By Lois Lee, Chief Officer, Vector Fields

Speeding the Design of Electrical Machines

Analytic computer programs are a starting point for many engineers designing rotating electrical machines. Such software solves electromagnetic equations for specific geometries, and is typically inexpensive and quick to run. However, analytic solutions can compromise accuracy, and more importantly, are closed systems that cannot be modified except by the originators.

The alternative is a CAE tool employing, for example, Finite Element Analysis (FEA). These programs typically offer flexible graphical user interfaces, allowing users to simulate any design concept with precision and accuracy. Wider analysis options are also on offer. For example, FEA programs can accurately compute eddy currents and naturally evaluate motional effects. However, the time required for analysis using FEA software, with its three step approach of pre-processing, solving and post-processing is unfavorable. While solution times have steadily decreased over the years owing to technological advances in computers, significant effort is still required by the user at the pre-processing stage. That is, building the geometry and setting the right conditions for solution.

If FEA techniques can be made more accessible, then much greater virtual prototyping integrity is possible, and this is the focus of development effort that has created a template-style front-end to a generic electromagnetic modeling tool.

The new approach, the Electrical Machines Environment, is an add-on 'toolbox' available with the established Opera commercial electromagnetic FEA package (2D and 3D). Within the environment, an FEA model for a generator or motor can be created in minutes using templates with 'fill in the blanks' style dialog screens. The software then builds the resulting machine model, performs the necessary solutions and provides simulation results at selected operating conditions. Variation of the given design parameters allows different scenarios to be tested, and through an iterative process the user could arrive at an optimal machine design. Alternatively, the parametric model can be used to drive an optimization tool within the software, setting specific objective functions.

Templates have been designed for most common electrical machine types (Table 1). One important feature of the environment is that the templates employ generic scripting and parameterization techniques and the underlying code can easily be modified by users. This provides the freedom to create customized geometries, including special proprietary features such as profiled stator teeth in switched reluctance machines (SRMs) or flux weakening features in permanent magnet (PM) machines.

Table 1. Machine Types Supported

Induction
Synchronous
Switched reluctance
Permanent magnet DC (rotor armature)
Brushless PM (many variants)

Example Design

Figure 1 shows an example definition phase for an induction motor. Lengths, angles and point positions are parameterized providing geometric flexibility. The program builds the machine geometry based on these parameters (Figure 2). If satisfied with the design, users can then proceed to analysis. Analysis data, specific to each type of machine is subsequently entered, as well as solution details, including mesh density and the required resolution of the results. The program proceeds to solve the model and process the results. An example of results, showing an induction motor's torque versus speed curve is presented in Figure 3.

Manipulating Design Constraints

The structure of the template-based design environment is open. The user is able to examine the logical organization of the models and analysis settings and change or add specific features, ranging from the addition of minor geometrical features, winding arrangements, to complete stator or rotor structures or alternative analysis and post-processing requests

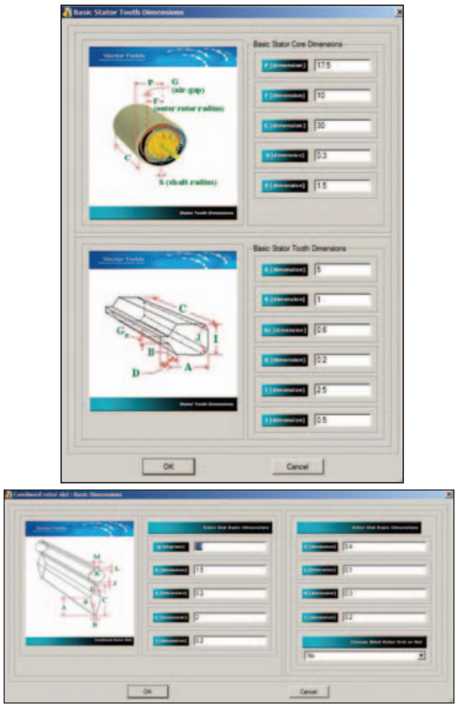


Figure 1. Dialog window requesting information for the stator (top) and the rotor of the induction motor.

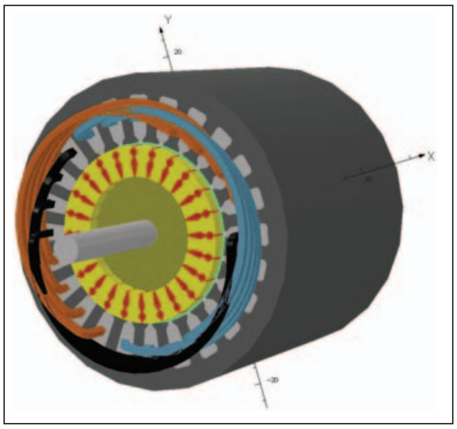


Figure 2. 3D model of an induction motor.

Machine design is subject to constraints that are activated during the model definition. These are geometrical constraints and are derived from the technical drawing. A set of algebraic expressions has been assigned for each design parameter so that the respective design constraint is implemented. When the input value of a geometric parameter is out of the range specified, the software responds with an error message and prompts the user to alter the input value. The use of variables and expressions in the design constraints allows changes to the geometric dimensions to be made quickly.

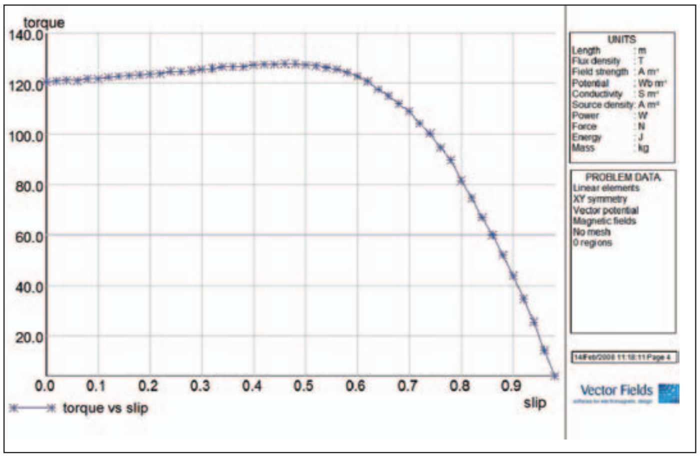


Figure 3. Graph of torque versus rotor slip of the induction motor (typical simulation results).

Design Optimization

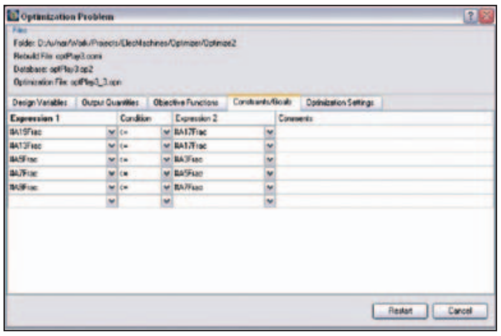
Once the user has produced a design they can optimize it automatically using the general purpose Opera tool. The process takes the original geometry, adjusts it automatically, solves the model using finite elements, checks the results for improvements and carefully selects a new geometry with a high likelihood of further improvements to the design.

During a simple interactive set-up procedure (Figure 4) the user is able to select important input parameters from the design environment. These will be adjusted as the optimizer creates new geometries in its search for a global minimum. A post-processing analysis with resulting parameters can be created to allow the optimizer to define the quality of the generated model.

Input parameters can be assigned upper and lower limits, to prevent the construction of unfeasible models and to define the size and shape of the input parameter space. However, due to the automatic geometry checking within the environment the optimizer will not construct geometrically bad models. These models are not simply ignored however; the optimizer realizes the implications upon this region of the input parameter space.

Constraints can be imposed on the optimization by creating functions of the input and output variables. Analysed model geometries can then be seen to satisfy the constraints in graphical form as a function of the interaction number. Again, the optimizer does not simply discard models which do not satisfy the constraints.

The optimizer begins by submitting a range of designs across the input parameter space to the Opera batch processor, to gain a diffuse knowledge of the relationship with the objective space. The searching algorithm then begins to home in on regions of interest where minima occur. However, exploratory models are also built in sparse regions of input space to reduce the likelihood of missing other small but potentially deep minima. A balance is therefore maintained between the two to prevent effort seeking tiny improvements on potentially false minima.



Folder: D:/u/nar/Work/Projects/ElecMachines/Optimizer/Optimize2
Rebuild File: optPlay3.comi
Database: optPlay3.op2
Optimization File: optPlay3_3.opn

Expression 1	Condition	Expression 2	Comments
#A15Frac	<=	#A17Frac	
#A13Frac	<=	#A17Frac	
#A5Frac	<=	#A3Frac	
#A7Frac	<=	#A5Frac	
#A9Frac	<=	#A7Frac	

Figure 4. Optimizer dialog window displaying the constraints tab.

The optimizer's search algorithm analyses the stochastic properties of the input space and utilizes a Kriging-assisted surrogate method to predict the shape of its solution surface and thus determine the position of the next model with the highest likelihood of improvement. Where multiple objective functions are specified, solutions are ranked according to their location between Pareto surfaces in the objective space.

Design Efficiency

This new approach to design can deliver significant advantages in today's market environment. The accuracy of FEA simulations, combined with easy to interpret results, gives designers the means to rapidly make informed decisions - whether the need is simply to make the most cost-effective solution for a given application, or to come up with something new. Currently, there's enormous pressure to improve energy efficiency for instance. FEA allows searching 'what-if?' investigations to be performed rapidly, identifying the design characteristics of the right machine with great accuracy.

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