined:

- EFF 1 (high-efficiency motors)
- EFF 2 (improved-efficiency motors)
- EFF 3 (standard motors).

An essential part of the agreement is that the EU motor manufacturers have agreed to reduce the market share of EFF 3 motors by at least 50 % by the end of 2003. The agreement applies

to two- and four-pole, 50 Hz squirrel-cage induction motors in the power range from 1.1 kW to 90 kW. Details of the efficiency classes are given in Fig. 1.
Efficiency measurement is based on the segregated-loss method according to IEC 60034-2, while the tolerance is given according to IEC 60034-1. The efficiency class is stamped on the motor rating plate and information is provided on rated efficiency and efficiency for 75 % of full load.
Special features have to be observed, when the energy efficient motor is exported to the USA. Then the manufacturer must send a declaration of conformity to the Department of Energy, which provides a certification number (CC-Number) to the manufacturer. The nominal efficiency and the CC-Number must be stamped on the rating plate.

The efficiency improvements are based on a variety of measures [5, 6]:

- low loss silicon steel
- optimised slot geometry by using finite element analysis
- improved insulation material with better characteristics to enlarge the fill-factor of the slot
- advanced software, which helps to solve coupled problems.

There are additional driving factors for the synchronous machines, dc machines and motors with a special geometry [4, 7, 8, 9]:

- improved permanent magnets with high energy product (sintered-, bonded-, hybrid-types)
- novel sensor technology for integrated sensors in power electronics and motor drives
- high-tech ceramic components for shafts, planet carriers, axles and gear parts
- softmagnetic composites for three dimensional flux path within the electrical machine [12]
- novel power electronic devices based on silicon carbide. (The thermal conductivity of SiC is several times that of GaAs and over three times that of Si. At room temperature SiC has a higher thermal conductivity than copper.) [10]
- novel topologies of the power electronic circuit e.g. matrix converters, new packaging concepts
- novel topologies of electric machines, e.g. based on transversal flux or flux concentration principles [11]

Fig. 2 and Fig. 3 are examples of new designs which result in an improved efficiency and make use of permanent magnets.

Efficiency improvements of electric motors offer large energy savings. The economical value of reduced losses e.g. by 1 kW can be calculated with the standard annuity calculation:

$$P = \left\{1 - [100/(100 + r)]^n\right\} 100a/r$$

with
P ... annual capitalised cost figure
a ... annual cost of “power” ($a^* \cdot T_o = a$)
r ... percentage interest rate (10 %)
n ... number of years over which losses are capitalised (10 years)
T_o ... operating hours per year (6000 h/year)
a^* ... energy costs (5 ct/kWh)

For this example we obtain P = 1824 €/kW.

In the case of reduced losses we do not have to generate more electricity in the power plants and in doing so we reduce e.g. the CO_2 emissions. The specific emissions for different power plants are given in table III.

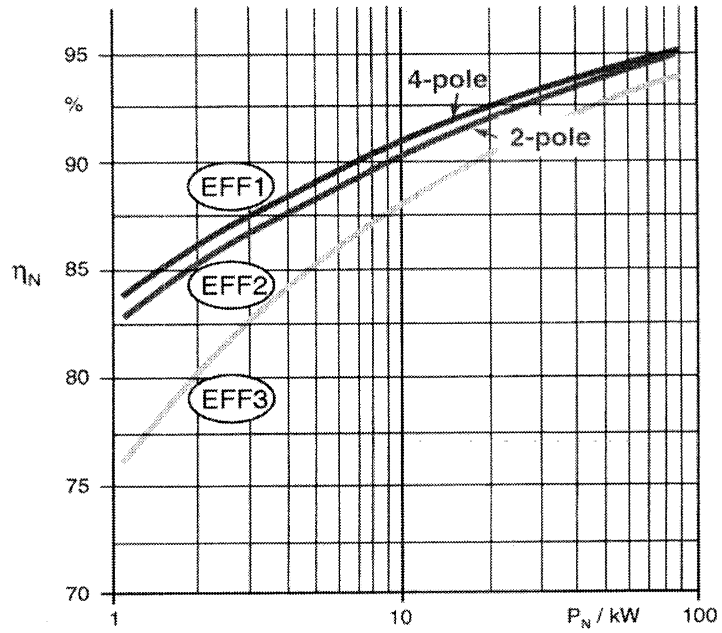

Fig. 1: Classification of efficiency

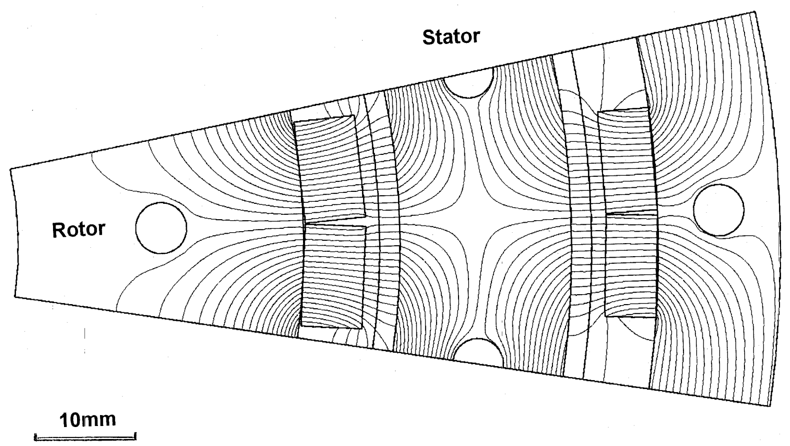

Fig. 2: Flux plot of 100 W-pm-generator with improved efficiency

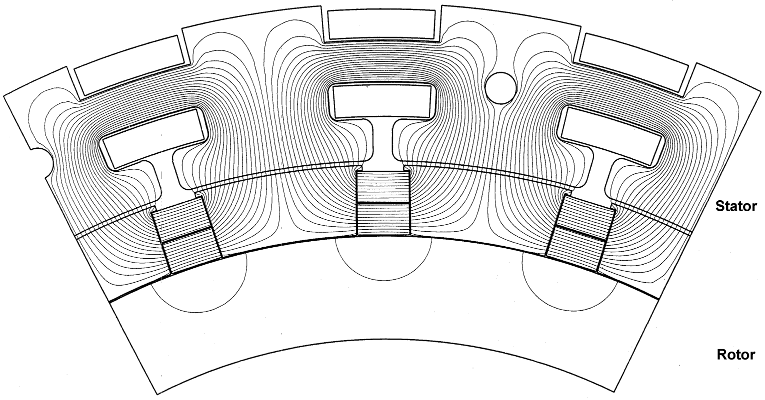

Fig. 3: Generator with flux concentration

Table III: Specific emissions from power plants

Type	kg CO_2/kWh$_{el}$
Lignite-power plant	1.02 ... 0.87
Hard coal-power plant	0.79 ... 0.73
Gas-turbine power plant	0.55
CHP (natural gas)	0.41

The benefit for the environment based on efficiency improvements of electrical devices is obvious.

4. Conclusions

Energy efficiency improvements is a rather complex phenomenon because of the variety of actors involved: manufacturers, retailers, original equipment manufacturer (OEM's), consumers and consultants.
There are still a number of barriers to the penetration of energy efficient drives:
- consumers' lack of information
- consumers' lack of capital for investment
- equipment owner not paying for running cost, or in detail:
  a) A large amount of motor is sold to OEM's, whose main concerns are price and delivery time rather than efficiency.
  b) Those departments of a company responsible for buying motors are often under pressure to recover their investments as quickly as possible. They are not responsible for buying energy.
  c) Maintenance managers make purchase decisions on replacement and not on energy efficiency.
  d) The majority of motors when they fail are rewound, because repair is usually cheaper than a new motor purchase. Therefore, rewinding reduces the maximum theoretical penetration rate for efficient motors. The penetration rate is estimated to be around 6 % per year, based on an average life of 15 years.

Only few engineer know that a rewound motor is characterised by an efficiency which is lower by – 1.1 % on average compared to the original winding arrangement.

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