Resonant Power Converter

Resonant Power Supply with an Integrated Inductor

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The presented invention introduces a method for increasing power transferred by an integrated inductor as well as the integrated inductor itself, that is used in resonant-mode electrical energy converters, enabling minimization of dimensions and weight of the ferromagnetic cores used in inductive elements as well as shifting the operating frequency to the range from 500 kHz to several MHz.

In short, the presented method uses a phenomenon of superposition of magnetic induction vectors in both time and space domain. For this purpose the windings of an integrated inductor are oriented with respect to each other in such way, that two magnetic fluxes can pass through the same magnetic circuit independently. The magnetic induction vectors are oriented orthogonally in space and, moreover, their time varying amplitudes are also mutually phase-shifted.

In a topology based on a series-parallel LCLC resonant circuit there is a possibility to use a dedicated integrated reactance element, that would incorporate all the heavy current inductive elements. The selected topology ensures reliable operation of the power converter under any load, from short circuit through nominal load to an open circuit, while keeping the current flow through the resonant circuit uninterrupted. From the perspective of requirements, costs, dimensions and weight the two most critical components are the resonant inductor Lr and transformer Lprim/Lsec (fig. 1 and 2).

Characteristics of LCLC topology

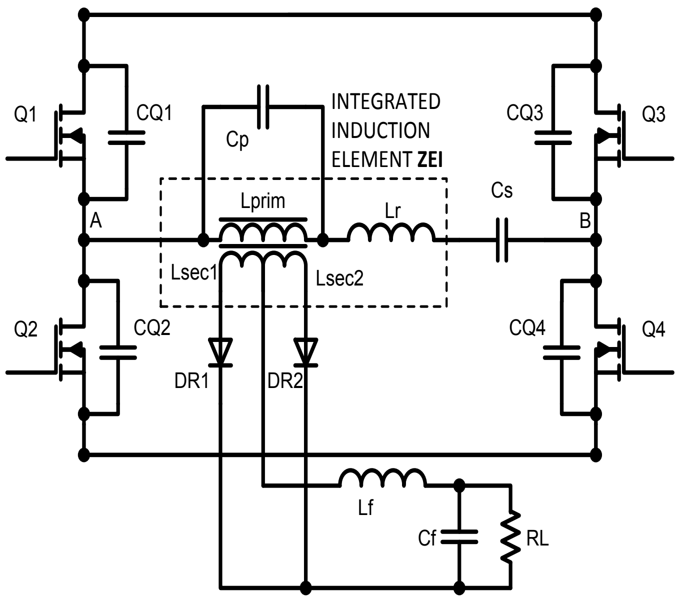

Fig.1. Diagram of the power converter with series-parallel LCLC resonant circuit operating in DE class, based on Integrated Induction Element (ZEI)

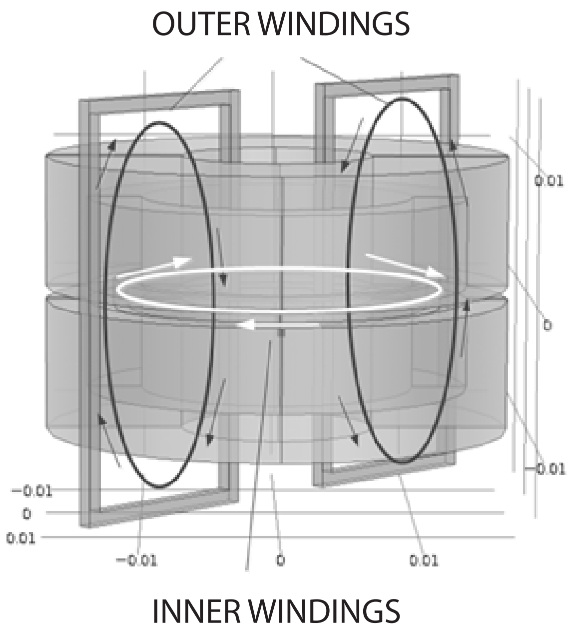

Fig. 2. Exemplary geometry of an Integrated Induction Element (ZEI). Inside the core, time varying magnetic induction vectors originating in currents flowing in the inner winding of transformer Lprim/Lsec and outer winding of resonant-mode inductor Lr superimpose while being perpendicular to each other.

Thanks to the soft zero voltage switching technique used, an ability to control the du/dt voltage change rate was gained, both in resonant circuit as well as in the commutation circuit. This also results in low level of conducted and radiated interference emissions, which translates into reduced costs of filtering components. Moreover, the circuit gives the possibility to have continuous and quasi-sinusoidal current flowing through the resonant circuit, independent of the connected load. An additional benefit is the possibility to regulate the output power in wide range of loads with a relatively small change of switching frequency – that is below 10-15%.

Technology characteristics

Mutually perpendicular spatial arrangement of transformer Lprim/Lsec winding against the winding of inductor Lr results in magnetic induction vectors in ferromagnetic core, originating in currents of those windings, being mutually perpendicular. In addition, when the phase shift of both vectors of magnetic inductions is nearly 90° increase in output transferred per unit of magnetic material volume occurs. Due to nearly sinusoidal waves of currents in resonant circuit, losses due to working frequency also reach the minimum value.

In professional literature, losses in ferromagnetic core are usually described with the formula:

$$P_V = P_{V,hysteresis} + P_{V,eddy\ current} + P_{V,residual}$$

According to manufacturer data, losses in ferromagnetic core $P_V(B,f,T)$ depend mostly on the value of magnetic induction B, magnetic field frequency f and core temperature T, and: $P_V(B) \approx B^{2+y}$ where y∈ [0,1]; $P_V(f) \approx f^{1+x}$ where x∈[0,1]; $P_V(T)$ has the minimum near 90°C.

Thus the highest contribution to losses shall have the value of magnetic induction (dependence stronger than square), field frequency (dependence stronger than linear), and as regards temperature the minimum is in the near 90°C (popular magnetic materials N97, 3F3, 3F4, etc.). Assuming, using simplification, operation of two induction vectors shifted in phase by 90° and in mutually perpendicular planes, and assuming the same induction amplitude related to inductors Lr and Lprim: $B_{Ax1}=B_{Ay2}=B_A$ for sinusoidal and cosinusoidal waves we obtain the module of resultant induction BAxy(t) taking the value described with the formula:

$$|B_{Axy}(t)| = \sqrt{B_A^2 \cdot sin^2\omega t + B_A^2 \cdot cos^2\omega t} = B_A \cdot \sqrt{sin^2\omega t + cos^2\omega t} = |B_A|$$

This is an extremely advantageous situation, as magnetic induction amplitude did not increase. Losses are obviously higher than in the case of sinusoidal wave, due to the fact that magnetic induction amplitude equals BA irrespective of time, however this helps to achieve the maximum use of ferromagnetic core.

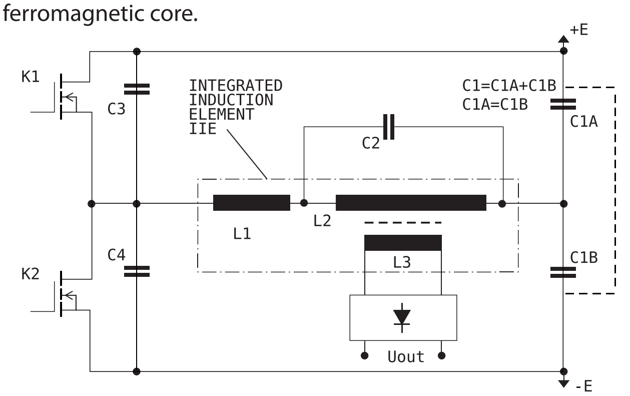

Fig. 3. Diagram of the power converter with series-parallel LCLC resonant circuit operating in DE class, based on Integrated Induction Element (IIE) and a photo of IIE

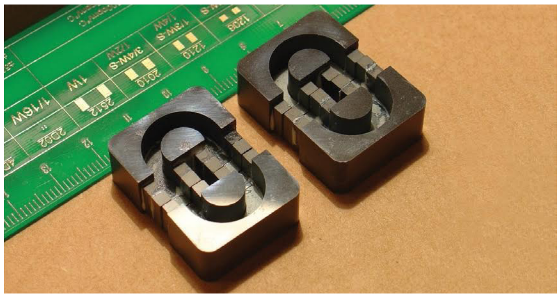

Fig 4. Preparation of integrated induction element (Step 1)

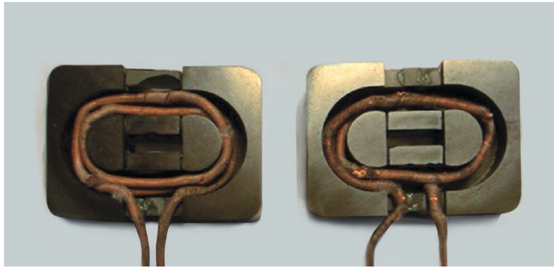

Fig 5. Preparation of integrated induction element (Step 2)

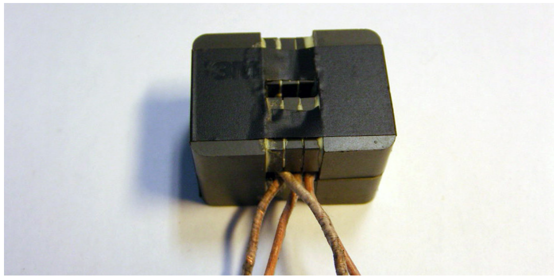

Fig 6. Preparation of integrated induction element (Step 3)

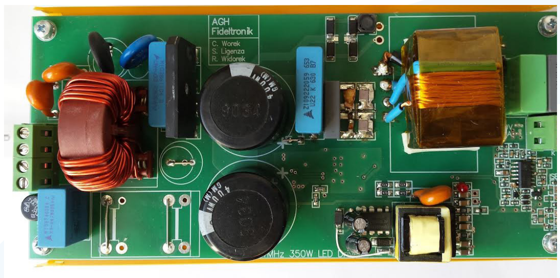

Fig 7. Resonant power supply dedicated for LED application based on the invention (300W@1MHz)

Advantage of the presented design of resonant-mode converter with integrated induction element ZEI is the possibility of easy adaptation to different values of transferred outputs. Presented examples of execution of integrated reactance elements meet strict requirements concerning high-performance, small and medium power supply systems.

Technology offer

The method for controlling a resonant-mode power supply and a resonant-mode power supply with a controller are subject to patent protection.

AGH University of Science and Technology in Krakow offers :

- a non-exclusive license for use of the technology in selected fields of application
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All interested parties may contact:

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Granted Patents:
Poland: PL219054(B1)
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