
An integrated approach and IT platform to optimise electric motor engineering and design

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Abstract: Electric motors are one of the most common electrical components. The design phase is the most important stage in which 'green' customised solutions can be ideated, evaluated and optimised. Different aspects have to be concurrently addressed to achieve a high quality product in a short time to market. The present paper describes an innovative approach and software platform to configure and simulate customised electric motors. A key feature of the platform is a knowledge-based system that aims to standardise the design process. The platform integrates different software tools to support the development and verification of several design aspects, such as energy efficiency, manufacturing costs and environmental impacts. It also provides a collaborative area to support collaboration along the whole supply chain. Different case studies are presented to show the effectiveness of the platform application in supporting designers in the creation of innovative products.

Keywords: energy efficiency; electric motors; eco-design; collaborative design; knowledge-based system; integrated approach; cost estimation; optimisation; IT platform; life cycle assessment; LCA.

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1 Introduction

Products' energy consumption and related environmental aspects have become key issues in modern society. The total amount of energy required worldwide has increased by approximately 2.5% during the last decade and by 5.5% in 2010 alone (Enerdata, 2011). The European Commission has issued the communication 'EUROPE 2020 – A strategy for smart, sustainable and inclusive growth' in which one of the central subjects is a strategy for a 20% reduction in greenhouse emissions and a 20% increase in energy efficiency compared to 1990 figures (European Commission, 2010). In industrialised countries, energy consumption by electric motors and electrical equipment represents

over 70% of the total consumption (European Commission – Joint Research Centre, 2000). This result emphasises the importance of improving the energy efficiency of electric motors. Electric motors are one of the fundamental components of every manufacturing machine or industrial plant. Furthermore, small electric motors used in household appliances (refrigerators, freezers, washing machines, dishwashers and cooker hoods) are responsible for approximately 80% of domestic electric energy consumption.

Energy efficiency and ‘green’ labelling have become the newest motivation for the development of industrial products that contain an electric motor module. Companies need to easily complete the rapid ideation, configuration and design of customised ‘green’ products. To achieve this result, engineering and design departments have to adapt to the following key points: manage multiple design requirements, use design tools to conceive, analyse and simulate performances of new products from different points of view and, finally, work in collaborative teams.

In this context, automatic and semi-automatic configuration tools or computer-aided systems have become very important. These systems help designers handle the huge amount of data and knowledge involved in the design process, such as technical solutions of previously designed products, guidelines and company rules for configuring new solutions, standards that have to be considered and documentation about production processes. The core issue of the described product design scenario is the level of integration among the different systems. In fact, several tools are available on the market to solve most of the problems that can occur during the early design phase, but the majority are isolated tools that focus on specific problems. The difficulty of data exchange among design departments complicates the whole design process.

The present paper proposes an innovative integrated information technology (IT) system, called the energy reduction oriented design (EROD) platform, which collects and integrates a set of tools intended to increase the efficiency of the design process. The purpose of the EROD IT platform is to provide a full-package system that is well integrated in the traditional design context, which is able to help designers in developing sustainable products and high efficiency electric motors. The EROD platform is built considering two different levels of integration:

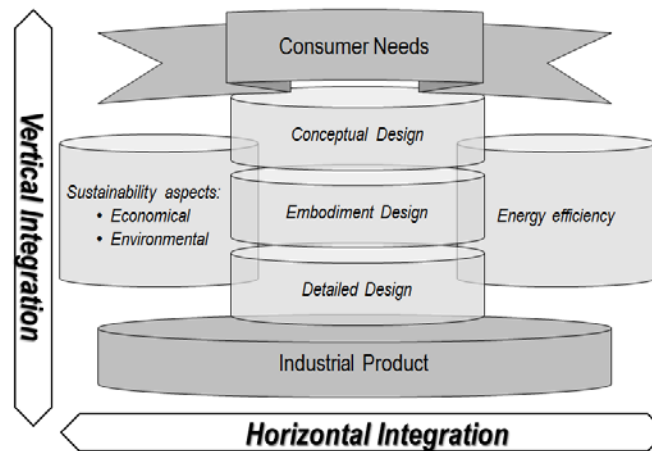
- *Vertical Integration*, by creating linkages among the main design stages, from the conceptual design to the final detailed aspects.
- *Horizontal integration*, for addressing all the aspects related to the energy efficiency and environmental and economic sustainability of the electric motors used in industrial products.

A schematic representation of vertical and horizontal integration is proposed in Figure 1.

Due to the synergy of the two integrated paths, designers can have a common base for conceiving new, efficient motors and developing more sustainable products. *Vertical integration* permits linkage with the design tools traditionally used during the various stages of the design process in the industry, such as computer-aided design (CAD), product lifecycle management (PLM) and finite element analysis (FEA) systems. *Horizontal integration* allows the connection of specific tools developed for the analysis of the efficiency and sustainability of electric motors. The final results achieved by the proposed IT platform are the standardisation of the design process, improved data sharing between the designers and company departments involved and the possibility of working in collaborative teams through a unique centralised system.

The software platform is able to simultaneously take into account multiple aspects that influence environmental impacts, energy consumption and production costs during the early stage of the design process, with the aim of creating customised electric motors with high energy efficiencies. The system also enhances synergistic cooperation all along the product design chain and the sharing of necessary know-how and data among engineers. In this way, companies can improve the efficiency of the design process, reducing the errors and repetitive operations that normally lead to an increase in development time.

Figure 1 Vertical and horizontal integration for engineering design of electric motors



2 Review of the electric motor design process

Even though electric motors are a very common, mature industrial product that have been under development for the last 100 years, the design process has not yet been well formalised. From the analysis of the literature about electric motor design processes, a lack of research regarding this topic is discovered. There are many books and publications about the physical and electromagnetic principles that form the basis for the various typologies of electric motors (Toliyat and Kliman, 2004; Yeadon and Yeadon, 2001). Nevertheless, there is little literature about the study of a systematic approach for the electric motor design process, how it is possible to recognise in other sectors, such as the mechanical engineering (Pahl et al., 2007). However, an analysis of the design processes of five different Italian motor manufacturers allows the definition of some common design steps that are generally followed by experts and industrial practitioners.

The design of electric motors generally begins with the definition of technical specifications, which are usually determined by the customers. Because it is common to configure a new electric motor starting from a previously designed solution, at this stage, one of the main problems addresses data retrieval. Electric motor documentation is usually not well organised within a company, and design methodologies belonging to individuals are not efficiently shared between all the stakeholders in the process. For this reason, subjective expertise plays a crucial role in identifying and achieving the best

solution. During the design process, conceptual and detailed designs are generally supported by different software tools, such as 2D and 3D CAD systems, computer-aided engineering (CAE) software, worksheets and excel tables. These are usually general purpose tools, not necessarily oriented toward electric motor design. In the preliminary stages, lumped-parameter software or spreadsheets are also used. Optimisation is carried out with the support of FEA techniques, which allow the prediction of the dynamic electromagnetic behaviours of systems. Another common way of proceeding in the design and optimisation process is the ‘trial and error’ methodology, which requires the creation of numerous costly intermediate physical prototypes.

From the analysis of current practices in electric motor development, the collaborative nature of the design process also emerges. The complexity of the product requires the involvement of multiple competencies to address the mechanical, electrical, electronic and software aspects, which are often distributed among different actors in the supply chain. In the literature, there are many examples of applying collaborative platforms in different sectors (Bouarfa and Toubaline, 2010; Mengoni et al., 2011; Wang et al., 2011; Weiping et al., 2008). These works demonstrate the effectiveness of these tools in virtual teamwork management with the aim of improving remote, synchronous collaboration among design actors involved in the product development processes of complex products. However, there are no examples in the industrial sector of electric motors, and this is one of the matters that the present work intends to address.

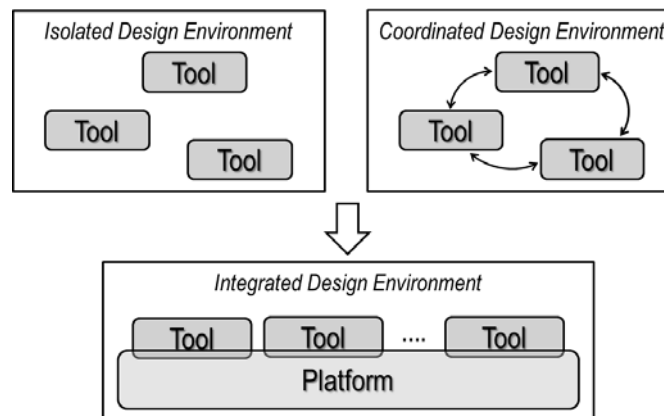
An additional issue in the current state of electric motor design processes relates to the environmental aspects associated with their use in machines. Concerning this, in 2003, the European Community issued the WEEE Directive (European Parliament and Council, 2002a) regarding the disposal and recovery of electric equipment and the RoHS Directive (European Parliament and Council, 2002b) regarding the restriction on the use of dangerous substances in the same products. Electric motors, which are the core of electrical and electronic equipment, are subject to these directives. All the available methods and tools for life cycle assessment (LCA) are general purpose; as a consequence, it is difficult to use them for a quick evaluation of the sustainability of electric motors. Very few instances of applying these types of techniques are present in literature, and the few that exist focus on particular motor types (Torrent et al., 2011).

In attempting to control production costs, it is very important to estimate these costs in the first design stages. In the traditional design process, costs are usually estimated at the end of the development process, before starting the production phase. As a consequence, products may suffer from a lack of cost optimisation. Cost estimation is a well-studied research topic, as proven by the number of approaches and methods available (Rush and Roy, 2000). In the field of electric motors, however, no methods or tools exist that address estimating manufacturing costs. Approaches only exist for calculating the cost of a single, specific manufacturing operation (Gara et al., 2009; Madan et al., 2007; Xie et al., 2001), but these have not been integrated in a single platform that is dedicated to the entire electric motor.

Therefore, the main bottleneck in the traditional process is due to the number of repetitive operations required to achieve a final design solution. The increase in development time and relative costs is also due to a lack of software tool integration and interoperability. In fact, designers currently apply two traditional design approaches: the isolated type, where the tools for verifying the various design aspects are completely unconnected, and the coordinated type, where each tool is independent from the others, but there is an exchange of data and models. One of the hypotheses of this work is that if

designers can easily retrieve past solutions to similar design problems, store new case studies, operate with shared design rules and use a large set of integrated supporting tools, then the amount of time necessary for developing a customised electric motor would decrease. For this reason, it is necessary to switch to an integrated design environment where the company's knowledge is efficiently managed and shared and all the tools are controlled by a univocal platform (Figure 2).

Figure 2 Comparison between the traditional design approaches and the integrated approach



Knowledge management has recently become very important for companies in creating new and innovative products and services and thus maintaining competitive advantages in the market. The introduction of IT, such as product configuration platforms or knowledge-based (KB) systems, has led to significant advances in this context. Several research studies have dealt with this topic from different perspectives (Datta, 2003; Franco and Pissarra, 2012; Lippert, 2008; Lu et al., 2007; Pappa et al., 2009). However, these types of technologies are usually general purpose or applied in specific industrial fields that differ from the one in the present research (Moon and McAdams, 2010; Wang et al., 2010). In the specific field of electric motors and machines, there are few examples of the application of IT (Bilgin and Krishnamurthy, 2011; Lacombe et al., 2007; Tedesco and Emami, 2010), and there is no extensive state of the art study regarding systems that support the entire design process (Gonzalez et al., 2010; Hamiti et al., 2008; Jabbar and Yeo, 2000; Jayasundara and Munasinghe, 2009; Scutaru et al., 2010). There is a lack of studies in the literature regarding the systematic design of electric motors and machines.

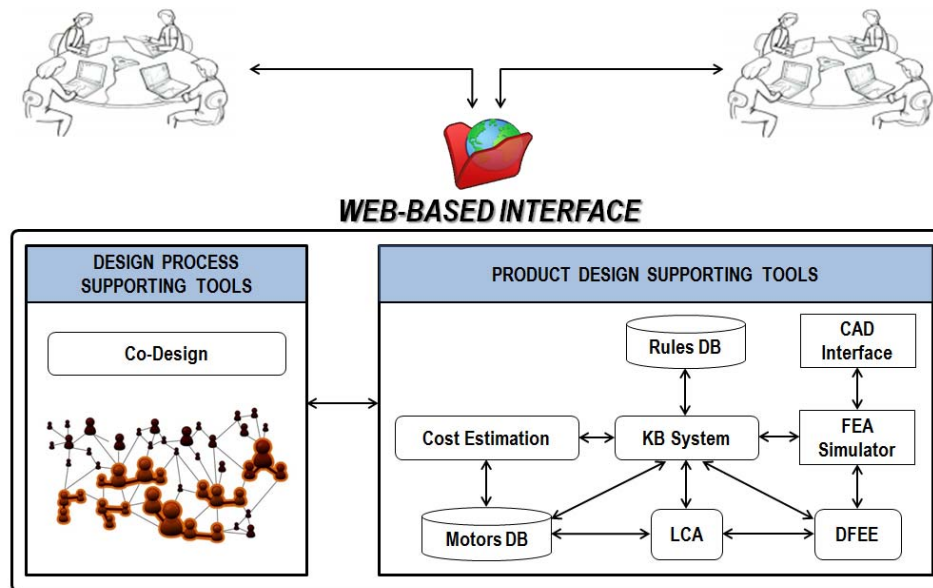
The present paper aims to overcome these limitations to develop a methodology and platform for integrated design in the industrial field of electric motors. With this innovative approach, electric motor manufacturers can standardise the design process and can easily configure and verify various aspects (performances, efficiency, sustainability, and cost) of their new products during the early phases of the development process.

3 EROD platform

The EROD platform is not a simple collection of several software tools but is a very articulated system of interactions among traditional design tools and new tools. The main

objective is to standardise the design process by efficiently sharing knowledge and to increase the sustainability and efficiency of electric motors used in industrial applications and products. The main advantages of this IT platform are that it covers all aspects of product design and supports electric motor designers throughout the entire design process. This platform is used in a website where all functionalities are controlled through a single user interface (Figure 3). The high usability of the user interaction favours easy data exchange and knowledge sharing within the company and along the whole supply chain.

Figure 3 EROD platform architecture (see online version for colours)



All the platform tools are hosted on a server and are available through a web browser. This aspect guarantees the possibility of using all provided resources by remote access. The EROD platform is composed of several systems that manage different functionalities. Some of these systems are commercial items (such as CAD or PLM), while others are specifically developed for this purpose:

- *KB system:* a tool oriented toward electric motor design that aims to guide designers in all phases of the design process.
- *Design for energy efficiency (DFEE) module:* a tool for the optimisation of products in terms of energy efficiency.
- *LCA module:* a software tool for the rapid estimation of the environmental impacts of electric motors.
- *Cost estimation module:* a software tool for rapid estimation of motor production costs.
- *Co-design module:* a collaborative design system for improving data communication and decision-making activities.

The platform allows companies to implement an integrated design approach where the company expertise is efficiently shared among all the design actors and has a key role during the design process, all the tools are synergistic and data and information can be easily exchanged. This favours the optimisation of new products from several points of view and, at the same time, contributes to reducing time-to-market and costs. The following subsections describe the main systems that have been specifically developed for the EROD platform, without considering the commercial tools in detail.

3.1 KB system

One of the most important points for the development of the IT system is the creation of the company KB system. The KB system is the core of the EROD platform. It is based on a database in which useful data and company configuration rules are collected and provides a structured design process for defining and optimising the electric motor design.

The first phase of a new electric motor configuration is the definition of technical specifications and design constraints. Subsequently, designers can easily search past solutions and case studies from the EROD platform database according to design specifications. This retrieved information represents the starting point for the new motor design. When the solution that best fits the design requirements has been identified, the KB system guides the user in entering proper input parameters and configuring the new design solution. Simulation of the configured model's behaviour allows the assessment of the electromagnetic performance. Thanks to the platform, all repetitive phases, such as the resizing of a component, are completely automated. When the final design solution has been found, the KB system stores the new optimised motor in the database and permits the creation of the final product model, including the automatic generation of technical datasheets and all documents used for production.

It is clear that the development of a KB system makes the design process faster than the traditional process because of the reduction of errors and repetitive iterations in the optimisation phase. The KB system (Figure 4) is based on two different databases, which store and share company knowledge:

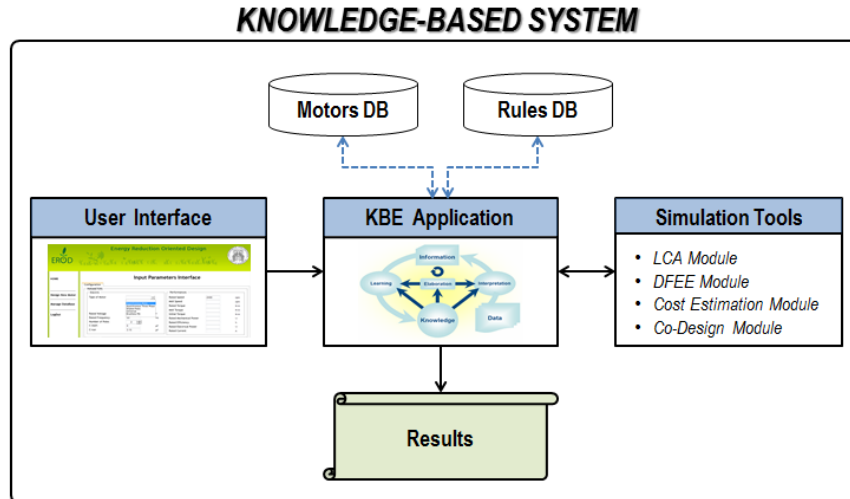
- The *motors DB* stores the documentation about previous solutions, such as geometrical models and data sheets.
- The *rules DB* collects design practices and company rules for the configuration of new products.

The KB system has a user-friendly graphic user interface (GUI) that is accessible by a common web browser; it allows all the necessary input parameters to be entered. The EROD platform is not a fully automatic configuration tool. It actually guides designers in the whole design process but requires some input in all phases.

As a result of the simulation of the configured electric motor, the designer can verify the mechanical and electrical performances of new products. For this purpose, a commercial electromagnetic FEA Simulator is used. This software is automatically controlled by the KB system through the generation of Python scripts. The EROD platform builds a 2D CAD representation sized according to the designer's input, simulates the performance of the configured model and displays the final results in the same GUI. This is another great advantage because CAD modellers and FEA simulators

usually require an expert user due to the high number of parameters that need to be considered.

Figure 4 KB system (see online version for colours)



3.2 LCA module

The LCA module is a tool that is integrated into the general framework of the EROD platform with the purpose of estimating the environmental impacts of electric motors. The impact assessment is carried out following the well-known LCA methodology (International Organization for Standardization, 2006a, 2006b).

The main goal of this module is for designers to be able to quickly estimate the environmental impacts of electric motors at two phases of the product lifecycle: the production/manufacturing phase and the use phase. These two phases are the most critical for analysing the design process of electric motors from an environmental point of view. Another great advantage compared to the current state of the art is the possibility of easily and automatically retrieving information for the life cycle inventory (LCI) phase, which is the most time consuming part of the LCA analysis. In fact, a dedicated repository of this module stores useful data for this phase, such as the components used in the motor, material types, masses, manufacturing processes, etc.

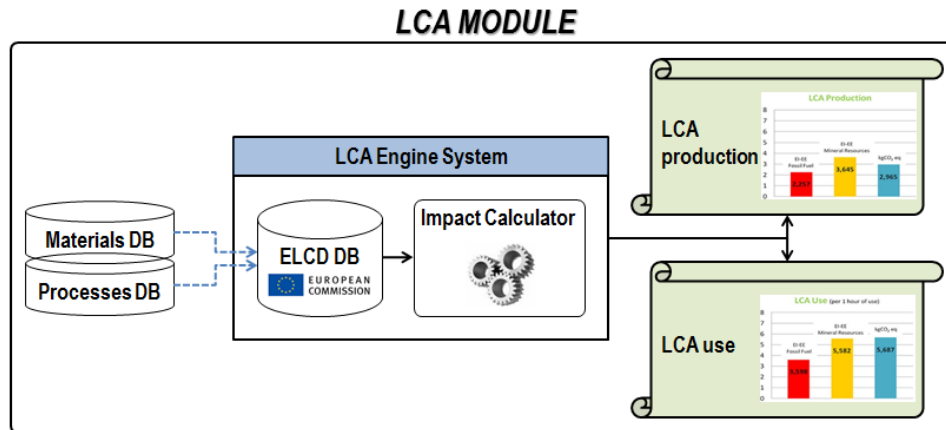
The evaluation method used for impact assessment is the eco-indicator (EI-99). This method permits weighted and normalised values of environmental impact to be obtained in three major categories of environmental damage: resources, eco-system quality and human health (Goedkoop and Spriensma, 2000). The possibility of managing only a few, simplified indicators makes the interpretation of results easier.

The architecture of the environmental impact estimation tool is presented in Figure 5.

The information is collected in two separate databases, the *materials DB* and the *processes DB*. The processes can be personalised, expanded and modified to consider the characteristics of electric motors and related manufacturing technologies. Otherwise, the existing manufacturing processes, modelled for the specific company, can be stored in the database and automatically selected by the system for a certain type of electric motor.

The LCA engine system consists of a certified open-source database from the European Commission (ELCD DB) (European Commission – Joint Research Centre, 2011) and an impact calculator that carries out the environmental impact evaluation. The original environmental impact flows are collected in the ELCD repository and are linked to the *materials* and *processes* repositories.

Figure 5 LCA module architecture (see online version for colours)



3.3 DFEE module

The DFEE module (Figure 6) supports designers in developing energy efficient motors.

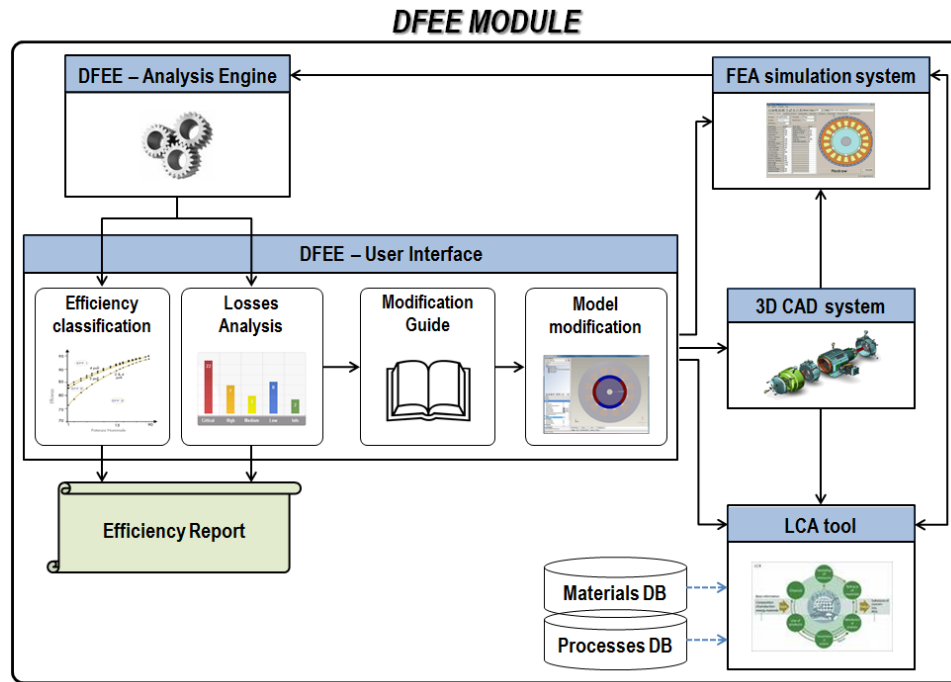
The module gives rules and guidelines for the optimal configuration of electric motors for increasing efficiency, reducing losses and improving the performance of the products in which they are used. In particular, the system guides engineers in the geometrical modification of the electric motor model, in selecting materials for a specific component and in designing windings. In other words, the tool provides solutions for reducing the energy consumption of the entire system (motor with its load) in use at a specific working point. Thanks to the link with a 2D FEA simulator, the DFEE tool allows the losses to be assessed and subdivided into three major groups: stator losses, rotor losses and winding losses (International Electrotechnical Commission, 2009).

The statistical analysis of the estimated losses, performed by the DFEE module, is the starting point for the successive phases of model modification. The system provides an efficiency classification of electric motors according to the information stored in the DFEE database. The electric motor classification is built from the European standards and directives (International Electrotechnical Commission, 2008; European Parliament and Council, 2005). The electric motors are divided into five groups (shaded poles, induction three-phases, induction single-phase, brushless PM and synchronous reluctance), and for each group, four different efficiency classes have been created (EFF0, EFF1, EFF2 and EFF3). The system gives the possibility of modifying the thresholds for each efficiency class according to the specific application of the electric motor and the evolution of directives.

The designer is guided in reconfiguring the electric motor to reduce losses in the various components. Depending on the predominant losses in the motor, the DFEE user

interface helps designers with proper modifications. For example, to reduce losses in laminated steel rotor and stator cores, one possible proposed modifications is to use materials with better magnetic properties.

Figure 6 DFEE module architecture (see online version for colours)



As in the KB configuration system, the model is automatically rebuilt and simulated again by the 2D FEA software. The DFEE tool is fully integrated with the LCA module to carry out a rapid evaluation of the environmental impacts of the new modified model, especially in the use phase. As a consequence, designers can simultaneously improve product energy efficiency and environmental sustainability.

3.4 Cost estimation module

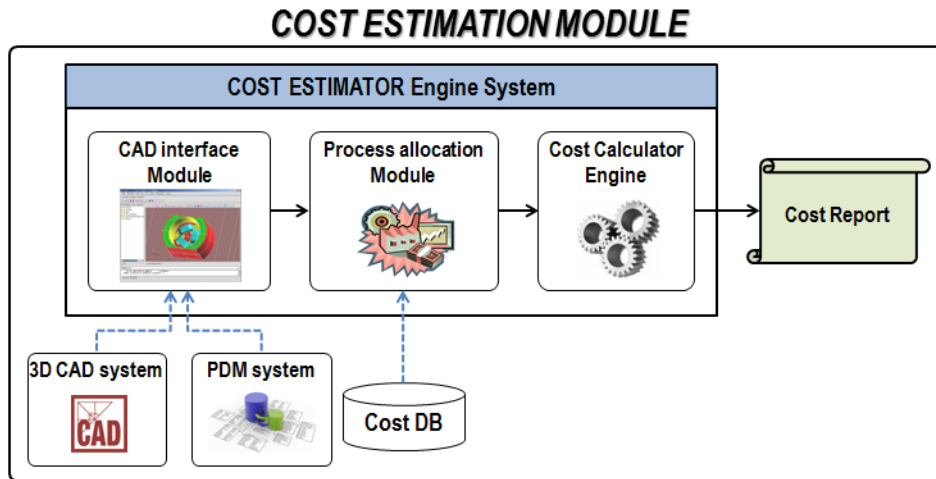
The cost estimation module (Figure 7) is used to control the production costs of the electric motor components during the design process. It is based on the determination of cycles and times, which are stored in the *cost* database, required for the production of electric motor components. It is based on the formalised knowledge of expert designers.

The module is composed of several packages. The first is a CAD Interface, which allows production cycles to be assessed. In this phase, the platform extracts the product structure and all the constitutive components of an electric motor by analysing a CAD model. This module can also retrieve all the information, such as geometric dimensions or materials, necessary to perform the cost analysis.

The next phase is the determination of the production cycles required to manufacture the product. The automatic identification is performed by the process allocation module. For each electric motor, the tool is able to recognise and compile a list of the necessary

production cycles by selecting them from the cost database. The assessment is influenced by the settings of several parameters, such as raw material costs or labour costs.

Figure 7 Cost estimation module architecture (see online version for colours)



The cost calculator engine is the module that performs the estimation of the production costs according to the information retrieved by the modules previously described. As the module completes its operations, the designer can visualise the costs for single components and production cycles. Costs are generally classified as follows:

- raw material costs due to the acquisition of starting materials
- production cycle costs due to transformation operations required for the component
- auxiliary component costs.

3.5 Collaborative design module

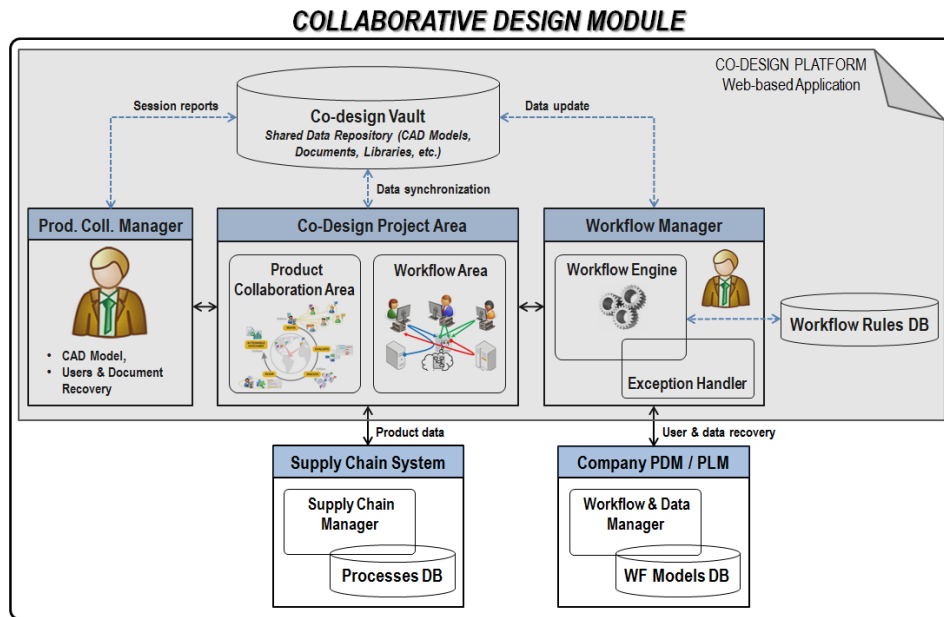
The collaboration module of the EROD platform provides important functionalities, such as efficient document management, collaboration among remote users and secure filtered access to the data stored in the common database. The developed architecture is presented in Figure 8. The fundamental modules of these tools are the project area, which is the user interface for accessing co-design sessions, the product collaboration manager, which allows the real-time exchange and sharing of important design data, and the workflow manager, which allows the collaborative processes to be managed. The basic block of the co-design area is the project, a 'logic box' that contains all the documents and data for a collaborative effort among remote users.

The collaborative design module provides electric motor designers with the following technologies to improve collaboration among remote actors involved in the same project:

- 2D/3D CAD model visualisation tool to import, compare and measure models.
- CAD data sharing tool for the simultaneous interaction of more than one user in the same model.

- Digital mock-up tool to add attributes and characteristics to 3D models.
- Documentation management tool for rapid information exchange with versioning management and modification traceability.
- Audio-video communication tool for virtual conferences among members in different places. This functionality, together with the others, facilitates the collaborative sessions.

Figure 8 Co-design platform architecture (see online version for colours)



4 Experimental results and discussion

The EROD platform and all the developed tools have been tested to support the design processes of five Italian companies involved in the production of energy efficient electric motors for different applications. The developed electric motors are innovative solutions in each of the relevant industrial and domestic fields: cooker hoods, washing machines, air cooler evaporators, electric vehicles and machine tools. The standardisation of the design process, the automation of repetitive operations, the possibility of easily applying an integrated approach to the simultaneous monitoring of performances from several points of view and the control of the collaborative design process in the whole supply chain, which are guaranteed by the EROD approach and platform, allow a significant reduction in the time required for the configuration and optimisation of innovative products. Furthermore, the new solutions show improvements in terms of energy efficiency and sustainability (Table 1).

From the results presented in Table 1, the improvements in electrical efficiency of the new motors are clearly visible. In particular, the increase is significant for small motors,

such as those used in cooker hoods. However, the improvement of more than 10% in high power motor efficiency (machine tool applications) is also very important because the industrial sector is currently the largest electric energy-consuming field. Moreover, because the use phase is the most critical one for energy-using products, the new configured solutions lead to important reductions in the environmental impacts during the entire lifecycle. These results are very important considering that National and European Governments are issuing directives to reduce greenhouse emissions and, consequently, global warming.

Table 1 Comparison between currently used and new motors

<i>Application</i>	<i>Efficiency improvement</i>	<i>CO₂ savings per 1 hour of use [kg CO₂eq.]</i>
Cooker hoods	+ 35%	0.126
Washing machines	+ 20%	0.0366
Air cooler evaporators	+ 31%	0.0594
Electric vehicles (for goods transportation)	+ 12%	1.8
Electric spindles (for machine tools)	+ 13%	0.82

The main advantage observed during the testing phase of the EROD platform is the possibility for companies to apply an integrated approach without heavily changing the traditional product design process. This is because the approach defined for the implementation of the IT platform has been based on an accurate analysis of the ‘traditional’ product design processes of electric motor manufacturers. Another relevant aspect is the easy integration of an eco-design strategy through the use of the proposed LCA and DFEE tools. This is a very important result that addresses the increasing demand for new green products, designs and manufacturing that take into account sustainability concerns during the early phases of the design process. Furthermore, the full integration of several dedicated tools in a univocal interface permits the reduction of errors and repetitive iterations and certainly leads to an increase in the quality and degree of optimisation of the newly developed products because electric motors can now be quickly and simultaneously verified from different points of view.

To further clarify the use and effectiveness of the EROD approach and platform, the following sections present two cases in detail.

4.1 Cooker hood test case

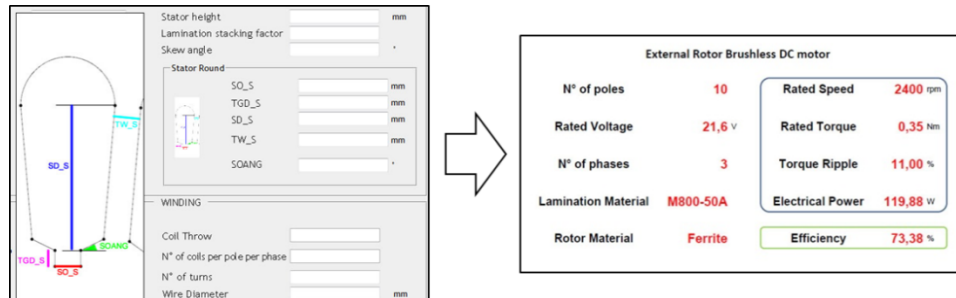
The electric motors currently used in the cooker hood sector have very low efficiencies. In particular, the most common solutions are shaded pole motors and asynchronous single phase motors. Though these motors provide a maximum efficiency of 30% to 35% (approximately 25% for shaded poles), they are widely used due to their very low production costs. In this context, the EROD platform has been tested for designing a brushless PM motor for high quality cooker hoods. The new configured motor has double the efficiency compared to most currently used motors. Even if these results could be reached by the company without implementing the proposed approach, this test case demonstrates that using the EROD platform leads to relevant savings of resources.

The first stage of the design process is the evaluation of four different solutions: a brushless PM motor with interior magnets, an external rotor brushless DC motor with

surface magnets, a synchronous reluctance motor and a brushless PM motor with surface magnets. Thanks to the KB system, the evaluation of the above design solutions is quite rapid. The platform is able to configure the 2D model automatically by recovering information from the databases. The user only needs to set several parameters in the web-based interface, such as the materials or the geometrical dimensions of the stator, the stator slots and the magnetic rotor. By using the platform, a comparative evaluation of the different design alternatives can be performed using the same basic motor model and simultaneously considering several different aspects (performances, efficiency, sustainability and costs). As a consequence, the final optimised solution can be reached without an excessive increase in the necessary development time.

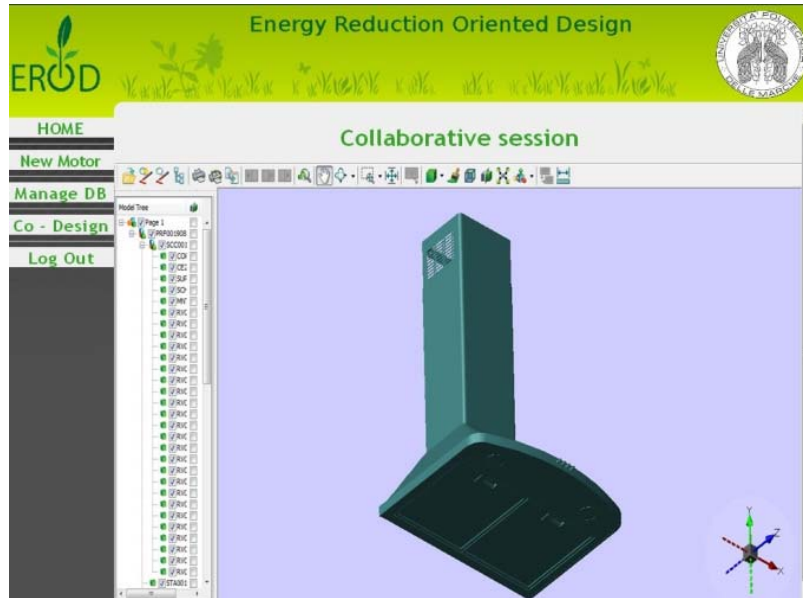
When the model configuration is finished, the FEA simulator, which is completely controlled by the platform, automatically evaluates the electromagnetic performance of the new motors. The final solution is obtained by using the DFEE module. Evaluating the losses in the various parts of the electric motor permits the understanding of the main causes of these losses, which, in this case, refer to the stator and rotor laminated cores. The variation of some input parameters, such as type and thickness of lamination steel and height of the stator core, permits the required performances to be reached and thus the energy efficiency class to be improved. The use of the EROD platform allows designers to rapidly modify these design parameters to verify the possible consequences from different points of view, not strictly in terms of efficiency. Figure 9 shows the platform interface and the performances obtained for the optimised solution of the external rotor brushless DC motor with surface magnets.

Figure 9 Input interface and optimised motor performances (see online version for colours)



Given that one of the greatest costs of brushless PM motors is related to the materials and, in particular, to the hard magnet used in the rotor, a cost analysis is necessary to assess the economic feasibility. The cost estimation module permits a rapid evaluation of the production costs of more than one solution. In this case, the final configuration uses a Ferrite magnet, which has worse magnetic characteristics compared to other materials, such as rare earth magnets, but has a lower cost.

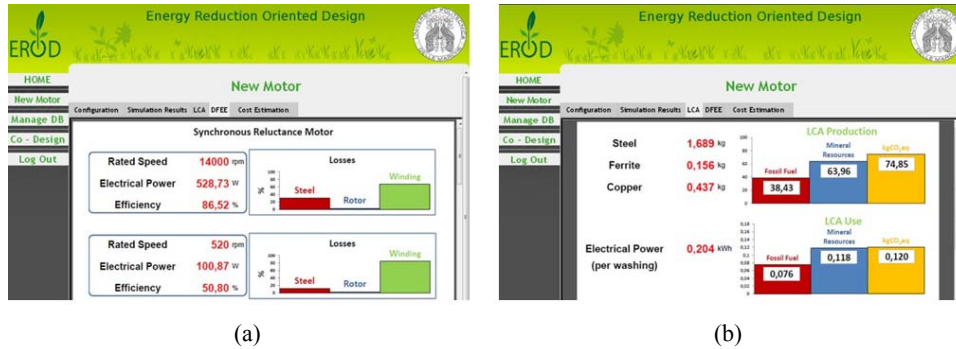
Finally, the co-design module is used throughout the project to host collaborative sessions among the actors involved in the above described design process. The CAD data sharing session (Figure 10) permits the configured model to be evaluated not only independently but also integrated in the whole cooker hood. By using the collaborative area of the EROD platform, all the actors in the cooker hood supply chain can easily exchange data and information and collaborate to satisfy all the product requirements (aesthetic, functional, dimensional, etc.).

Figure 10 A CAD sharing session of a cooker hood 3D model (see online version for colours)

4.2 Washing machine test case

The second case study is another important domestic appliance, the washing machine, in which the currently used motors are universal and asynchronous three-phase. In this context, the EROD approach has been tested to configure a new synchronous reluctance motor with the aim of improving the electrical efficiency by at least 20% in comparison with the traditional solutions.

The use of the KB system combined with the integrated FEA software permits the evaluation and simulation of an innovative type of motor with a permanent magnet (ferrite magnet) in the flux barriers of the rotor. The use of the DFEE tool to evaluate the various types of losses in the motor model allows the optimisation of the dimensions of the flux barriers to obtain further improvements in efficiency. A subsequent structural analysis also confirms the resistance of the rotor laminated structure. The electromagnetic performances obtained for the optimised motor at different work points (14,000 rpm for spin-dryer and 520 rpm for washing) are presented in Figure 11(a). In addition, the use of the LCA module permits the evaluation of the environmental impacts of the innovative motor in both the production and use phases. The use of these dedicated tools allows the company to take into account the sustainability aspects, which are usually neglected in the electric motor industrial field because the LCA methodology is time consuming and most common LCA simulators are general purpose and require a huge amount of input data that designers do not have available during the design phase. In the successive diagrams, the indicators chosen for the impact estimation are the consumption of fossil fuel and mineral resources and the quantity of CO₂eq emitted into the air [Figure 11(b)].

Figure 11 Performance and loss evaluations (a) and LCA assessment (b) of the synchronous reluctance motor with interior permanent magnet (see online version for colours)

5 Conclusions

The design process in the electric motor industry is usually driven by designers' experience; for this reason, it needs to be standardised to eliminate inefficiencies and improve the quality of configured products. This paper proposes an integrated approach and a related semi-automatic web-based platform, called EROD, which seeks to standardise and support the entire design processes of electric motor manufacturers. The full integration of several modules permits the rapid configuration of new products and the concurrent verification of many important design aspects (performance, efficiency, sustainability and cost). As a result of the use of the proposed platform, companies can continuously innovate their products to rapidly satisfy different customer needs. This allows the company to gain a competitive advantage over market competitors.

The proposed case studies demonstrate the effectiveness of the developed approach and software system in helping designers reach an optimised configuration. The innovative motors, designed for applications in cooker hoods and washing machines, exhibit relevant improvements in terms of energy efficiency and sustainability in comparison with the motors currently in use. Because the platform guarantees the standardisation of the design process, the reduction of errors and iterative repetitions in the optimisation phase and the possibility of rapidly perform comparative analysis from several points of view, the final solution can be configured with relevant savings in terms of development time and, consequently, costs.

Future works should verify the robustness of all the developed tools by testing the platform on other types of electric motors used in different applications. It is also necessary to improve the automation of the platform to reduce the number of input parameters required. In this way, the design process will become more repeatable and rapid, and unwanted errors and time required will further decrease.

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