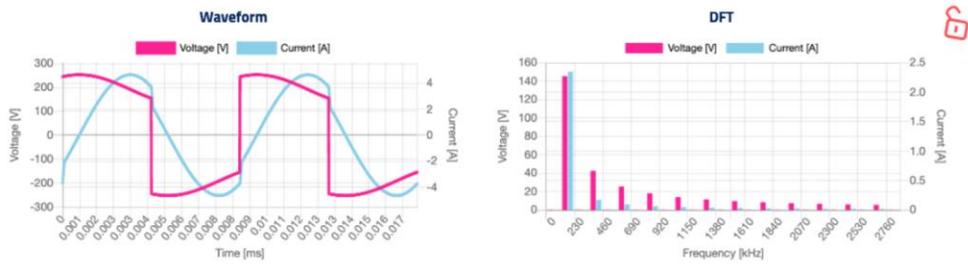


The importance of Hysteresis losses in LLC converters

The power electronics industry is moving to high frequencies due to the latest improvements in semiconductors and the LLC converter is becoming a very common topology. The waveforms of an LLC converter are quasi sinusoidal waveforms, high AC ripple without DC current. In the picture below you can see an example.



In order to be able to optimize the resonant inductor and the transformer of this converter, the losses due to the hysteresis loop are very relevant. The hysteresis loop in buck or boost type inductors, with DC current and a small AC ripple, is translated as a small hysteresis loop, however, AC currents without DC bias show a higher hysteresis loop.

In these series of articles, I will briefly describe briefly the main effects of losses in magnetic components. In my previous [article](#), I talked about Eddy-Current losses. Here, I'm going to describe hysteresis losses in the core.

Let's start with the basic origin of these losses:

"Hysteresis loss is the energy used to align and rotate magnetic moments of the core material. The physics of core losses are very complex, therefore, predict these losses based on the magnetic properties with high accuracy is very complex". Mariam Kazimierczuk [1]

In other words, we need the energy to rotate the particles of any magnetic core. Part of this energy returns to the circuit, but the rest is lost in the process, transformed into heat.

$$P_h = \frac{P_H}{V_c} = f \oint HdB = f A_{BH} (\text{W/m}^3).$$

It is important to understand the relation between the magnetic flux density amplitude and the losses which is shown in the equation below. The larger the flux density amplitude B_m , the larger the Area BH.

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$$P_h = f \oint \mathbf{H} \cdot d\mathbf{B} = 4f H_m B_m = 4f \mu_{rc} \mu_0 H_m^2 = \frac{4f \mu_{rc} \mu_0 (N I_{Lm})^2}{l_c^2} = \frac{4f B_m^2}{\mu_{rc} \mu_0}$$
$$= 4f A_{BH} (\text{W/m}^3)$$

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Now that we understand these losses, we must ask ourselves. Is this effect affecting equally all kinds of materials? The answer is no.

A good magnetic material will have a large permeability and a narrow hysteresis loop. For example, hard steel has a wide hysteresis loop, having larger losses, while soft iron cores present lower hysteresis losses. In the soft irons, there are a wide variety of chemical compositions. Some materials have higher permeabilities and therefore, higher hysteresis losses (Ferrites). On the other hand, there are other materials having low permeability (distributed gap or powder cores) and lower hysteresis loops.

The selection of the material for each case could be critical, especially, in LLC converters with two different magnetics.

Conclusions

The current challenge in Power Electronics is increasing the power density. The semiconductor industry is increasing the performance of the switches at higher frequencies, reducing their size. Therefore, the bottleneck are the high-frequency inductors and transformers. Resonant topologies are one of the main tendencies. The power topology LLC is very common in automotive, telecom, and server applications. The goal of this converter is to work at MHz levels, and the resonant inductor and the transformer must manage a quasi-sinusoidal current, creating a big hysteresis loop in the cores. The designer's challenge is keeping the losses under minimum and the hysteresis losses play an important role.

References

[1] Marian Kazimierczuk - High-Frequency Magnetic Components, Second Edition-John Wiley & Sons, Ltd (2013)