Electromagnetic Design: Towards Energy Efficiency.

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Despite many efforts to save energy, demand for electricity is expected to grow and much faster in comparison with other energy sources. Electricity's share of the total energy market in OECD countries is expected to grow from 24% in 1970 to 40% in 2020 [1]. This migration towards electricity, the refurbishment of electrical equipment in advanced countries and the domestic energy rise in emerging countries will lead to US$10 Trillions of investments in the production, transmission and distribution of electricity in the next three decades [2]. Moreover, as you can see in figure 1 which draws the energy demand in the US during the last half century: whatever the sector or the technological period, the losses are always twice of the final consumption. In this context, searching for the most efficient energy flow between the producer and the consumer of electricity becomes a major point of interest in electrical engineering and power management. It implies not only how electrical power is produced and supplied (renewables, micro-generation, transmission losses, …) but also, on the demand side, many electrical equipment that contribute to the power flow and unfortunately also to the losses: generators, transformers, electrical connections, actuators, sensors, … All these components have to be optimized to maximize their efficiency and a smart management of the power grid is necessary to keep reliability. This article gives a quick overview of what simulation tools can bring to design energy efficient systems.

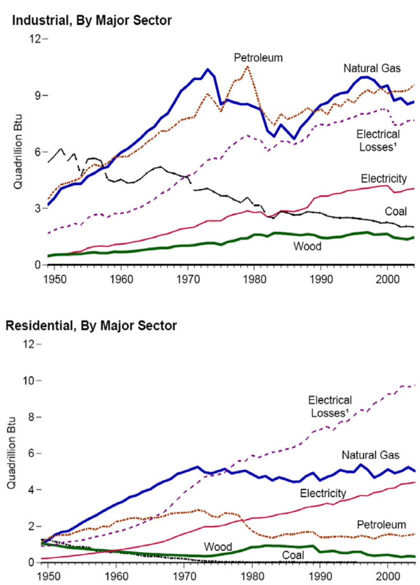


Figure 1: Half-century evolution of energy consumption in industrial and residential sectors in the US [3].

Electrical connections

Looking at the yearly production of aluminum and copper used for the manufacturing of electrical conductors and from there drawing a rough estimation of the losses they produce, it leads to about 430 SENPP (Standard Equivalent Nuclear Power Plant = 7 TWh/year), which is about 20% of all electric energy production. Henceforth it is easily understood how important the design of electrical connections is. As shown in figure 2, in addition to DC losses, AC losses due to skin and proximity effects have to be taken into account. Considering the shapes of the conductors and their relative positions as design parameters, it is possible to minimize the AC losses [4].

The PEEC method available in InCa3D® is particularly suitable for this matter. It has the ability to precisely evaluate skin and proximity effects in conductors with no need of meshing the air region surrounding them. It allows dealing with geometries with high aspect ratios very efficiently, which would be quite difficult to handle with the finite element method. The very fast calculation times provided by the tool also opens the doors for either the robust design or optimization of devices.

Devices with ferromagnetic parts

New regulations in US and Europe appear to enforce high efficiency motors and transformers. When considering these devices, not only joule losses in conductors, in these cases both windings and the losses within ferromagnetic parts have to be evaluated.

For example, as shown in figure 4, a very useful feature can be found in Flux to assess the losses within a transformer:

- Proximity effects in windings efficiently calculated using homogenization techniques
- Iron loss computation thanks to either Bertotti or Loss Surface modelling.
- Specific surface models to assess losses in thin regions like the tank.

Life Cycle assessment.

Design is classically focused on cost, performance and time-to-market.

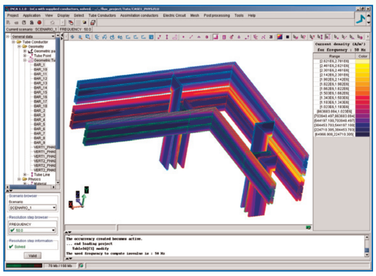
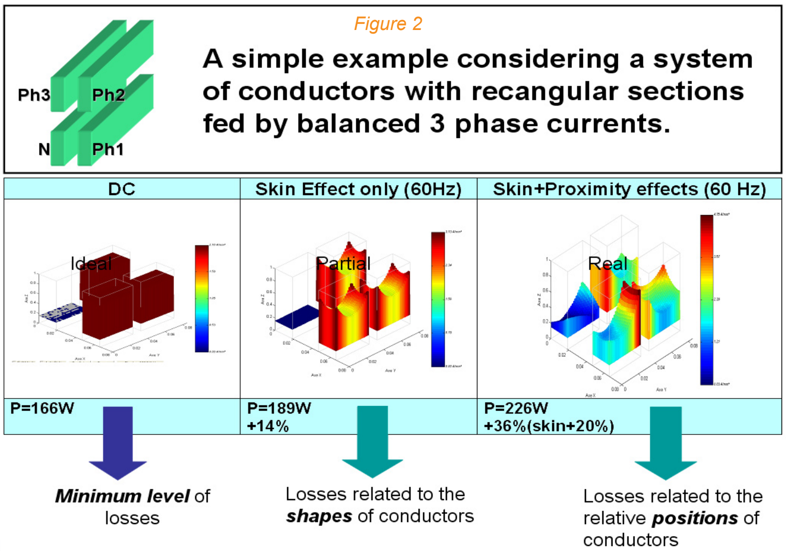


Figure 3: Busbar system simulation with InCa3D.

Figure 2



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The environmental cost including the whole life of the product has now to be considered as a new constraint in the early phases of the design. Life Cycle Assessment has then to be done, that is the evaluation of the impact of manufacturing, logistics, use and recycling of devices on the environment. For this, specific tools like EIME [5] [6] exist. They are able to produce environmental profiles and indicators of a design. For example, when permanent magnets are used in motors or actuators, it will for sure reduce the power consumption for the operation of the device, but what about hazardous waste production and the energy required for mining and manufacturing process when using rare-earth magnets ? FLUX ® is able to exchange data with EIME and gives information on the quantity of material used and the power consumption for the device to operate. Such coupling between simulation software and LCA tools is essential to evaluate the impact of technological choices.

From the source to the load, a full chain to be optimized

The minimization of the joule losses produced by each element of the power network or a mechatronic system is necessary, but isolated optimizations are not sufficient: energy efficiency should also be considered at the system level. Moreover the introduction of power electronics and embedded systems are now key technologies to control the flow of electrical energy from the source to the load precisely according the requirements of the load.

This is true at the level of power networks with "smart grids", not only to achieve an optimum power flow but also to ensure power quality, security and to be able to deal with intermittent sources of energy like solar and wind. PSCAD® is particularly well suited for design at this level.
This is also true for many fields: industry, transportation systems, buildings and home appliances, where mechatronic systems can be found. An interesting point to look at is the control of electric motors. Many motors still run at fixed speeds and motor drives use 50-60% of all electrical energy consumed in the developed world. By using power electronics controlled motor drives a potential reduction in energy consumption of 20-30% is achievable [7]. For such designs, the system level tool Portunus® and its connection to Flux® is essential to be able to optimize the efficiency of the whole system.

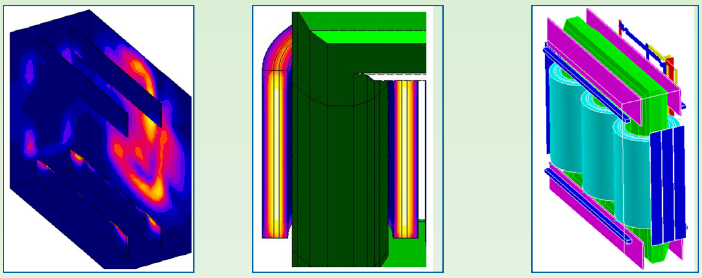

Figure 4: Stray losses in the tank - Proximity effect in the windings - Full geometry of the transformer

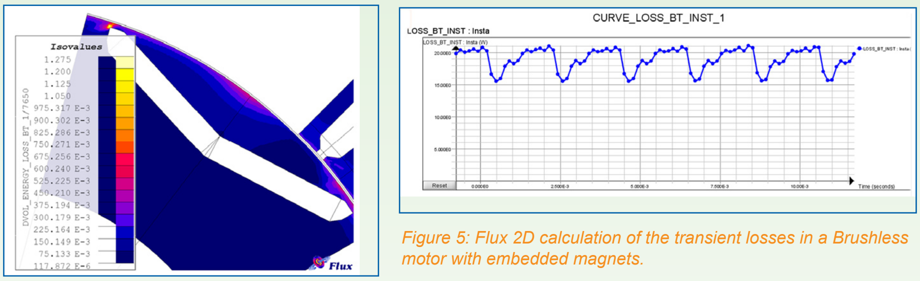

Figure 5: Flux 2D calculation of the transient losses in a Brushless motor with embedded magnets.

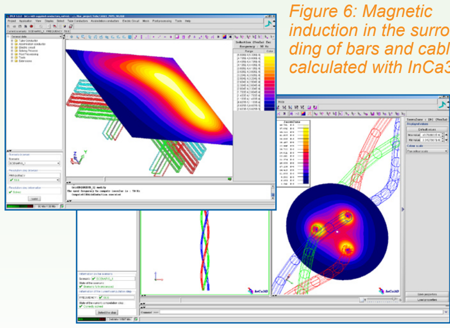

Figure 6: Magnetic induction in the surrounding of bars and cables calculated with InCa3D.

Because power electronics tend to introduce intermediate frequencies and because the use of embedded systems makes signal and power closer to each other, the system designer has to cope with new EMC issues. For this matter, the ability of InCa3D® to compute fields radiated by cables or more generally by electrical connections is an essential feature (Figure 5).

Conclusion

To design systems that achieve an efficient electrical power flow, a multi-scale modelling approach is required [8]. Depending on the scale or the nature of the device, different methods and tools can be proposed. Power network analysis is addressed by tools like PSCAD®; mechatronic systems can be modelled using system simulators like Portunus; the component level is undertaken by using fine analysis tools like InCa3D® and Flux®. Connections between different levels of modelling, as well as the connection with LCA tools are also essential. Providing a full and coherent suite of simulation software for you to be able to face these new challenges of energy efficiency is a very strong motivation and a major axis for the future for CEDRAT.

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