The simulation of electrical machines is done in several steps. First the construction is to be done using the bottom up or top down method resulting in a model consisting of components, volumes, areas, lines and points with different properties according air, steel, aluminium or copper. Within the second step the meshing is done respecting areas with high magnetic work such as the airgap with very small Finite Elements. After finishing the model with border conditions and loads within the third step the user may analyze his problem. Following this way the user can do static and harmonic calculations in a short time, a user friendly menu is helpful.

The problem of those Finite Element simulations is the impossibility to simply change parameters such as airgap distance, machine diameter or yoke thickness. On the other hand motion of machines, that is the moving of the rotor within or towards the stator according, or the changing voltages or currents at the windings is impossible. To do those electromagnetic simulations the engineer needs a Finite Element System with macro language and changeable parameters, electromagetical elements such as voltage or current sources, resistors, inductances and coils to switch the elements of the Electrical machine together to a complete system, methods for building sliding interfaces between stator and rotor according the motion of the machine and at least the transient analyzes method. ANSYS as a multipurpose and multiphysical Finite Element System includes all features for building moving 2D and 3D models of Electrical machines taking switching and changing of voltages and currents into account.

In the following chapters the simulation of two different types of Electrical Machines, one is a synchronous linear induction machine, the other is a rotating DC machine taking the commutating process into account in 2D is explained.

The synchronous linear induction machine

Synchronous linear induction machines are used for performing a linear motion of a system. At low speeds for example gates or elevator doors are moved, at high speeds they can be used for transportation such as the German TRANSRAPID.
The preparation of the whole Finite Element model consisting of stator and rotor mesh using a user menu or macros with subprogram techniques taking parameters into account.

Figure 2. Finite Element Model of the synchronous linear induction machine

Within the first step the designer of synchronous linear induction machines is interested in designing the magnetic circuit as a result of the field current using the static simulation. Result of such a simulation is the magnetic field in the airgap and steel and the force between stator and rotor, of course this may include nonlinear materials for steel.
In order to calculate the inductive voltage as a result of the motion of the rotor consisting of pole pairs by still standing stator consisting of switched AC windings the engineer has to build a complex Finite Element System consisting of a slightly different separate model with mesh for stator and rotor and an electric circuit with coils representing the windings within stator and rotor and resistors, inductances, wires and voltage or current sources to complete the electric circuit switching of the machine separately for stator and rotor. The coils within the electric circuit are connected to the Finite Element coils with coupling equations. Using this way the voltage or current sources may be changed according the time respecting sinusoidal or other wave forms for voltages or currents by changing only the property parameter.

Respecting time and speed the rotor is to be moved, the connection of stator and rotor is done with a sliding interface using couplings or constraint equations for each Finite Element border node in the stator to the nearest node within the stator border. After each simulation step the time changes. As a result the coupling between stator and rotor has to be released and afterwards new configured. In order to calculate the
Inductive voltage the voltage sources of the stator have to be changed to resistors with very high resistors, this is the simplest method for calculation.

**Figure 5. Inductive voltages of the three phases at speed according 50 Hz with planar stator and rotor borders at airgap**

In order to calculate the reaction of the stator according the load angle delta between stator and rotor the rotor has to be accelerated from speed 0 to working speed according the frequency of the voltage sources within the stator from 0 to working frequency. To do a well performed acceleration the amplitude of the voltage sources has to be changed following the U/f-dependence between the voltage source U and the frequency f according the speed of the linear motor. To get a well performed transition process the increment of the frequency has to be changed very slow when narrowing the working speed. The transition process needs up to 2000 time steps for convergence.

**Figure 6. Voltage sources in the phases in the transition process according the U/f-dependence**

With respect of time, frequency and state between stator and rotor stator current, raise and push forces and other electromagnetical terms may be calculated.
Figure 7. Magnetic field within the airgap under load angle 30 degrees at a special stator-rotor-position

Whereas the static simulation of the synchronous linear induction machine without sliding of stator towards rotor is to be calculated in very short total wall clock time in only seconds. For calculating the inductive voltage there is a need for a transition process of nearly the length of a pole pair. Due to accurate inductive voltage calculation there is a need of 48 up to 200 steps within one sinus time period. All in all there is a need of 96 up to 400 steps for calculating the inductive voltage. The solution time need is at least several minutes cause ANSYS has a problem with element and node renumbering according the shift of the rotor versus stator. This problem is solved yet after changing over from frontal solver to sparse matrix solver after clearing a problem with coupling of freedom of degrees and master nodes. For calculating a synchronous linear induction under load the transition process from speed 0 to working speed takes a very long time, up to 3 or for more day according the accuracy, number of pole pairs and number of steps within one sinus time period of the model. For calculating the load process after the transition process there is a need of only hours for each load step.

The rotating DC machine respecting the commutating process

Rotating Electrical machines models are to be designed simpler than linear machine models cause the sliding of stator towards rotor is to be simulated simpler. When rotating the rotor within the stator the sliding interface is simpler cause for each angle it is possible to find a near node at the rotor border for each stator node. The generation of the model is nearly the same as that of the linear induction machine. The big difference is the representation of the commutation process of the DC machine cause the brush move on the copper lamells of the rotor and the situation between brushes and lamells changes each angle step. To implement this into the model each lamell is connected to the plus and minus poles of the DC voltage source with a high resistive resistor.
According the angle between stator and rotor and the offset commutating angle the resistor parameter that represents the brush connected lamell is changed from high resistive (1e6 Ohms) to low resistive (1e-6 Ohms).

After building the model of the rotating DC machine there are several possibilities for calculations. First the engineer may calculate the magnetic circuit according the field current with static simulation. Harmonic analysis makes no sense for DC machines. With transient analysis the inductive voltage may be calculated according the motion between stator and rotor. The transition process from speed 0 to working speed can be done immediately, after about 10 iteration steps the transition process is done and the simulation is true.

Under load with rotor current the transition process is nearly the same, a bit slower than without load.
Conclusion

Static and harmonic calculation of linear and rotating electrical machines is to be done very simple with Finite Element Systems such as ANSYS. The calculation of moving and rotating electrical machines needs a complex model with sliding interface between stator and rotor and electric circuit presentation of windings and wires. The sliding interface has to be changed according the move of the rotor. Once done this complex model can be used for calculating inductive voltages and simulations under load are possible. Simulations with AC sources need a very long transition time, whereas DC simulations are to be done very simple. The major problem of transient analysis of rotating and linear move electrical machines is the long solution time for each angle step calculation.