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Finite Element Modeling of Hydrogenerators with Flux®

Hydrogenerators parameters extraction and dynamical behavior prediction can be easily determined with a two dimensional finite element modeling. Comparisons with experimental values have shown that a high accuracy can be achieved for classical or non conventional tests, among them :

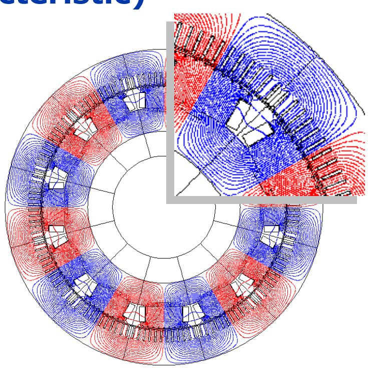
- **No-load characteristic**
- **Synchronous inductance in the d- and q-axis**
- **Transient and sub-transient inductance in the d- and q-axis**
- **Field and damper winding inductances**
- **Standstill frequency response (SSFR)**
- **Form factors C_1, C_{ad} and C_{aq}**
- **THF factor**
- **Sudden short circuit analysis**
- **Interaction of the alternator with its working environment (System simulation)**

These tests can also be conducted with Flux on other types of rotating machines (turboalternateurs, induction motors, DC motors,…).

Machine geometry and study domain

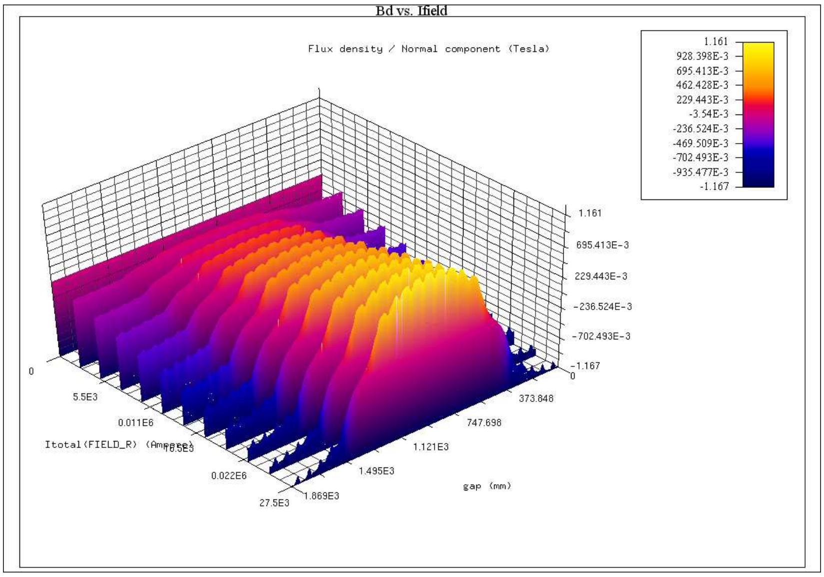
For hydrogenerators and other types of rotating machines exhibiting a periodic configuration, cyclic conditions are used in order to minimise the computation domain. For a full slot winding, one or two poles are usually modeled. With fractional slot windings, the minimum periodicity is required. By using Flux functionalities such as the coupling to electrical circuits it is easy to make static or dynamic tests on the generator. Moreover, Flux allows the computation of rotor torque, electric power, as well as iron and copper losses for steady-state and transient operation. As illustration of the software capabilities, the next sections will show some tests we have conducted on a full winding hydrogenerator.

No-load test (U_0-I_0 characteristic)



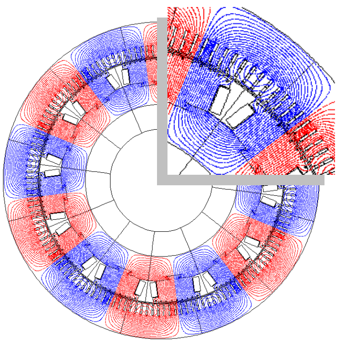
The figure above shows the Flux lines generated by the excitation winding on a hydrogenerator cross-section. By varying the excitation current from 0 to I_{f0}, we can draw the no-load U-I characteristic.

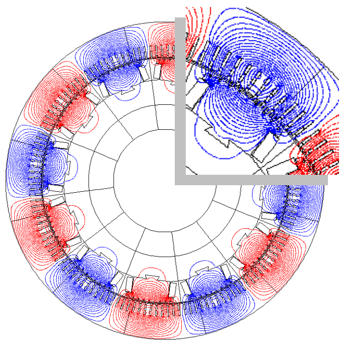
Normal component of the airgap Flux density vs. field current at no-load



The normal component of the airgap Flux density can be displayed in a 3D curve (position on the x coordinate, Flux density on the y coordinate). In a non linear situation the Flux density varies proportionally to the field current.

Synchronous inductance in the d- and q-axis (Ld, Lq)



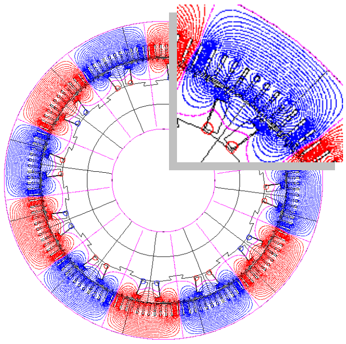


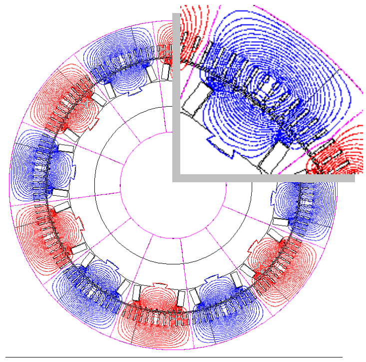
The synchronous inductance in the d- and q axis are determined through a magnetostatic resolution. The Flux software allows to freely move the rotor in any position during a magnetostatic analysis. Therefore the pole axis is moved in order to be oriented in the phase A axis then 90 electrical degrees forward. Phase A is supplied with a current $\hat{I}$ and phase B and C with $-0.5\hat{I}$. The Flux coupled with phase A is equal to $L_d\,\hat{I}$ or $L_q\,\hat{I}$.

Transient inductance in the d- and q-axis ($L_d^{'}, L_q^{'}$)

The transient inductance in the d- and q axis are determined with the help of a harmonic analysis. The damper short circuit ring is assumed to be open while the field circuit is short circuited. The information on the damper winding bars connection as well as the field winding connection are given through a coupling of the finite element domain to an electrical circuit.

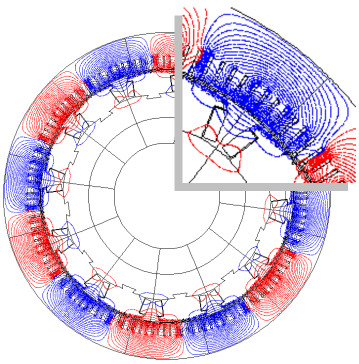
Phases A, B and C are supplied with a sinusoidal currents shifted by 120°. The rotor axis is oriented along the phase A axis then 90 electrical degrees forward. The Flux coupled with phase A is $L_d^{'}\hat{I}$, respectively $L_q^{'}\,\hat{I}$.

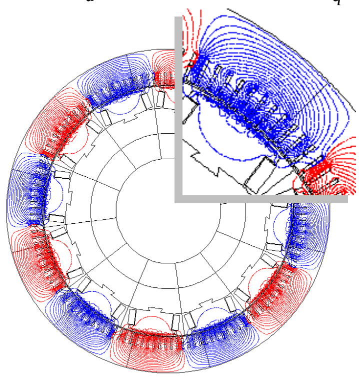




Subtransient inductance in the d- and q-axis ($L_d^{"}, L_q^{"}$)

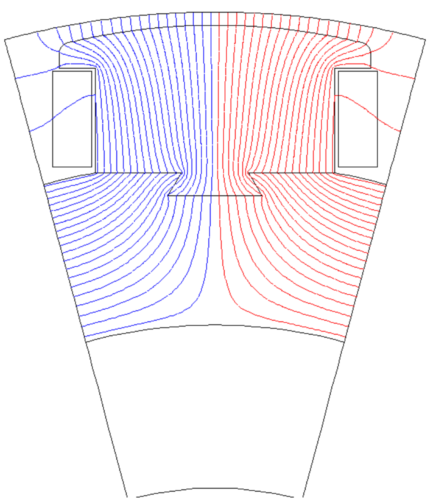
The subtransient inductances in the d- and q axis are determined with the help of a harmonic analysis. The damper and the field circuit are short circuited. Phases A, B and C are supplied with a sinusoidal currents shifted by 120°. The rotor axis is oriented along the phase A axis then 90 electrical degrees forward. The Flux coupled with phase A is $L_d^{"}\hat{I}$, respectively $L_q^{"}\hat{I}$

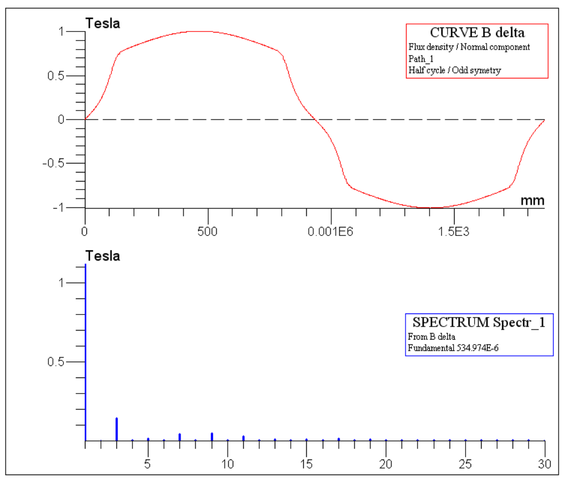




C_1 form factor

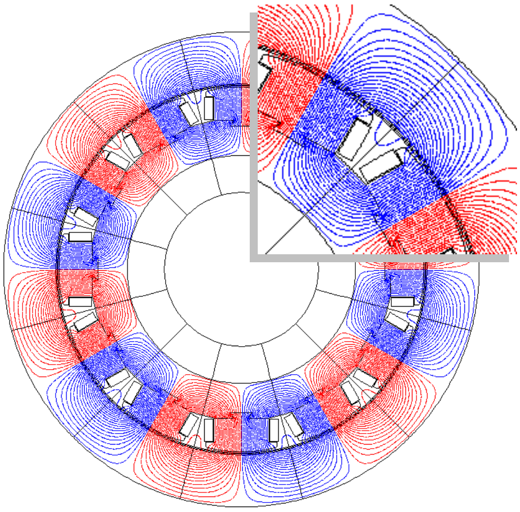
The C_1 factor is determined for one pole. The airgap width is equal to $\delta_0 k_c$, δ_0 being the minimum airgap and k_c the Carter factor. The iron is considered to be infinitely permeable. The stator bore is assumed to be a smooth surface. The field winding is supplied with a constant current. The normal Flux density in the airgap fundamental value and peak value yields the C_1 factor.

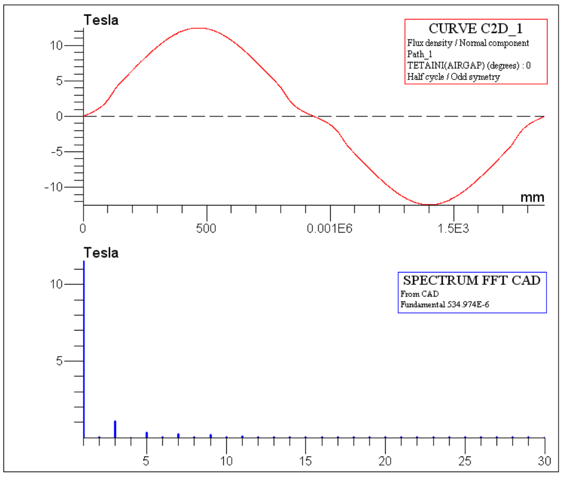




C_{ad} form factor

The C_{ad} factor is determined for one pole. The airgap width is equal to $\delta_0 k_c$, δ_0 being the minimum airgap and k_c the Carter factor. The iron is considered to be infinitely permeable. The stator bore is assumed to be a smooth surface. The armature reaction is oriented along the d-axis. The normal Flux density in the airgap fundamental value and peak value yields the C_{ad} factor.

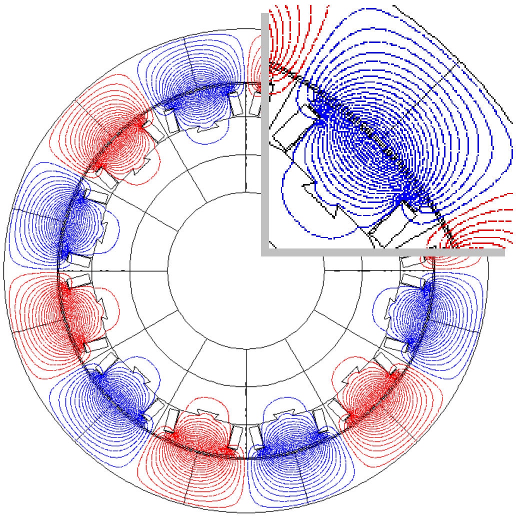


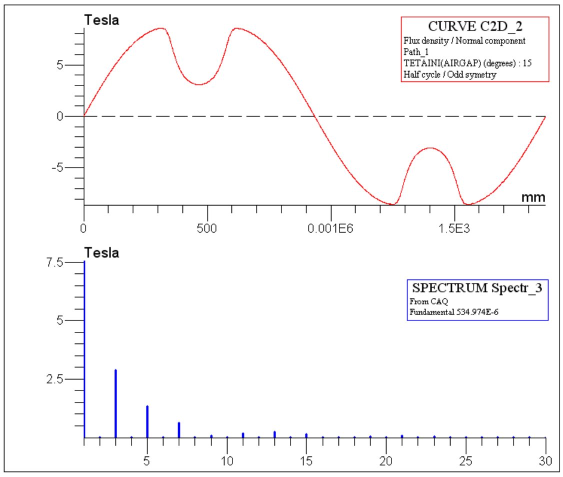


C_{aq} form factor

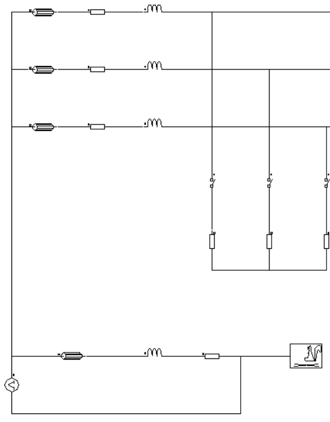
The C_{ad} factor is determined for one pole. The airgap width is equal to $\delta_0 k_c$.

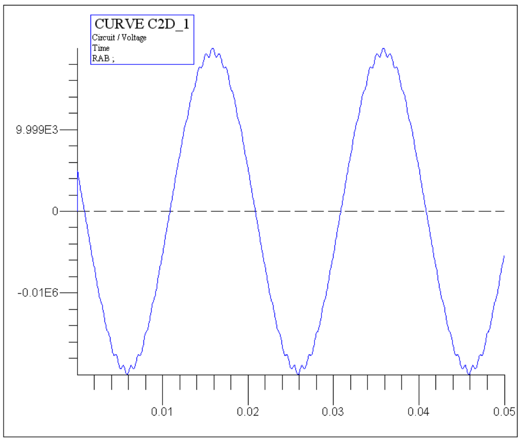
The iron is considered to be infinitely permeable. The stator bore is assumed to be a smooth surface. The armature reaction is oriented along the q-axis. The normal Flux density in the airgap fundamental value and peak value yields the C_{aq} factor.

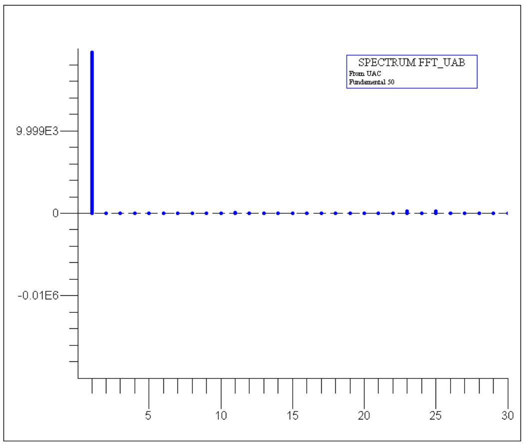




THF form factor (influence of the damper winding currents on the THF factor)



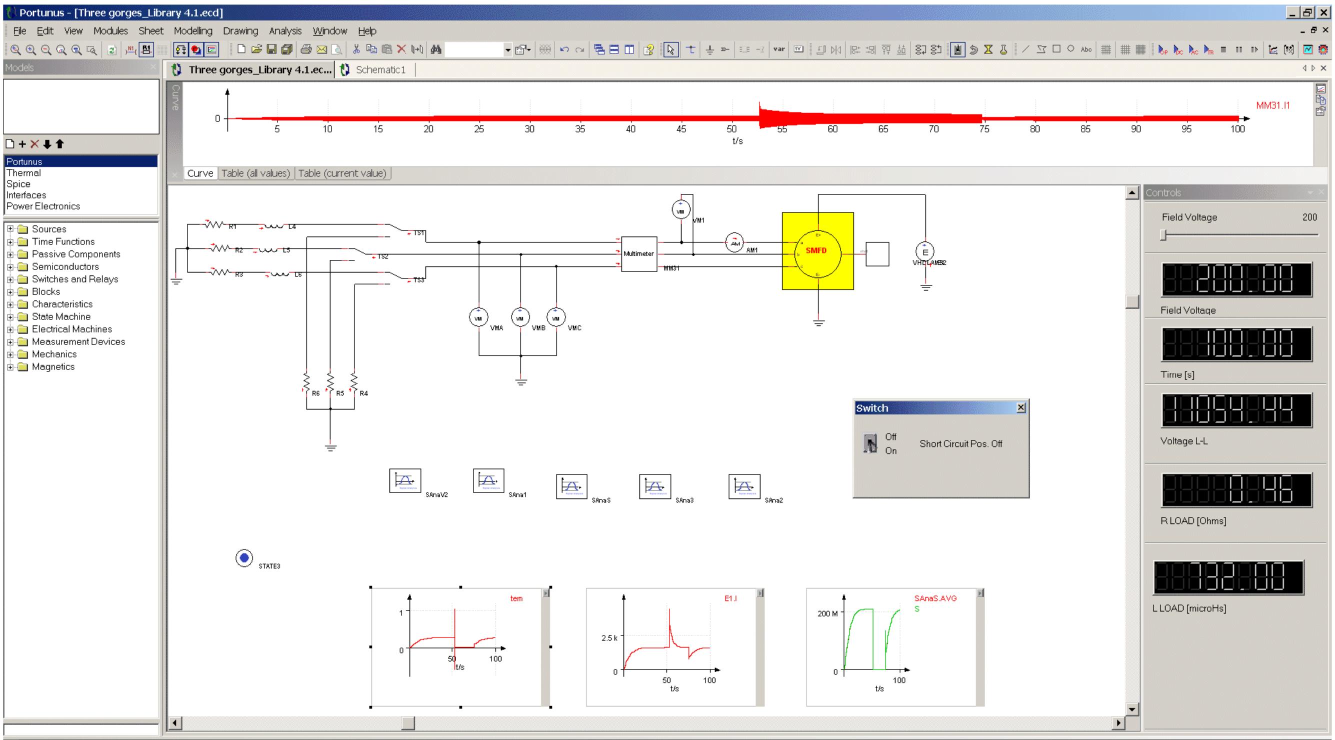




The THF factor is determined in a transient analysis, with the rotor moving at constant velocity. The field winding is supplied with rated value and the damper winding is active. The oscillations on the stator terminals voltage are due to the damper currents variations as well as to the stator and rotor slots. The THF factor is computed from the no-load voltage harmonic components. The curves displayed above show the line to line no load voltage vs. time and its Fourier transformation.

Interaction of the alternator with its working environment

By coupling the finite element software Flux to the system simulation software Portunus®, we can investigate the interaction of the alternator with its working environment using a complex non linear model and not a model based on the Park equations (figure below). It is thus possible to integrate transformers, transmission lines, turbine, regulation, machines in parallel,...



Sudden short-circuit investigation on a large hydrogenerator