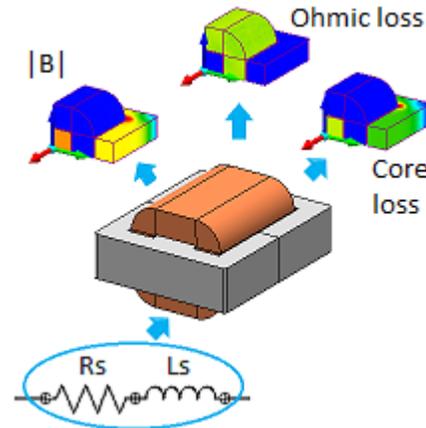# Boost Converter Inductor Analysis

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# Boost Converter Inductor Analysis

Analytic methods are widely used in inductor and coil designs. However, these methods do not fully account for core nonlinearity, skin-depth, gaps, 3D, load variations, capacitive and switching effects. In addition, it is difficult to map the non-uniform distributions (hot spots) as shown in the figure. Simcenter MagNet can address most of these issues save for capacitive and thermal analysis. In this application, it is used to analyze the inductor of a 27 kW boost converter that steps-up an electric vehicle's battery voltage from 200 V to 200 - 650 V range. Two boost circuits utilizing a hysteresis current controlled switch, and a PWM voltage controlled switch are used to regulate the inductor current and output voltage, respectively. The two circuits demonstrate how current and voltage controlled switches can be implemented in Simcenter MagNet. The analysis includes meshing of the core to account for skin-effects, extracting inductor parameters, use of controlled switches to account for switching effects and loss distribution.

Siemens PLM Software
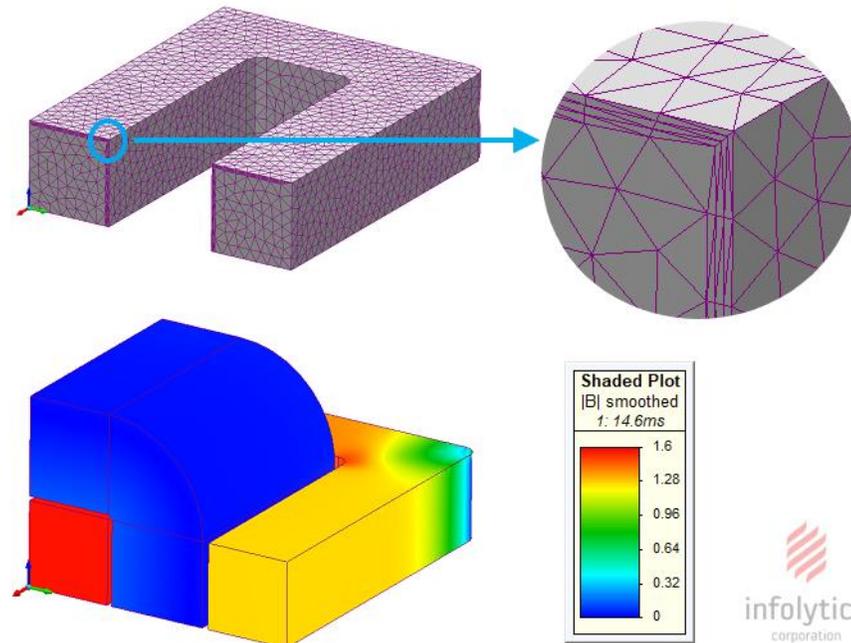
INDUCTOR MODEL

A 3D model of an E-core inductor was used in the analysis. This required the scaling of the relevant results. A 2D model would have underestimated the core flux-density and losses, as it neglects the end-windings, which are of the same dimensional order as the coil-sides.Simcenter MagNet via the Modeling Toolbox allows the mesh layers to be conveniently parameterized and applied on faces of the core or solid conductors predisposed to skin-effect. This improves numerical efficiency since the mesh layers do not propagate inside the component as shown in the figure. The figure also shows the non-uniform flux-density distribution, which is usually assumed uniform in analytic design.

INDUCTOR PARAMETERS
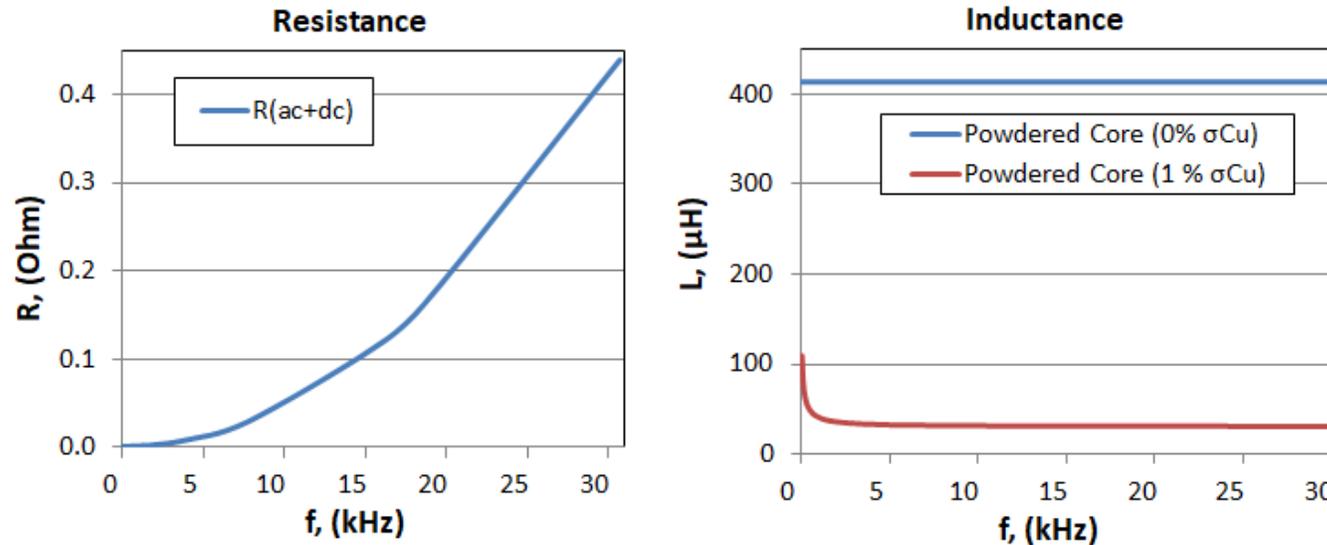
The parameters of an inductor are dependent on the design and operating frequency. Simcenter MagNet is easily applied in the determination of resistive and inductive parameters. The increase in the coil resistance with increasing frequency due to ac effects is seen in the resistance chart. The contributions from the core were mitigated by assuming a zero conductivity for the core (0% of σCu) in resistance analysis. Simcenter MagNet static and time-harmonic solvers were used to generate these results. The inductance chart shows that a higher core conductivity (1% of σCu) will effectively reduce the inductance with increasing frequency. The coil was stranded to minimize its contributions during inductance analysis. That is, the skin-depth is much greater than the strand area. Therefore, Simcenter MagNet can be used to improve the inductor design by analysing the coil and core effects independently, as a function of the operating frequency.
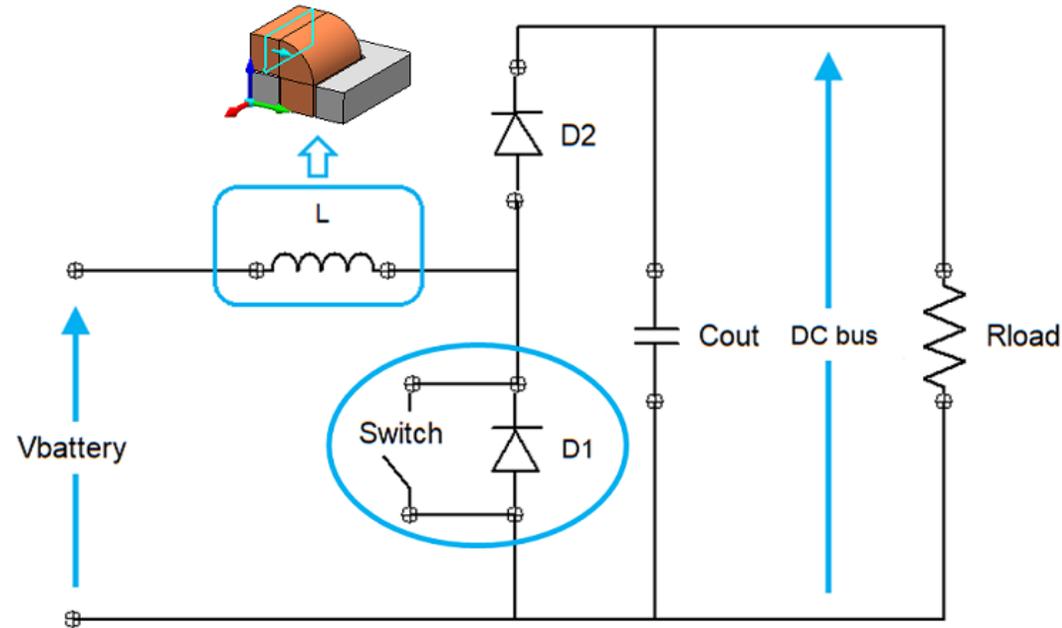
The boost circuit shown in the figure was fully implemented in Simcenter MagNet; negating the need of a secondary circuit simulator. In this example, a hysteresis current controlled switch (hysteresis-CCS) and a PWM voltage controlled switch (PWM-VCS) were used to control the inductor current and the output voltage, respectively.

# HYSTERESIS CURRENT CONTROLLED BOOST CIRCUIT
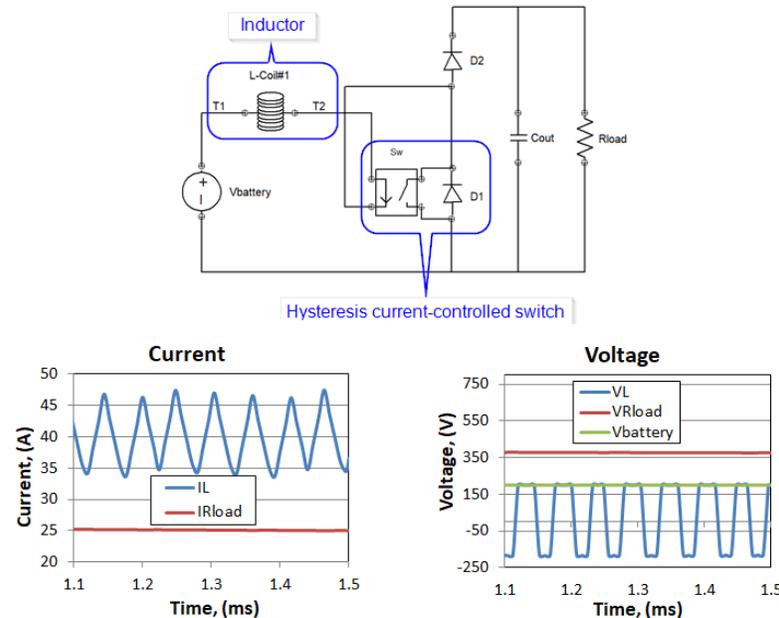
Inductors can be used as storage elements by regulating the inductor current. In this example, the reference inductor current was set to 40 A with a 10 A hysteresis band. The realized inductor current is as seen in the current chart. The figure also shows the load current and the respective transient voltages.

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PWM VOLTAGE CONTROLLED BOOST CIRCUIT
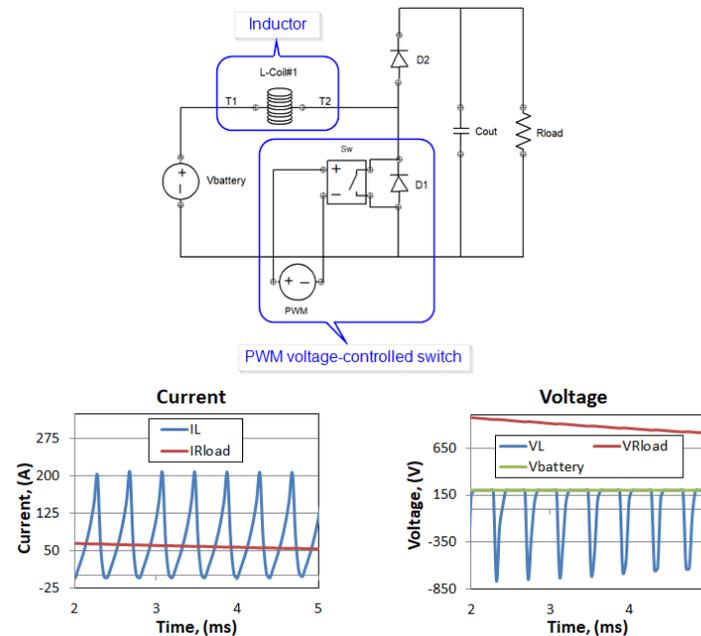
A PWM voltage source of the desired duty ratio was used to control the switch; hence, the output voltage as seen in the figure. It is, therefore, possible to analyze the effect of a PWM switching scheme on the performance of the magnetic element(s) of a converter in Simcenter MagNet. A voltage measured across a circuit element or two nodes can also be used to control the switch. The figure also shows the inductor and load currents, the battery, inductor and load transient voltages.

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SWITCHING INDUCTANCE TRANSIENTS
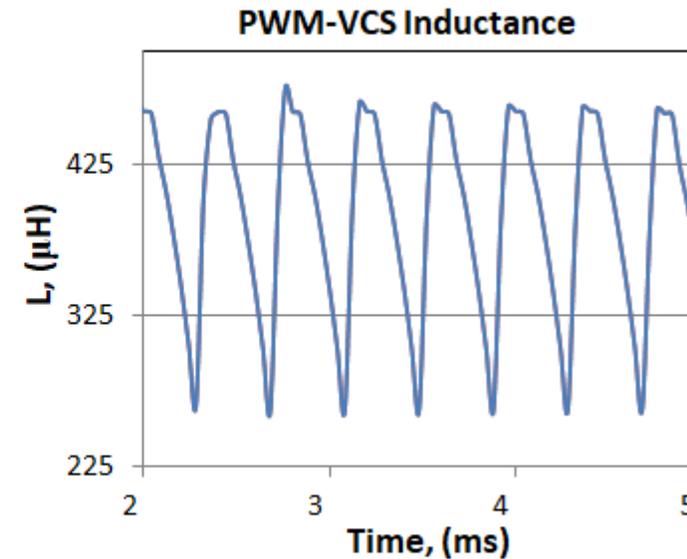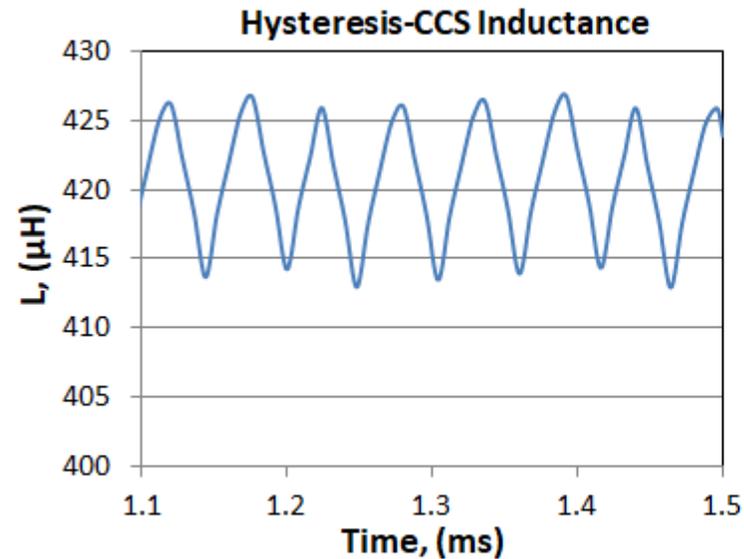
Inductance is dependent on the operating conditions of the inductor, whose performance under transient conditions can be evaluated using Simcenter MagNet's transient solvers. The effect of the two switching methods on inductance is shown in the next charts. This analysis is useful in checking whether the inductor meets the design requirements under different transient conditions such as fault analysis.

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TOTAL LOSS DENSITY DISTRIBUTION
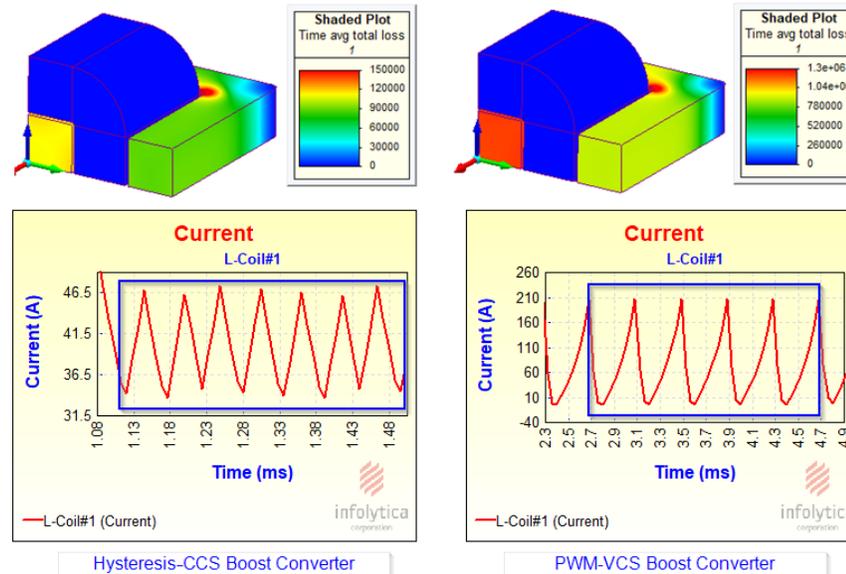
Conductor and core losses can be analysed in Simcenter MagNet by specifying the strand area, and the material properties. In this example, the copper loss was kept low relative to the core loss as shown in the figure, by assuming stranded coils as would be expected in practical applications. However, if it is necessary to take into account skin and proximity effects, solid coils can also be explicitly modelled. The figure also shows the total loss density distribution in W/m^3. The losses were averaged over the windows highlighted in the inductor current plots. This is useful in analyzing the impact of faults and transients, and in comparing different switching schemes.

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This example has shown the ease of using in inductor and coil design by taking into account core nonlinearities, ac effects, switching transients and mapping of losses (hot spots). In addition, it has demonstrated the use of current and voltage controlled switches to realize hysteresis and PWM boost circuits without the need of an external circuit simulator. The choice of the length and location of the averaging window used in the calculation of losses is valuable in analysing faults and loading transients, and in comparing different switching schemes.

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