Electrical Machines Design

Multiphysics Analysis and Optimization with SIMULIA OPERA

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The global electric machinery market is set to amass significant growth in the upcoming years. Factors such as booming electronics & the semiconductor industry in tandem with rapid industrialization and commercialization are driving the growth of the electric machinery market. Increasing utilization of electric generators and motors in industries such as the automotive, renewable energy, robotic, aerospace and defense, etc. are stimulating the industry outlook.

An Electric Machine (EM) is a general term for machines using electromagnetic forces, such as electric motors, electric generators, and others. They are electromechanical energy converters: an electric motor converts electricity to mechanical power while an electric generator converts mechanical power to electricity. EMs are used in multiple applications such as motors for electric drive or industrial processes and generators for renewable and conventional energy supplies.

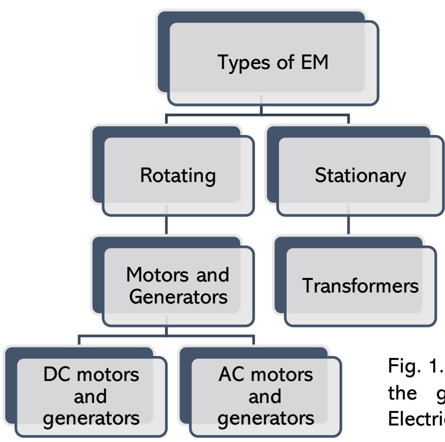


Fig. 1. Diagram showing the general types of Electric Machines.

An electric generator is mechanically identical to an electric motor but operates with a reversed flow of power. In general, an EM consist of the following elements:

- A stationary part known as Stator which usually consists of either windings or permanent magnets.
- A moving part called Rotor, which turns the Shaft to deliver the mechanical power (motor case). Depending on the type of motor the Rotor can have conductors laid into it or can carry permanent magnets.
- Windings, wires usually wrapped around a laminated soft iron magnetic core to form magnetic poles when energized with current.
- The distance between the Rotor and Stator is called the Air Gap.
- The Commutator contains circuit elements to control the EM.

Electric motors' principle of operation is due to the interaction of magnetic fields and current-carrying conductors which generates a rotational force, the opposite is valid for electric generators.

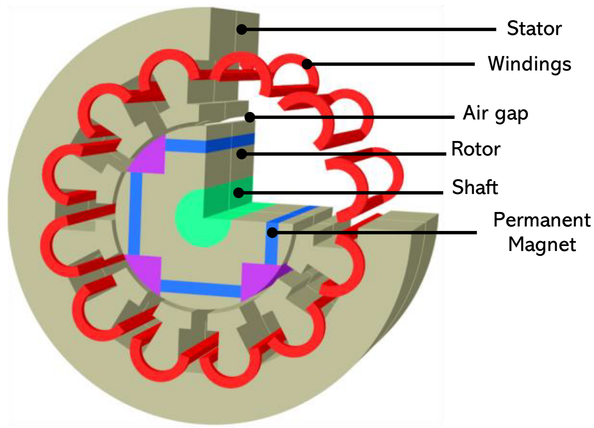


Fig. 2. 3D model created in Opera by the Machine Environment. A 4-pole, 3-phase Permanent Magnet Synchronous Machine (PMSM) with concentrated windings and 12 slots. The permanent magnets are embedded in the Rotor.

EMs are very complex devices, being multidomain by nature involving electromagnetics, thermal, and mechanical aspects. The presence of ferrous materials and permanent magnets demands the use of nonlinear data to capture important saturation effects that can limit performance. In addition, the CAD modeling process of an EM can be a cumbersome task due to the complexity of its geometry. Furthermore, the winding configuration employed in the design will have an impact in several requirements, such as harmonic losses, torque pulsations and acoustic noise and vibrations.

Opera Finite Element Analysis (FEA) simulation software provides the Machines Environment module, which uses a wizard style data entry for ease of use. The Machines Environment have been engineered to aid the design of motors and generators. It provides a wide range of parametric templates of industry-standard machine types and enables model, build and test to be carried out very easily without the need for extensive software training.

Several machine topologies can be automatically modelled and solved, including induction machines, synchronous machines, brushless machines, SRM, claw-pole generators, axial flux machines, commutating machines, external rotor, magnetic gearing, linear motion machines and many others. Since the environment was written in the Opera programming language, which is fully documented and available in the developer version, the command files are mainly open source, so the user is free to make adjustments to the standard command file. This could be a small tweak to a slot shape right through to a completely new topology of Rotor or Winding.

Apart from the Machines Environment, Opera includes an easy-to-use CAD graphical user interfaces, which allow geometries to be created or imported from other CAD programs.

The Machine Environment comprises a series of dialog windows presented to the user to start the machine definition. Stator and Rotor type/dimensions can be defined according to the type of EM selected. Users will be prompted to select from a list of available analysis, they range from simple electromagnetic analyses looking at static Torque versus Angle through to dynamic (Transient Multiphysics, Dynamic mechanically coupled analysis, etc.) and inductance analyses. Once the model is built and depending on which analysis was submitted, the Machines Environment will send a series of jobs to the Opera Manager

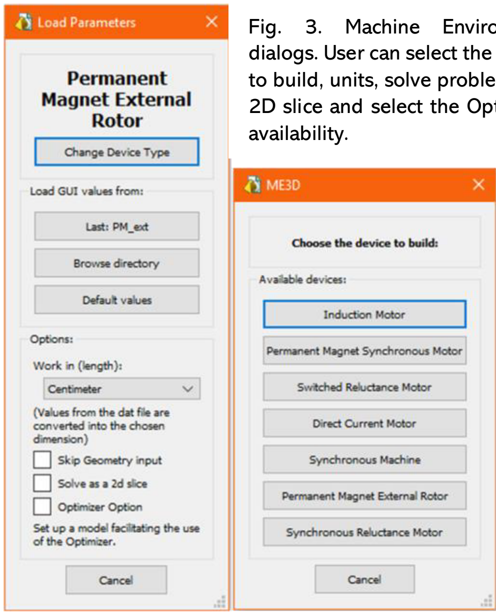


Fig. 3. Machine Environment dialogs. User can select the device to build, units, solve problem as a 2D slice and select the Optimizer availability.

to be solved. The analyses can be performed using static or dynamic (transient and harmonic) motional solvers in Opera.

The mesh size is calculated automatically, but the user can override the default settings to either perform a quick cost analysis or to define a fine high-resolution mesh. Opera 3D capability for creating hexahedral, pentahedral, prism, and tetrahedral meshes, and even a mixture of types allows the discretization of very complex structures.

Definition of complex material properties for the elements of the model also take place in the Machine Environment, from the simplest linear material to full hysteresis models of soft magnetic materials, and the demagnetization of hard permanent magnets, allowing fault conditions to be fully investigated.

For multiphysics analyses thermal and stress solvers can be used. Thermal solvers can be used to calculate thermal distributions on a static or transient basis or automatically pass results between the thermal and electromagnetic solvers. So, users can also use temperature dependent materials and account for thermal strains. The static stress module may be used in a standalone mode with the user defining the distribution of forces or it can be used in a multiphysics simulation with other Opera 3D modules, providing the force or temperature distribution. The deformation computed by the stress analysis can be used to modify the geometry in subsequent

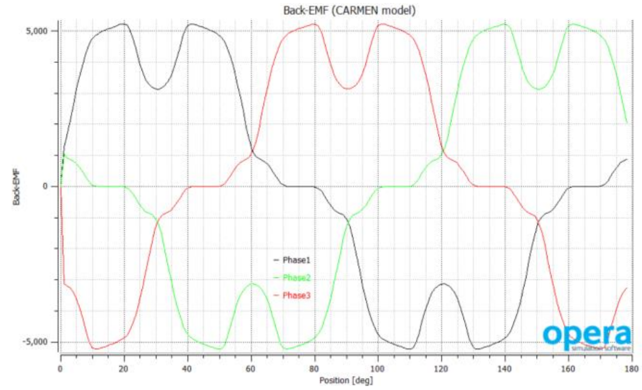


Fig. 4. Back EMF results at different angular positions for a PMSM using a Transient Motion analysis.

thermal and electromagnetic simulations. In addition, eigen value analysis can be applied to structural models. The selection and setting up of the solvers are done automatically by the environment according to the selected analysis.

Drive circuits for the EM are created automatically by the Machine Environment, although users can access the Circuit Editor in Opera and override defaults circuit for circuits of their own. In case of loss calculations are required the user can enter properties required for copper and iron losses (hysteresis loss and eddy current loss).

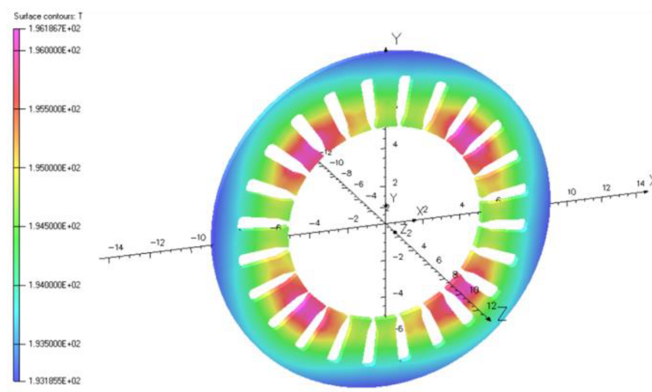


Fig. 5. Temperature distribution in the Stator of a motor after performing a Multiphysics EM-Thermal simulation. The temperature distribution is evaluated based on the iron losses from the EM solution and the copper losses, these results are passed automatically to the thermal job.

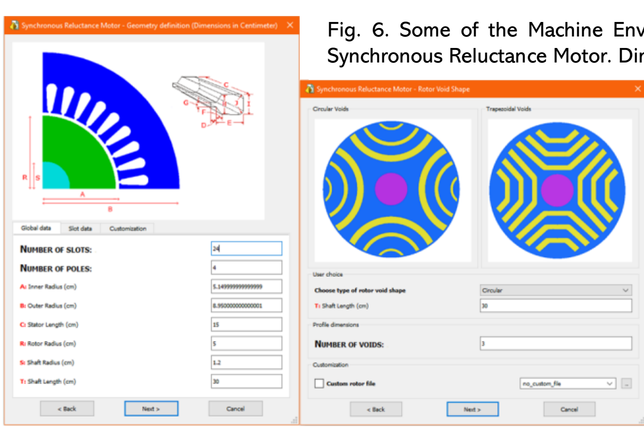
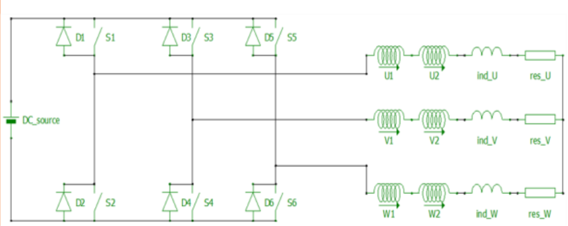


Fig. 6. Some of the Machine Environment dialogs presented to the user for the creation of a Synchronous Reluctance Motor. Dimensions and shape of Stator and Rotor can be selected. Apart from modifying the main geometric parameters of the model users also have the possibility of running custom-built scripts at various points during the building stage. Circuit and command control script can also be customized during or after the creation of the device.



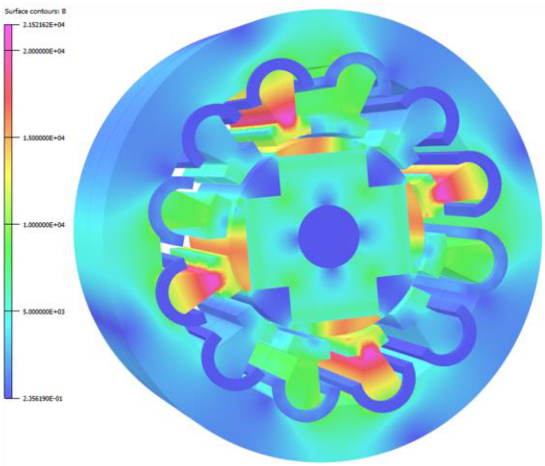


Fig. 7. Magnetic flux density (Gauss) result after running the Magnetostatics solver for a PMSM. The Machine Environment exploits any type of symmetry present in the model to reduce the simulation time. The rotational symmetry that exists in the model is used to reduce the analyzed section of the motor to 90 degrees. The model also allows for an axial symmetry boundary, hence only 1/8 of the original model is needed to be solved.

Winding layout properties like the current per phase, turns per phase, frequency and others can also be defined in the Machine Environment. Additionally, Opera FEA software provides a winding toolbox dedicated for electrical machine design. The Winding Tool helps users assess feasibility and optimality of different winding configurations that can be used in Opera.

Since the created model is completely parameterized and the Machines Environment offers a direct coupling with the Opera Optimizer, refinement and optimization of designs based on user requirements can be performed easily. In addition, the environment offers an option to run the 3D geometry using a 2D approximation by simply clicking on this option, no data is lost, and no extra information is required for this. This leads to a significant reduction of simulation time. Furthermore, multi-thread acceleration is also available implementing parallelization of the solution process to make the most of the multi-core processors installed in standard laptops or desktop computers as well as high-end servers.

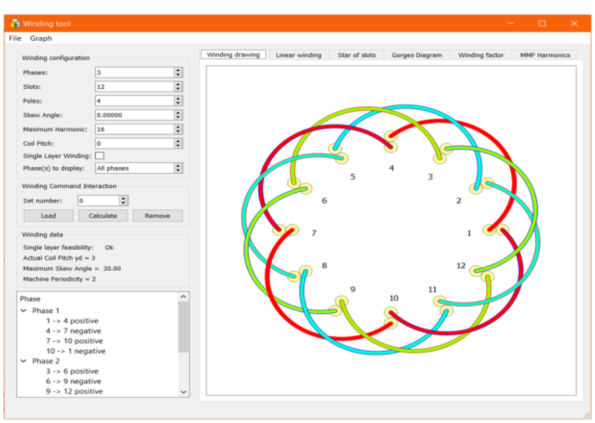


Fig. 8. Winding Tool of Opera. Provide information about the optimal winding layout, winding harmonic factor, Star of Slots representation, winding factor harmonics, Görges diagram, etc…

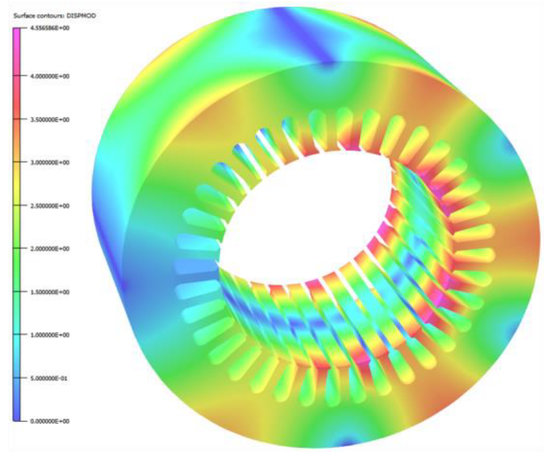


Fig. 9. Stator displacement (cm) results at a frequency of 4626.21 Hz after a Stress EV analysis. Stator fixed in three points. The analysis uses the Modal Stress solver to calculate the eigenvalues and eigenvectors for the Stator (and/or Rotor). The output from this analysis is a list of eigen frequencies found in the interval specified by the user.

Whether designing a motor or a generator, an axial or radial flux topology, rotating or linear motion, Opera FEA simulation software provides the right tools for the task. Allowing users/companies who use it to differentiate themselves with optimal design performance, short development timescales, and cost-effective manufacture.

WHO WE ARE: VIAS delivers integrated engineering solutions using simulation-based design and analysis, and data analytics for a variety of industries including Aerospace and Defense, Automotive, and High-Tech. We bring to our clients dedicated, cost-effective, quick, and safer solutions with an experienced team of simulation experts and industry professionals. VIAS provides engineering design, root cause analysis, optimization, and project management services. We also provide knowledge transfer through customized training, and workflow automation and GUI customization. VIAS has relevant experience in EM-Thermal analysis, thermo-mechanical analysis, finite element analysis (FEA) involving large material deformation, and non-linearity (geometry, contact, plasticity). Our team of experts has several years of combined experience covering multiple low-frequency application areas including electrical machines, electromechanical devices, sensors, power generation/distribution, and charged particles.

ABOUT THE AUTHORS:

Daniel Ochoa has 9 years of experience working on topics related to RF and microwave systems, modeling and simulating different types of electromagnetic problems. He has worked in areas like Antenna, Antenna Array, PA design, broadband matching networks design, and Filter design. He also has experience on the simulation of statics/low-frequency systems including electrical machines and electromechanical devices. He provides technical support and engineering services to customers on CST Studio Suite and Opera Simulation Software solutions. He was an Assistant Professor and Researcher with the Technological University of Habana, where he received his B.S and M.S degrees in electronics and telecommunications engineering.

Pankaj Jha is a Senior EMAG Solution consultant at VIAS. He has 7 years of academic and industrial experience in modelling and simulation of different types of Electromagnetics problems. He has worked in areas of Antenna, Antenna Array, Filter Design, Microwave and RF circuits from GHz to THz, Bio-Electromagnetics, EMI/EMC and EDA/Electronics. He provides technical support and engineering services to customers and helps drive growth of VIAS electromagnetics solutions. He worked with Dassault Systèmes SIMULIA as a Solution Consultant and was responsible for Aerospace & Defense, High-Tech and Automotive industry technical portfolios for CST. He is a graduate from Indian Institute of Technology, Delhi (IIT-D), where he studied Radio Frequency Design and Technology.