

© 2023 IEEE. Personal use of this material is permitted. Permission from IEEE must be obtained for all other uses, in any current or future media, including reprinting/republishing this material for advertising or promotional purposes, creating new collective works, for resale or redistribution to servers or lists, or reuse of any copyrighted component of this work in other works.

Digital Object Identifier [10.1109/MPEL.2023.3273892](https://doi.org/10.1109/MPEL.2023.3273892)

IEEE Power Electronics Magazine

Voltage controlled magnetic components for power electronics –technologies and applications: an overview

Marco Liserre

Yoann Pascal

Jeffrey McCord

Thiago Pereira

Rainer Adlung

Lukas Zimoch

Soeren Kaps

Xiabin Li

Nian X. Sun

Suggested Citation

M. Liserre et al., "Voltage Controlled Magnetic Components for Power Electronics," in IEEE Power Electronics Magazine, vol. 10, no. 2, pp. 40-48, June 2023, doi: 10.1109/MPEL.2023.3273892.

Voltage controlled magnetic components for power electronics – technologies and applications: an overview

Authors: M. Liserre⁽¹⁾, Y. Pascal⁽²⁾, J. McCord⁽¹⁾, T. Pereira⁽²⁾, R. Adlung⁽¹⁾, L. Zimoch⁽¹⁾, S. Kaps⁽¹⁾, X. Liu⁽³⁾, N. X. Sun⁽³⁾

(1): Kiel university, Kiel, Germany

(2): Fraunhofer Institute for Silicon Technology, Itzehoe, Germany

(3): Department of Electrical and Computer Engineering, Northeastern University, Boston, MA, USA

Corresponding author: yoann.pascal@isit.fraunhofer.de

Abstract:

Voltage controlled magnetic components, which consist in dynamically controllable inductances and transformers, are a promising yet understudied technology of growing interest. In fact, these components offer circuit designers an additional degree of freedom to achieve multi-objective optimization with improved Pareto fronts. This article provides a review of some technologies that can be used to create controlled magnetics, including emerging technologies with high potential. Furthermore, a list of possible applications is proposed, where these components can provide a significant advantage in terms of efficiency, size reduction, or controllability. Special emphasis is laid on a use case: a 20 kW multiport DC/DC converter in which power flow control is achieved using voltage-controlled inductors based on partially saturable magnetic cores.

1. Introduction

Magnetic components constitute one of the basic devices in power electronics systems. As a matter of fact, inductors and transformers can be used for short-term energy storage, filtering, and to transfer power while providing galvanic isolation between circuits [1].

Nonetheless, they remain amongst the bulkiest parts and account for a significant share of the losses [2, 3].

Magnetic component design results from trade-offs between a variety of parameters. For instance, in a filter, a higher inductance value will improve the filtering, which is related to pulse width modulation choice, but also increases the response time and, often, the losses [4]. In some power converter topologies, inductance values result from a trade-off between power lost in the active and reactive devices. Capability to bear higher currents, which are dictated by fault conditions, will also translate to higher volume [5]. In general, inductance and conduction losses are positively correlated. Furthermore, magnetic component selection, either custom or off-the-shelf, results from trade-offs between several variables such as cost, losses, and size.

Dynamically controlled magnetics [6], which have the capability to change their values online based on an external control signal, constitute an opportunity for power electronics, by bringing an additional degree of freedom in finding a compromise among minimal size, minimal losses, maximum filtering, limiting current rise without compromising dynamic response, etc.

After a brief introduction on magnetics and reluctance modeling, this paper gives in section 3 an overview of technologies and physical phenomena used to create tunable magnetics. Section 4 provides a list of relevant possible applications, while a use case is detailed in section 5. Finally, section 6 concludes the paper.

2. Basis of magnetics design

Figure 1 (a) shows a schematic of a generic inductor, composed of the winding, a magnetic core, and an air gap. Its equivalent reluctant model, analyzed using basic circuit theory, can be derived by replacing the core and the air gap by reluctances \mathcal{R} . The winding is replaced by a magnetomotive force (MMF) source – calculated as shown in Figure 1 (b). l_g is the length of the air-gap, l is the average length of the magnetic core, A its cross-sectional area, N the number of turns, and the magnetic material has a relative permeability μ_r – which characterises its ability to increase or channel the magnetic flux ϕ .

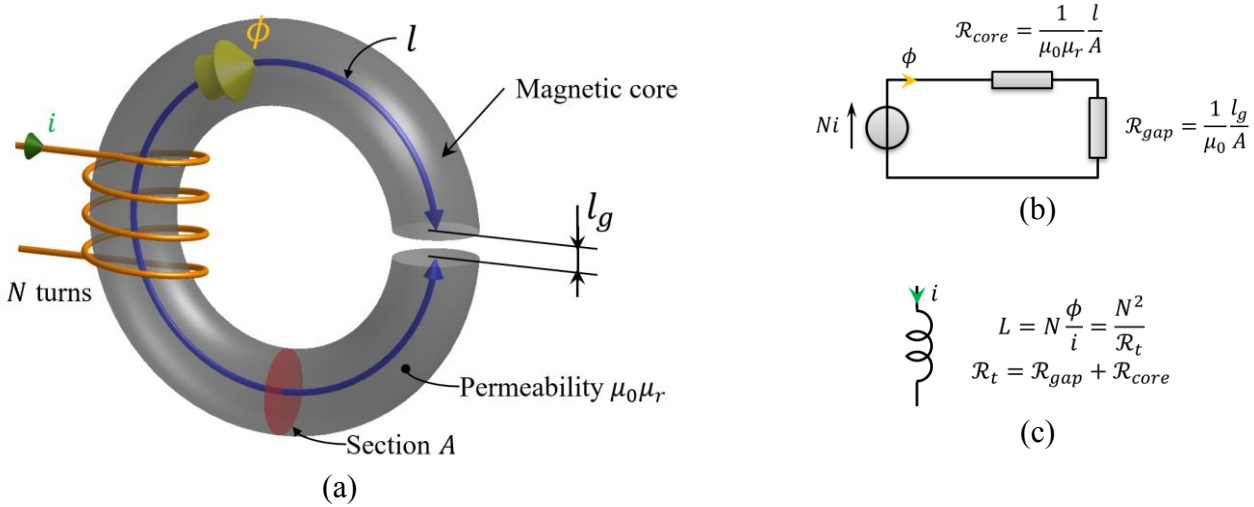


Figure 1. (a) Physical schematics of an inductor, (b) equivalent reluctant model, and (c) inductance calculation.

The inductance, which links the magnetic flux and the electric current (Figure 1 (c)), can be expressed as

$$L = N^2 A \mu_0 \cdot \left(\frac{l}{\mu_r} + l_g \right)^{-1}.$$

The rms current through the coil imposes that large wires and few turns be used to limit losses. On the other hand, the peak current through the coil dictates that a large number of turns (small due to the limited window area) be used to avoid magnetic saturation which would result in a drop in permeability – and therefore inductance. As a matter of fact, unwanted saturation may lead to over currents, increased losses, and control issues. The device must be designed such that, given the peak current \hat{I} , the peak magnetic flux density \hat{B} , given by

$$\hat{B} = \frac{\hat{I} L}{N A},$$

remains below the saturation flux density B_{sat} of the material of the core. In practice, this means selecting a core of sufficient size.

When considering dynamically tunable magnetics, the models must be updated to account for the energy stored through the inductance-tuning mechanism, and that may sometimes be recovered. In particular, the relation between the voltage v_L and the current i_L reads

$$v_L(t) = N \cdot \frac{d\phi}{dt} = \frac{d(L \cdot i_L)}{dt} = L \cdot \frac{di_L}{dt} + i_L \cdot \frac{dL}{dt},$$

where L is a function of time. However, most applications currently operate the tunable magnetics in quasi-static conditions, whereby the second term can be neglected. When considering tunable technics with low enough response time, this effect could nonetheless be leveraged, for instance for active filtering.

The following section highlights how these variables can be tuned online to achieve dynamic inductance control.

3. Physical effects and technologies for inductance control

The basic model presented in the previous section provides guidance on how the inductance can be dynamically tuned by changing the number of turns, the length of the air gap, the permeability of the magnetic core, and the overall shape of the inductor.

Tapped coils with tap changers (mechanical or solid-state) constitute tunable inductances that can take discrete values. Practical use in power applications remains limited to voltage regulating distribution transformers due to the high cost and complexity of discrete implementations [7]. On-chip integration of both the winding and the tap-changer (MEMS- or solid-state-based) have been demonstrated for low-value inductances, benefiting from the high-density integration enabled by wafer-level technology [8].

Magnetic cores are usually used in their linear region, where they exhibit constant permeability. However, when increasing the field and approaching saturation, the permeability drops (Figure 2). This is exploited to create tunable inductances, whereby a magnetic core is submitted to a biasing field by means of an auxiliary winding, that polarizes the material on its B-H curve around the target operating point. This technology has, in particular, been used to regulate power converters [9]. The main shortcoming of this approach is the significantly increased power loss in the DC-biased portion of the core. An application is detailed in section 5 [10].

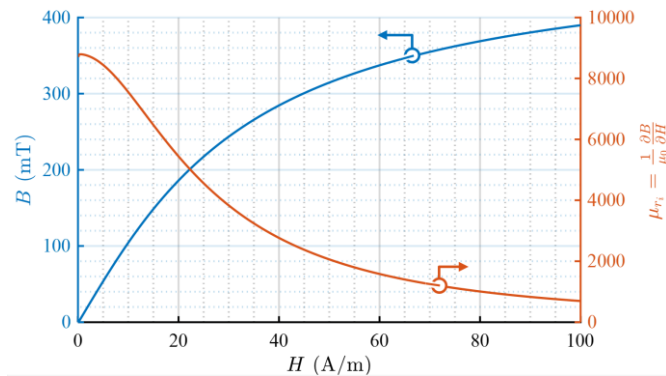


Figure 2 First quadrant magnetization curve of a typical ferrite for power electronics (N87): (BH) curve (blue) and incremental permeability $\mu_{r,i}$, (red). External biasing allows to move the operation point along the (BH) curve and thereby tune the inductance, which is inversely proportional to $\mu_{r,i}$.

Mechanical variability of the inductance is achieved by various types of micromanipulators that vary the length of the air gap (Figure 3) or move a magnetic shunt into or out of it. Due to the large influence of the air gap on the inductance, this allows efficient and wide tunability. Other concepts rely on modifying the coil dimensions. Yet, the use of mechanical means results in high response times and is also considered a critical reliability issue. This, added to the high cost and potentially high power consumption, limits the practical applicability of the concept.

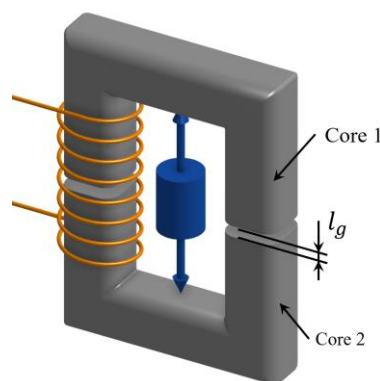


Figure 3 Mechanically adjustable inductor in which the length of the air gap l_g can be tuned by moving the cores using an actuator (in blue).

If piezoelectric materials can be used as actuators for voltage-controlled mechanical adjustment of the air gap, they offer another way to tune the inductance. In combination with magnetostrictive core materials, voltage-tunable magnetolectric composite inductors have been realized, which allows voltage adjustment of the effective permeability of the inductors. In this case, a possible increase in core losses must be avoided [11]. For this purpose, magnetolectric components have been integrated into the inductor or part of the inductor as variable permeability magnetic flux valves. This approach has been the subject of much research, including magnetic thin film and MEMS devices. Figure 4 shows the results obtained with voltage-controlled

magnetolectric inductors, reaching a 450% tunability in the kHz-band. For power electronics applications, electric field modulation of permeabilities has been achieved for ferromagnetic bulk and wound cores, ferrite cores, and magnetic piezoelectric material composites [11, 12], resulting in significant inductance changes. The magnetic material of choice is defined by magnetoelastic properties (magnetic anisotropy and relative permeability) and resistivity versus thickness. All these parameters must be specifically tuned in terms of inductance and operating frequency for the intended variable inductor applications. By transferring the concepts to high-power, bulk material-based applications, the aforementioned limitations for the mechanical approaches in response time and energy consumption could be overcome.

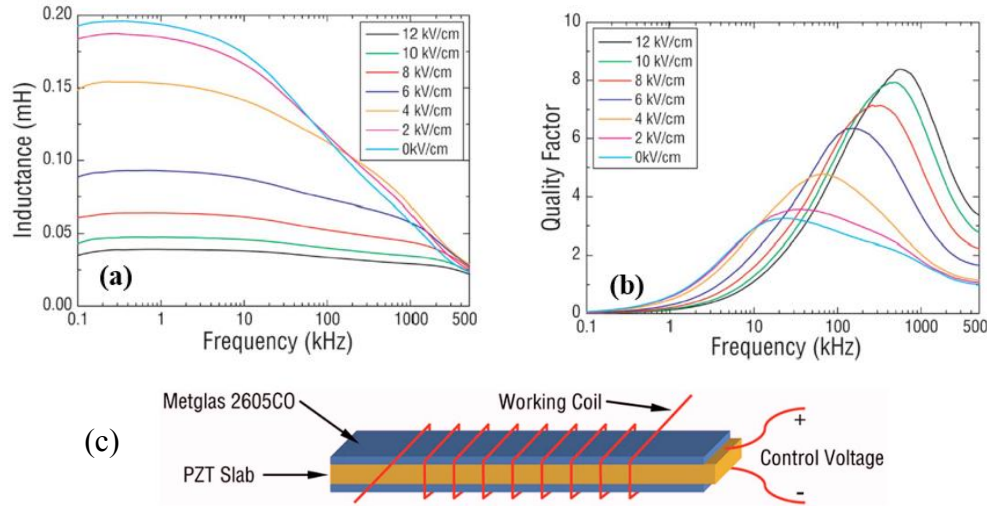


Figure 4 (a) Measured inductance and (b) Q -factor of the integrated tunable inductor at voltage tuning with applied electric field from 0 to 12 kV/cm. (c) Schematic of the magnetolectric inductor with a multiferroic composite core (Reproduced from [13]).

Other methods of tunable inductors rely on the use of ferrofluids in the air gap of the inductors or as a variable separation material in a pancake coil arrangement, or the use of deformable magnetic composites. Although permeability is an intrinsic property of a material, shielding by eddy currents may lead to some additional frequency-dependence [14], which could be exploited for inductance dynamic tuning. These methods are still at the proof-of-concept stage at best and are also subject to similar reliability issues as discussed above.

4. Applications – brief overview and simple calculation of gains

Tunable inductances have long been used as controlled impedances, e.g., to adjust lighting intensity or for arc welding. Nonetheless, the wide spreading of power electronics will greatly benefit from online adjustable magnetics, which will further push optimal Pareto fronts. This will bring significant improvements in the operation of a wide set of circuits and applications. This section describes some of these, summarized in Table I.

Table I: Summary of the gain expected from the use of tunable magnetics for some applications.

HVDC circuit breaker	- 45 % breaking current
Wind generator inverter	- 20 % inverter loss
Battery charger	- 10 % loss

Magnetic designs are constrained by trade-offs, making it impossible to achieve optimal operation over a wide range of operating points with conventional components. For instance, in phase-shifted full bridge (PSFB) and dual active bridge (DAB) converters, a high inductance is required to achieve soft switching – and thereby high efficiency – at low load, but this increases the copper loss and limits power transfer. Dynamically adjusting the inductance therefore offers an additional degree of freedom to track the maximum efficiency point. For example, the energy saving considering a lithium-ion battery charging cycle using a PSFB would reach 10 %.

Although switching energies of wide-bandgap semiconductor-based devices can fall to a few percent of their silicon counterparts, full potential of SiC and GaN is achieved in resonant topologies, owing to the loss

reduction offered by soft switching. However, LC-circuits have resonant frequencies with low initial accuracy, and possibly significant shift due to ageing and temperature. This is an issue when matching tanks are required, such as in multiport converters or wireless power transfer. The ability to dynamically tune tanks is then of great interest to maximize power delivery and efficiency — as showcased in section 5.

New topologies of power converter could further benefit from controllable magnetics. For instance, critical conduction mode converters, and more generally hysteretic controllers, suffer from complex control and EMI management due to their variable switching frequency. Online tunable inductors would solve this issue by enabling such converters to run at constant frequency.

The output filtering inductance of an inverter is limited by the voltage drop across it at fundamental frequency and nominal load. However, under reduced loading, the inductance could be increased to keep the voltage-drop constant. This would allow the switching frequency to be reduced proportionally without power quality degradation, resulting in a proportional reduction in switching power loss. Under this control strategy, the analysis of the annual production profile of a wind turbine located in northern France and equipped with an IGBT inverter shows that the potential average power loss reduction reaches 20 %, assuming a tunability of $\pm 30\%$.

In DC networks, minimal parasitic inductance is required to create a strong grid with good controllability. On the other hand, the line inductance limits the rate of current rise during short circuit, thereby limiting the constraints on the circuit breaker. In such application, the use of a low inductance value in normal operation, which is then increased in case of fault, would enable a reduction in the circuit breaker rating (-45% breaking current in a typical HVDC network, assuming $\pm 30\%$ inductance tunability – Figure 5), while maintaining controllability.

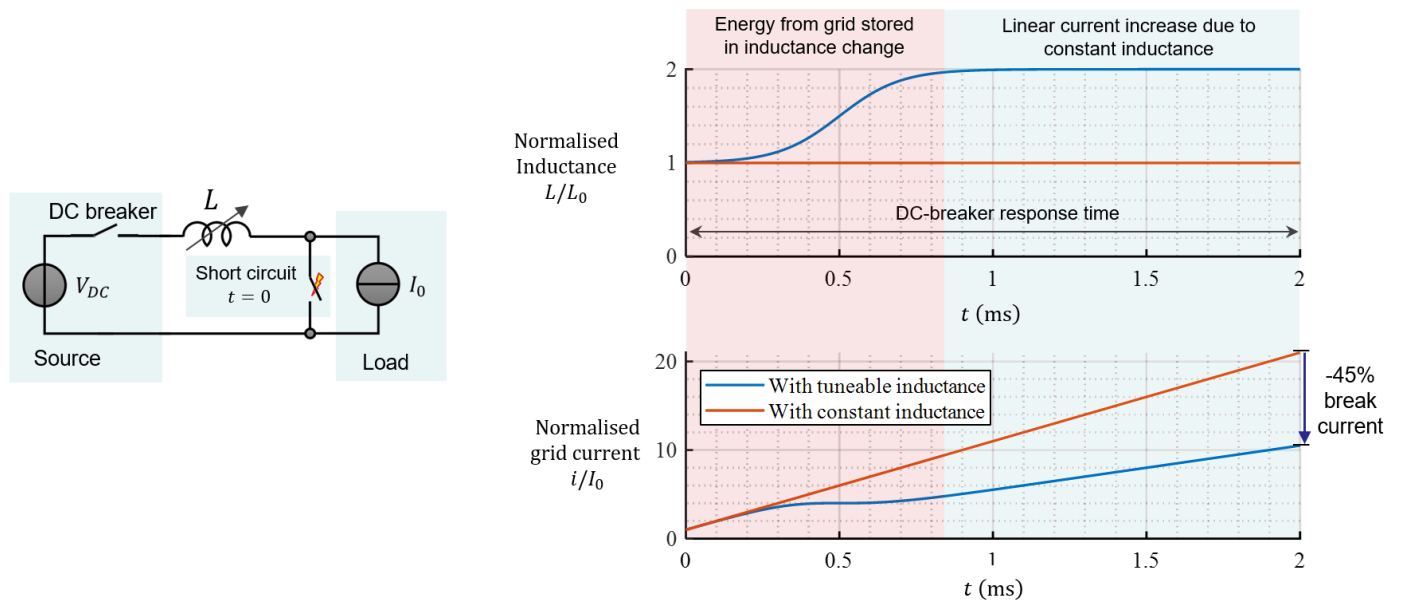


Figure 5: Current rise after load-side short-circuit of a HVDC transmission line: constant vs. tuneable line inductance. Simulation performed with $V_{DC} = 400$ kV, $I_0 = 2$ kA, $L_0 = 20$ mH.

Although today's electric network is exclusively either exploiting a single spectral component (typically 50 or 60 Hz) or DC, tomorrow's networks may exploit a wide spectrum to transfer power: not only the fundamental, but also the harmonics would be used to convey energy between sources and loads in a targeted manner (Figure 6). In such multi-frequency network, tunable magnetics would enable power routing based on spectral content [6].

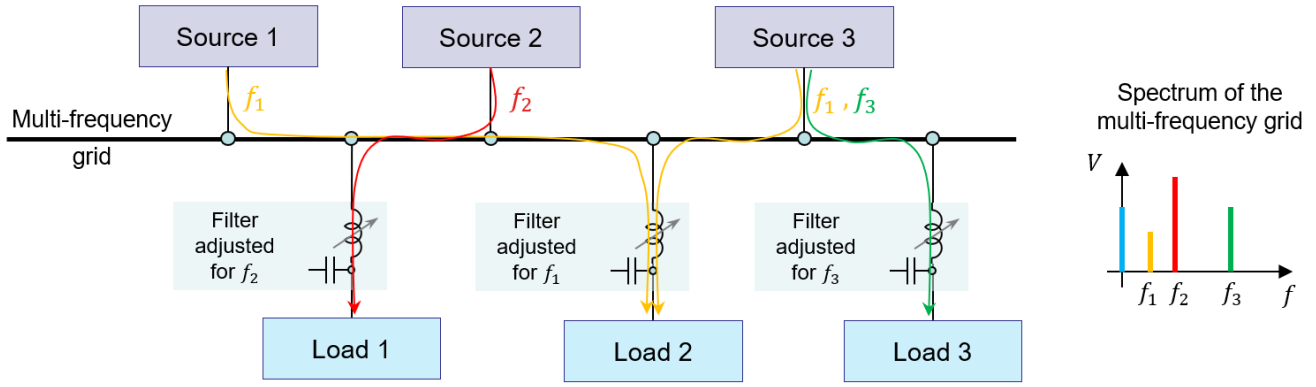


Figure 6: Structure and spectrum of a multi-frequency grid in which the spectral components supplying each load or sub-network can be dynamically selected by tuning the inductance of the respective filter.

5. Use case: self-tunable multiport resonant converter

Several isolated dc/dc topologies have been proposed in the literature for interconnecting multiple energy storage systems (ESS) with different capabilities. Nevertheless, resonant multiport isolated converters, in particular those based on a multiwinding transformer (MWT), have been receiving more attention in applications where multiple DC sources and/or loads must be integrated (Figure 7). This results from their reduced number of conversion stages, which leads to an increased power density and efficiency.

On the other hand, the increased number of windings at the same magnetic core makes the resonant MWT-based (RES-MTB) topologies more susceptible to parameter deviations on the MWT and multiple reactive networks, which can lead to power flow control issues. Thus, the multiple resonant tanks must be properly tuned to reduce these parameter deviations and unbalance.

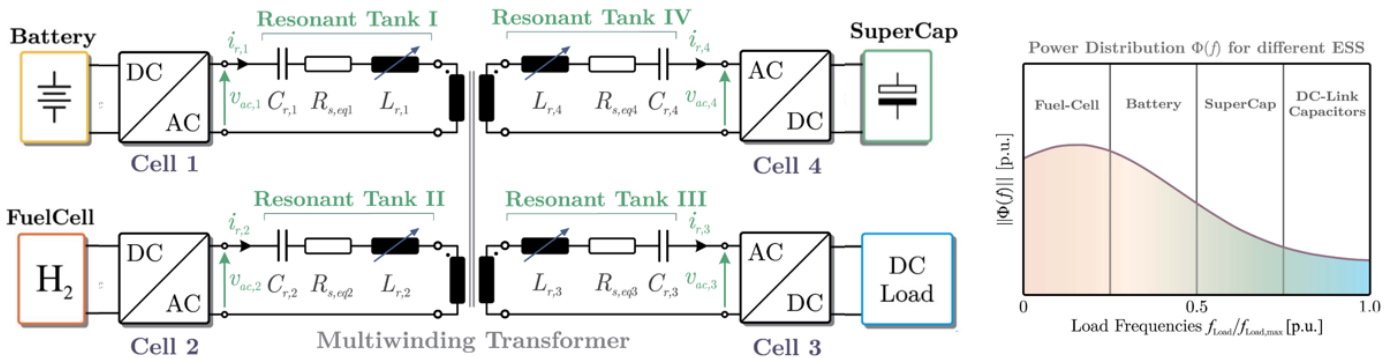


Figure 7: left: RES-MTB converter embedded with actively controlled inductors (ACI) for multi-source integration; right: Power distribution in function of the load frequencies considering the different ESSs [15].

In this context, the integration between actively controlled passive elements and the RES-MTB converter can be used as an additional degree of freedom to tune individually the values of the resonant inductors. Hence, it allows not only the self-tuning of the multiple resonant tanks against parameter deviations but also the power flow control among the ports.

The concept of integrating a variable inductor into the RES-MTB converter is experimentally validated with a prototype of 20 kW (Figure 8), cf. [10, 15].

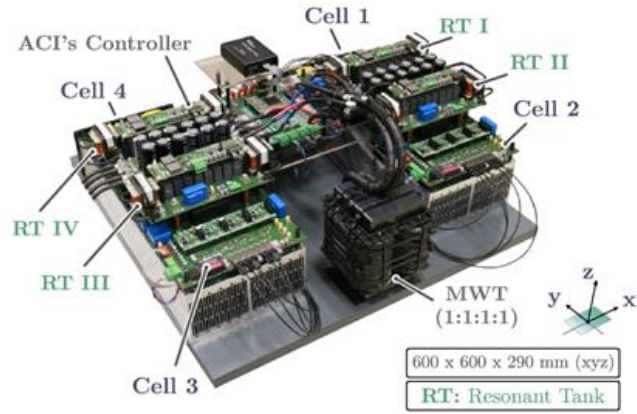


Figure 8 – Hardware prototype of the RES-MTB converter [10].

The structure of the variable inductor is based on the gapped E-core, cf. Figure 9 (a). The control winding, which is responsible for changing the inductance value, is divided into two identical parts with the number of turns equal to N_{dc} . The control winding is mounted on the outer legs of the E-cores, cf. Figure 9 (a,b), while the main winding is placed on the air-gapped center leg.

The control and generation of the dc bias current can be realized, for example, via a non-isolated switched mode dc/dc converter for optimal efficiency. By increasing the dc bias current up to the point where the magnetic flux density enters the saturation region, the increased reluctance of the core reduces the inductance value (Figure 9 (c)).

Experimental results were obtained under two conditions: unbalanced and balanced operations, cf. Figure 10. In the first condition, the resonant tanks RT I and RT III are configured with the same inductance value to ensure the resonance frequency of 20 kHz, while RT II is configured with the maximum inductance to reduce the processed power cf. Figure 10 (a). In the second case, all tanks are matched so as to ensure balanced power transfer (Figure 10 (b)).

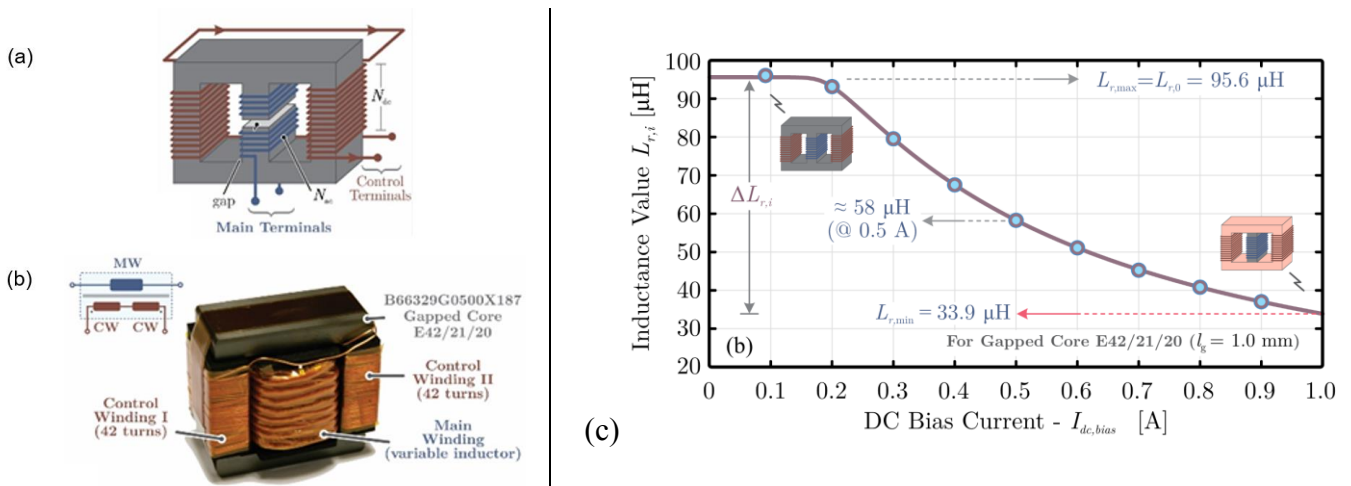


Figure 9: (a) Concept of actively controlled inductors considering the control and main windings. (b) picture of the prototype and (c) measured inductance as a function of bias current [10, 15].

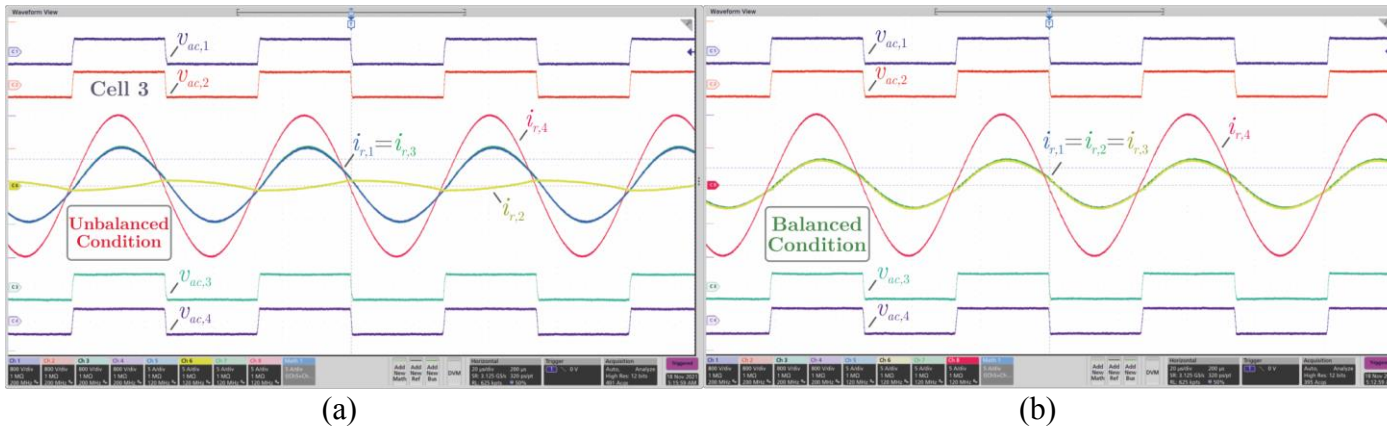


Figure 10: Experimental results considering the steady-state operation: under unbalanced (a) and balanced (b) conditions [10].

6. Conclusion

Tunable magnetics bring an additional degree of freedom to circuit designers, enabling to further push Pareto fronts in online multi-objective optimizations. A wide variety of physical phenomena and technologies have already been investigated to create such devices. Further research should investigate the limitations of each technology in terms of upscaling, bandwidth, response time, complexity, failure rate, etc. Future work should also focus on innovative topologies and control strategies to better understand the full potential of this new family of components. Although this article focuses on tunable inductances, the same phenomena can be and have been applied to designing transformers with tunable coupling coefficients, leakage, and magnetizing inductances. A dramatic leap forward in tunable magnetics design for the next generation of power electronics is expected from the combination of circuit design and magnetic materials expertise.

7. References

- [1] V. Valchev and A. Van den Bossche, *Inductors and Transformers for Power Electronics* (1st ed.), CRC Press, 2005.
- [2] R. Chen, R. Lu, X. Bao, C. Li, W. Li and X. He, "Efficiency-Oriented Parameter Design and Comparison of Medium Voltage Isolated Bidirectional DC/DC Converters," *IEEE Open Journal of Power Electronics*, 2023.
- [3] R. Guan, Z. He, M. Xiao, R. Liang, Y. Xiao, Z. Li, L. Wang and A. Luo, "A Medium Voltage Input Multiport Isolated Output DC Transformer With Power Self-Balancing and Output Fault Isolation," *IEEE Transactions on Power Electronics*, 2023.
- [4] M. Liserre, F. Blaabjerg and S. Hansen, "Design and control of an LCL-filter-based three-phase active rectifier," *IEEE Transactions on Industry Applications*, 2005.
- [5] L. Camurca, M. Langwasser and M. Liserre, "Design Approach of Inductive Components in Medium Voltage Modular Multilevel Converter Considering DC Side Fault Protection Conditions," in *IEEE Applied Power Electronics Conference and Exposition (APEC)*, 2020.
- [6] A. Boyajian, "Theory of D-C. Excited Iron-Core Reactors and Regulators," *Transactions of the American Institute of Electrical Engineers*, 1924.
- [7] M. Sojer, "Voltage Regulating Distribution Transformers as new Grid Asset," in *Procedia Engineering*, 2017.
- [8] P. Park, C. S. Kim, M. Y. Park, S. D. Kim and H. K. Yu, "Variable inductance multilayer inductor with MOSFET switch control," *Electron device letters*, vol. 25, no. 3, 2004.
- [9] S. Brandt, M. Meissner, N. Polap, G. Schierle and K. F. Hoffmann, "A Survey on Adjustable Inductances for Power Electronic Circuits," in *PCIM Europe*, 2022.

- [10] T. Pereira, Y. Wei, Y. Pascal, H. A. Mantooth and M. Liserre, "Self-Tuning Multiport Resonant DC/DC Converter Based on Actively-Controlled Inductors for Hybrid Storage System Integration," *IEEE Transactions on Power Electronics*, 2023.
- [11] Y. Yan, L. D. Geng, L. Zhang, C. Tu, R. Sriramdas, H. Liu, X. Li, M. Sanghadasa, K. D. T. Ngo, Y. U. Wang and S. Priya, "High-Power Magnetoelectric Voltage Tunable Inductors," *IEEE Trans. Ind. Electron.*, vol. 6, p. 68, 2021.
- [12] J. Cui, L. Qu and W. Qiao, "A Three-Phase Adjustable-Voltage-Ratio Transformer Based on Magnetic Flux Valves," in *IEEE Energy Conversion Congress and Exposition (ECCE)*, 2018.
- [13] J. Lou, D. Reed, M. Liu and N. X. Sun, "Electrostatically tunable magnetoelectric inductors with large inductance tunability," *Applied Physics Letters*, 2009.
- [14] W.-T. Franke, J. Dannehl, F. W. Fuchs and M. Liserre, "Characterization of differential-mode filter for grid-side converters," in *Annual Conference of IEEE Industrial Electronics*, 2009.
- [15] T. Pereira, Y. Pascal, M. Liserre, Y. Wei and H. A. Mantooth, "Multiport Resonant DC-DC Converter using Actively-Controlled Inductors for Hybrid Energy Storage System Integration," in *IEEE Applied Power Electronics Conference and Exposition (APEC)*, 2022.

Author biographies:

M. Liserre

Marco Liserre (S'00-M'02-SM'07-F'13) received the MSc and PhD degree in Electrical Engineering from the Bari Technical University, respectively in 1998 and 2002. He has been Associate Professor at Bari Technical University and from 2012 Professor in reliable power electronics at Aalborg University (Denmark). From 2013 he is Full Professor and he holds the Chair of Power Electronics at Kiel University (Germany). He got offered and declined professorships at the Technical Universities of Ilmenau, Munich and Hamburg. He has published more than 600 technical papers (1/3 of them in international peer-reviewed journals), a book and 2 granted Patents, with more under evaluation, some of them involving companies. These works have received more than 49000 citations. Marco Liserre is listed in ISI Thomson report "The world's most influential scientific minds" from 2014. In 2022 he joined part-time Fraunhofer ISIT as Deputy Director and Director of a new Center for "Electronic Energy Systems" funded for 5 million Euro.

He is member of IAS, PELS, PES and IES. He has been serving all these societies in different capacities. In PELS he is AdCom member (second mandate), Co-Editor of the IEEE Open Access Journal in Power Electronics, Associate Editor of TPEL and JESTPE, Guest Editor of Several Special Issues of JESTPE, Technical Committee Chairman of the new Committee on Electronic Power Grid Systems and Member of the IEEE Digital Committee, IES-Liaison responsible, eGrid 2021 Workshop Co-chairman and PEDG 2022 Co-chairman and organizer in Kiel. He has received the IES 2009 Early Career Award, the IES 2011 Anthony J. Hornfeck Service Award, the 2014 Dr. Bimal Bose Energy Systems Award, the 2017 IEEE PELS Sustainable Energy Systems Technical Achievement Award, the 2018 IEEE-IES Mittelmann Achievement Award and 6 IEEE Journal Awards.

Y. Pascal

Yoann Pascal received the Engineering degree from École polytechnique (Paris, France) in 2015 and a Ph.D. from École normale supérieure Paris-Saclay (France), in 2019. His PhD research was focused on PCB-embedding of power electronics dies and magnetic components. From 2020 to 2022, he was a post-doctoral researcher at the Chair of Power electronics of Kiel University (Germany). Since 2022, he has been a post-doc at the Fraunhofer ISIT - Institute for Silicon Technology (Kiel, Germany). His research activities include thermal management and reliability, magnetic components, and wide-band-gap transistor-based power conversion.

J. McCord

Jeffrey McCord is Professor in the Department of Materials Science at Kiel University. He holds a Dipl.-Ing. degree in Materials Science from the University of Erlangen-Nuremberg, where he also received his Ph.D., working on magnetic thin films and magnetic domains. From 1997 to 2001, he was with the IBM Storage Division in San Jose, where he was responsible for the development of magnetic recording heads. From 2002 to 2009 he was a research scientist and group leader at the IFW Dresden, until he accepted a position as head of the Nanomagnetism Department at the Helmholtz-Zentrum Dresden-Rossendorf. He is a co-founder and former managing director of evico magnetics GmbH. In 2011, he was appointed Heisenberg Professor for "Nanomagnetic Materials and Magnetic Domains" at the Department of Materials Science at Kiel University. He has authored more than 180 articles in peer-reviewed journals in the field of magnetic films and magnetic domains and has given more than 80 invited talks. He holds several patents related to magnetic thin film technology. Dr. McCord has been involved in the organization of several conferences, including serving as Program Co-Chair for Intermag 2017.

T. Pereira

Thiago Pereira (S'14) received the B.S. degree in Mechatronics (2011) from the Federal Institute of Santa Catarina (IFSC) in 2011, B.S. and M. S. degrees in electrical engineering from the Power Electronics Institute (INEP) at Federal University of Santa Catarina (UFSC), Florianopolis, SC, Brazil, in 2016 and 2018, respectively. Since 2019, he has been working toward the Ph.D. degree in electrical engineering with the Chair of Power Electronics at Christian-Albrechts-Universität of Kiel, Kiel, Germany, and since 2023 with

Fraunhofer ISIT, Germany. His research interests include DC-DC converters, power converter topologies, reliability in power electronics, high-power converter systems, and wide-bandgap semiconductor devices.

R. Adelong

Rainer Adelong is a Professor in the Department of Materials Science at Kiel University. He obtained his doctoral degree in physics from Kiel University in the year 2000. After spending a year in the Materials Science department at Case Western Reserve University in the USA, he returned to Kiel as a Habilitation candidate and obtained his *venia legendi* in 2007. Initiated with a Heisenberg Professorship award in 2007, his research group on functional nanomaterials became the chair for functional nanomaterials in 2010. Since then, he has continuously participated in collaborative initiatives such as collaborative research centers funded by the German Science Foundation on magnetostrictive materials and magnetic composites. He has been a Professor of Materials Science (Heisenberg Professorship) at Christian-Albrechts-Universität since July 2007. Professor Adelong has published more than 250 peer-reviewed papers on functional Nanomaterials.

L. Zimoch

Lukas Zimoch received the B. Sc. degree in materials science and engineering in 2017 and the M. Sc. degree in materials science and engineering in 2019 from the Christian-Albrechts-University of Kiel, Germany. Since 2020, he is a PhD candidate at the faculty of engineering (Kiel, Germany) and is currently working with magnetostrictive polymer composites in the field of magnetoelectric and pressure sensors. Other research interests include tunable inductors, gas sensors for H₂ and volatile organic compounds, as well as superparamagnetic aero-magnets.

S. Kaps

Soren Kaps is a Senior Researcher at Christian Albrechts University Kiel (CAU), Kiel, Germany, in the Chair for “Functional Nanomaterials.” He received the Ph.D. degree from CAU in 2015. His primary research revolves around porous materials and the application of additive manufacturing techniques. His work primarily aims to develop innovative design for memristive devices and magnetic field sensors. Additionally, he has a keen interest in surface interface-related materials science and actively explores advancements in this field.

X. Liu

Xiixin Liu received the B.E. degree in electronic science and technology from Xi’an Jiaotong University, Xi’an, China, in 2020, and the M.S. degree in electrical and computer engineering from Northeastern University, Boston, USA, in 2023, where he is currently pursuing the Ph.D. degree in electrical engineering. His research interests include new magnetoelectric antennas and sensors.

N. X. Sun

Nian Sun is a College of Engineering Distinguished Professor of Electrical and Computer Engineering & Bioengineering, and Director of the W.M. Keck Laboratory for Integrated Ferroics, Northeastern University, and founder and Chief Technology Advisor of . He received his Ph.D. degree from Stanford University. Prior to joining Northeastern University, he was a Scientist at IBM and Hitachi Global Storage Technologies. Dr. Sun was the recipient of the Humboldt Research Award, NSF CAREER Award, ONR Young Investigator Award, the Søren Buus Outstanding Research Award, Outstanding Translational Research Award, etc. His research interests include novel magnetic, ferroelectric and multiferroic materials, devices and microsystems, novel gas sensors and systems, etc. He has over 300 publications and over 30 patents and patent applications. One of his papers was selected as the “ten most outstanding full papers in the past decade (2001~2010) in *Advanced Functional Materials*”. Dr. Sun has given over 200 plenary/keynote/invited presentations and seminars. He is an elected fellow of the IEEE, an editor of *Sensors*, and *IEEE Transactions on Magnetics*.