ERC Consolidator Grant 2018
Research proposal [Part B1]

Medium Voltage Direct Current Electronic Transformer

EMPOWER

- Principal Investigator (PI): **Prof. Drazen Dujic**
- PI's host institution for the project: **Ecole Polytechnique Fédérale de Lausanne – EPFL Lausanne, Switzerland**

- Proposal duration in months: **60 months**

Summary:

More than a century ago, the invention of alternating current (AC) transformer has made AC the preferred choice over the direct current (DC) technologies. Line AC transformers are bulky but simple and reliable devices, made out of copper and iron, providing voltage adaptation and galvanic isolation in AC power systems.

Currently, DC technology is increasing its presence in AC power systems, enabled by progress in semiconductor devices and power electronics based energy conversion. DC power distribution networks can effectively support energy transformation and high penetration of distributed energy resources and energy storage integration (both increasingly being DC by nature) in future energy systems. Despite this shift towards the DC power distribution networks, *DC Transformer*, offering AC transformer like features (and beyond) does not exist, either conceptually or practically.

To enable the next (r)evolution in power systems, the EMPOWER project will develop the *DC Transformer,* a novel, flexible, highly efficient, compact, and reliable conversion principle for seamless energy routing in high-power DC distribution networks. Through a holistic approach, novel concepts, integration and optimization, we will demonstrate new design paradigms for galvanically-isolated power conversion. Our approach relies on resonant conversion utilizing high-voltage semiconductor devices in combination with high-frequency magnetic materials. We propose a new approach for the *DC Transformer*, avoiding active power flow control and instead utilizing control effort for the safety and protection. The *DC Transformer* will unify functions of a power converter and a protection device into a single power electronics system, improving drastically the conversion efficiency, reliability and power density in future DC power distribution networks. The success of this project will place Europe at the edge of reliable, efficient and safe energy distribution and transmission technologies.

Extended Synopsis of the scientific proposal

1. Motivation and Objectives

The aim of this project is to solve the problem of DC power transformation at medium voltage (MV) level and to enable the future medium voltage direct current (MVDC) power distribution networks. To achieve that goal, we will develop a *DC Transformer,* a missing enabling technology, integrating conversion, isolation and protection functions into a single device.

In the early days of electrification [1], both DC and AC technologies were equal contenders, but inherent simplicity and efficiency of conversion of AC voltages, with ability to interrupt faults currents thanks to the presence of zero current crossing, were the main reasons for AC becoming the technology of choice. Operating principles of the *AC Transformer* are simple, well understood and require no active power control. It is a simple, static, passive conversion device that has enabled the electrification of the world.

Today, with advancements in material science and semiconductor technologies, power electronics has made various DC technologies possible, as clearly evidenced with proliferation of mobile devices and gadgets in the low voltage direct current (LVDC) area, but also high voltage direct current (HVDC) bulk power transmission. Interestingly, MVDC[1] area has been largely unexplored and unexploited, due to various challenges, both technical and economical. With increased use of scattered and spatially distributed renewable energy generation (e.g. photovoltaic) and energy storage (e.g. batteries), MVDC power distribution networks are being generally considered as flexible addition or complete replacement of existing and ageing AC systems. An active DC power distribution network should provide fully bidirectional and highly efficient power flow and seamless integration opportunities with existing grids, while continuously guaranteeing the security of supply. The *DC Transformer* is the missing link for the electrification of the world in a more compact, flexible and reliable way.

Fig.1 shows a state-of-the-art AC power system where AC transformers and circuit breakers are used to interface and protect, various AC voltage levels (e.g. V_{AC-1} to V_{AC-2}). While the converters for high-power AC-DC conversion or vice versa, are state-of-the-art largely thanks to standardized AC voltage levels, presently there is no available technology for high-power[2] DC-DC conversion that could be used in DC power systems. The lack of natural zero current crossing in DC systems, makes protection difficult and DC circuit breaker technologies are only available for relatively modest voltage levels (e.g. up to 3kV in traction applications) or very high voltage levels in HVDC bulk power transmission. There is a large technology gap, both conceptually and practically, preventing realization of MVDC power distribution networks.

For the MVDC power distribution networks to gain a foothold, there is a need to systematically devise and develop, application independent and highly flexible, conversion and protection platform. Therefore, the development of the DC Transformer proposed here, which will fulfill a missing link, is a groundbreaking and key-enabling technology for future MVDC grids. Our ambitious agenda addresses high-risk, high-reward research, unique in its kind with an integrated research approach based upon three closely interlinked research strands, addressing the different challenges and serving the common goal:

1) ***DC Transformer as Conversion Device*:** We will develop a highly flexible, bidirectional, isolated, modular and scalable DC transformer platform. We will exploit resonant conversion principles relying on the high voltage semiconductors and high frequency magnetic materials, optimally arranged to produce desired electric circuit performances. We will demonstrate that the *DC Transformer* can be simple and open-loop controlled device, yet with intelligence/ability to integrate advanced protection features and fault-limiting functions.

2) ***DC Transformer as Protection Device*:** We will develop and integrate DC circuit breaker alike functionalities directly into the structure of a *DC Transformer*. Otherwise seen as a passive DC-DC conversion device, the *DC Transformer* will become an active protection device when required. We will manipulate controllable semiconductor devices inside the *DC Transformer* and combine with fault detection algorithms to achieve fault-limiting functionalities.

3) ***MVDC Power Distribution Networks*:** Focusing only on the DC-DC interface, we will demonstrate optimal network layouts, energy management schemes and protection coordination in future MVDC systems with large number of *DC Transformers*. Operating regions guaranteeing dynamic stability assessment will be systematically derived allowing for predictable system behavior, especially for systems involving multiple nodes, sources or loads.

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[1] By MVDC we consider DC voltage range from 1.5kV up to 100kV
[2] By high-power we generally consider several tens of megawatts (MWs)

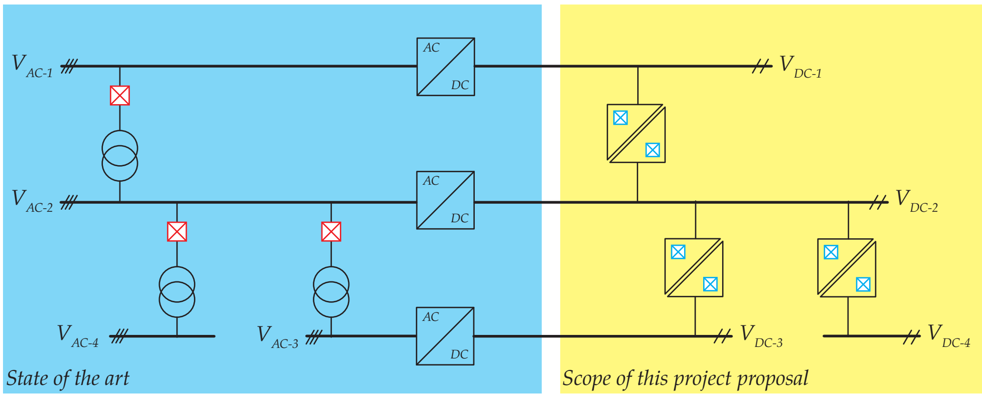

Figure 1: *State-of-the-art AC power system with multiple voltage levels interfaced with AC transformers and protected by circuit breakers, and future MVDC power distribution networks enabled by DC Transformers.*

The results of the EMPOWER project will indeed empower future power systems by offering them a key missing conversion and protection technology. Our high risk but high reward project will demonstrate new design paradigms and features that provide benefits and translate across a multitude of energy systems and power applications, having a profound impact on the future energy landscape.

2. State-of-the-art

All future energy scenarios demand improvements in the power conversion technologies. Comparative analyses (AC versus DC) for the off-shore wind farms have been presented in [2-4], highlighting techno-economical trade-offs. While multiple advantages of DC systems have been recognized, a number of challenges still remain (protection, no standardized DC voltage level, no suitable power converters, etc.). Shipboard electrical distribution systems, usually realized with MVAC, increasingly consider or use DC distribution [5,6], and while IEEE recommendations are already put in place [7], conversion and protection technologies are not available [8]. Utility applications have been already using short MVDC links for various "soft-open point" connections between AC systems, such as in projects "EAGLE PASS" [9], "MACKINAC" [10], or as in still an ongoing project "ANGLE-DC" [11].

Research in directions of new conversion topologies has been intensified recently, through concepts of solid-state transformers (SSTs) [12,13]. The majority of relevant literature targets either three-phase SST for smart-grid applications [12-17], as in large European projects such as UNIFLEX [14] and HEART [15], or single-phase SST for traction on-board applications [11]. While the SST is only a concept, notable and recent exception is the world's first ever, 1.2 MW power electronic traction transformer (PETT) for 15kV, 16.7Hz railway grid, developed by ABB and successfully commissioned on a locomotive [18,19]. The PI of this project proposal has been actively involved into this R&D activity, for more than three years [12,18,19].

Research on the high power DC-DC converters for MVDC systems is rather scarce. Dual active bridge based DC-DC concepts have been proposed in [20], modular multilevel DC-DC converter with adjustable voltage ratios has been presented in [21], while non-isolated thyristor based proposal presented in [22]. Increased interest into the SST technologies has been well supported by the activities in the area of semiconductor devices and means for the switching frequency increase. Use of high voltage Si-based insulated gate bipolar transistors (IGBT), both as standard or irradiated 6.5kV IGBTs have been reported in [23,24]. The high voltage IGBTs were analyzed in relation to soft switching high power applications in [25,26], and optimization by means of anode engineering has been presented in [28], achieving significant reduction of switching losses. SiC diodes were analyzed in [31], while the custom developed 10kV SiC MOSFET [29] and 15kV SiC IGBT [30] have demonstrated potentials of wide band-gap technologies.

The increase of switching frequency of semiconductors has a direct impact on size reduction of medium frequency transformers, used to provide the galvanic isolation [31-34]. Designs have been proposed and prototypes developed using different core materials, such as silicon steel, nanocrystalline, ferrites, or iron amorphous in combination with different insulation materials (air, oil, solid insulators). While the function of galvanic isolation relies on the magnetic coupling between different circuits, semiconductor devices are the key active components for DC grids that can provide variable voltages in order to create time varying flux in a core.

Even though the increase of research activities is evident, it is also strongly diversified, application specific and leading to a diluted effort and constant increase in the complexity of the conversion topologies. The *DC Transformer* concept cannot be identified in the state-of-the-art, and its conceptual development and practical demonstration are the main objectives of this project.

3. State of the Personal Research

With the establishment of the Power Electronics Laboratory (PEL) at EPFL in 2014, the PI has initiated research in the domain of high-power medium-voltage power electronics for electrical energy generation, conversion and storage. We have proposed and developed novel concepts for highly modular power electronic conversion. Galvanically isolated modular converter (GIMC) for highly efficient MVDC-LVAC conversion, using low voltage IGBT sub-modules in combination with open-end winding line frequency AC transformer is presented in [35]. We have proposed DC-DC-DC multiport energy gateway (MEG) for rapid demand response, integrating storage technology directly into converter and providing highly flexible energy management [36]. We are active in domain of marine MVDC electrical distribution systems [8]. Our research activities also cover electromagnetic area related to design optimization of MFTs [34] (3 conference tutorials were given during 2017) a key technology component of the SST, as well as analytical and numerical modeling of passive components for transient electric circuit simulations [37]. PEL has been identified and selected by CERN as partner to develop novel superconducting magnet power supply concept with energy saving capabilities for LH-LHC project. In a short time, the PI has been able to establish consolidated research roadmap in the domain of high power electronics and gain substantial visibility not only in in Europe, but worldwide as well (PEL is also recognized as Competence Center by the European Center for Power Electronics – ECPE).

Prior to joining EPFL, and following his PhD completion in 2008, PI has spent five years in industry (ABB Switzerland), where he was involved in the research and development of conversion technologies for high power applications. More notably, the PI has been part of R&D team that has developed, and successfully demonstrated in the field, the world's first ever 1.2MW Power Electronic Traction Transformer (PETT) for 15kV, 16.7Hz railway grids. Despite never holding a Post Doc post, PI has successfully published his research results obtained in the industrial research environment and has filed several patents in the respective field. The complete list of publications is available on the PEL web page: http://pel.epfl.ch.

The EMPOWER project will help to consolidate the evolution of enabling technologies for DC grid, generalize and develop novel concept and unique, groundbreaking conversion platform.

4. Innovation and Expected Impact

The EMPOWER project will develop a completely new paradigm for efficient, safe and reliable energy routing in the *MVDC power distribution networks*. In contrast to the mainstream approach that relies on complex converter structures and actively controlled power flows, we believe that the *DC Transformer* can be a simple, robust and non-controlled device (i.e., not utilizing closed loop control), yet with fast and intelligent protection and fault limiting functions (bypassing present technical gaps caused by the lack of DC breaker technology) due to use of fast semiconductor devices. Combination of active semiconductor and magnetic devices, with resonant conversion principles will allow for highly reliable and efficient electrical energy conversion. The EMPOWER results will be ready for seamless integration into emerging DC power distribution networks, allowing further growth, expansion and widespread penetration into energy landscape.

We believe that only an approach such as ours can empower future energy systems and drive them forward in a sustainable way. The proliferation of DC producers and consumers requires wider consideration of DC power distribution networks, as a more efficient way of energy routing. Because the MVDC area is largely unexplored, highly flexible and scalable *DC Transformer* will achieve what AC transformers did more than a century ago – revolutionize the way we exchange energy in a new post-fossil fuel world.

5. Project Activities and Methodology

Our approach relies on several underlying power electronic technology constituents that we will significantly advance and optimally exploit in this project: high-voltage semiconductor devices, high-frequency magnetic materials, resonant conversion and advanced control/protection algorithms. Our research approach will involve system level modeling and simulations studies, done either as offline or with real-time simulators for time critical applications on the MVDC system level. Through characterization, multi-objective optimization and advanced integration we will develop building blocks for modular and scalable *DC Transformers* for MVDC power distribution networks. Specific control algorithms for differentiation of regular operation from faulty cases will be devised and demonstrated on the real prototype. Main work packages, their relations (Fig.2) and methodologies are briefly described next.

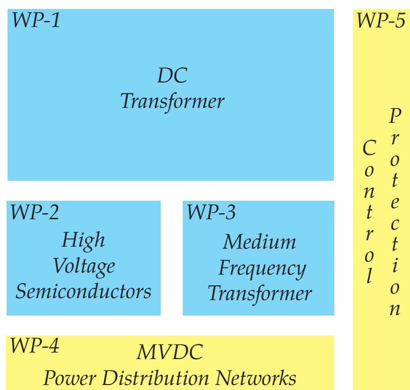

Figure 2: *The work-packages*

WP-1: DC Transformer – The Enabling Technology

Blocking voltages of present semiconductors are significantly lower than requirements of MVDC power distribution networks, and to realize the *DC Transformer,* power processing must be done fractionally and through multiple series- or parallel-connected semiconductors or sub-modules. As size (*weight and volume*) is mostly determined by the size of passive components (*inductors, transformers, capacitors*), there is a strong need for innovative designs and technologies operating at higher switching frequencies. We will address this through development of novel conversion technologies that are *modular, flexible and scalable*.

Successful realization of the *DC Transformer* relies on optimal use of advanced semiconductor and magnetic devices. High switching frequency operation results in thermal, electric and magnetic stresses that directly impact components and operation, and these effects will be quantified, modeled, measured and used in subsequent optimizations. We aim to utilize, for the first time at this scale, resonant conversion principles as they offer the closest behavioral properties similar to AC transformers. Tuned resonant circuits, combined and excited with switched squared waveforms can provide soft-switching conditions for the semiconductors, but also controllable impedance of the *DC Transformer*. All theoretical developments will be verified on the *DC Transformer* prototype under realistic operating conditions (see WP-2 and WP-3)

WP-2: High Voltage Semiconductors – The Switching Elements

To produce time varying flux within a magnetic device, semiconductor based switching cell of some sort is required. Novel wide band-gap semiconductor materials such as Silicon Carbide (SiC) and Gallium Nitride (GaN) combined with magnetic materials such as nanocrystalline, iron amorphous and ferrites, offer in prospect significantly improved performances compared to the state-of-the-art Silicon (Si). Devices such as high voltage IGBTs, MOSFETs and IGCTs are all feasible candidates for high power resonant conversion, and are available from key semiconductor manufacturers, minimizing the projects risks.

To achieve high frequency operation and low switching losses, we will explore impacts of various technological layers, from the semiconductor device (technology curve), device packaging, soft or resonant switching techniques, on the overall system. Research activities will involve device simulations using TCAD and mixed circuit simulations, characterization and testing in our laboratory, as discrete components, as part of sub-modules and inside the *DC Transformer*. Considering target MVDC applications, trade-off between short-circuit withstand properties and reduction of switching losses, will be quantified. Understanding similarities and differences between different semiconductor technologies is fundamental to understanding the extent to which future energy conversion technologies can be improved and optimized.

WP-3: Medium Frequency Transformers – Galvanic Isolation

Galvanic isolation of a *DC Transformer* realized at higher operating frequency is severely impacted by insulation coordination requirements due to MVDC application and thermal constraints due to high power operation. While semiconductor devices are with discrete ratings, ratings of the medium frequency magnetic devices are not bound and can be freely chosen for the optimization. We will explore design space and interdependencies between different magnetic and insulation materials on the implementation of high-voltage high-power medium-frequency transformer (MFT). Our interest is in SiFe, nanocrystalline and iron amorphous materials. Core and winding losses will be accurately predicted, and considering non-sinusoidal waveforms, new models [37] and measurement techniques will be further developed. Mixed frequency stresses due to high *dv/dt* of switched voltage waveforms, impact the choice and lifetime of dielectric materials, requiring thorough investigation, modeling and integration into optimization process.

Resonant power conversion requires precise, accurate and robust design of leakage and magnetizing inductances of a MFT. Finite elements method (FEM) simulations will be used for design verification, and as support for analytical or semi-numerical optimization methods. We will design and realize high-voltage isolated MFTs, and verify their performances, as standalone apparatuses, as well as within *DC Transformer* under different operating conditions. PEL is equipped with high voltage test setup that can support dielectric and partial discharge testing up to 100kV.

WP-4: MVDC Power Distribution Networks – A Missing Link

System aspects will be investigated focusing on the multi-bus MVDC power distribution networks enabled by the presence of *DC Transformers* (Fig.1). Considering that the *DC Transformer* will be power electronics based, interactions with other active elements (sources and loads) must be addressed. The ultimate goal is for the *DC Transformer* to behave as a simple, stable and passive AC transformer, providing the voltage insulation and voltage adaptation, without any strong closed-loop control interactions. The system stability and the *DC Transformer* passivity will thoroughly investigated, as they represent big challenge and big unknown of the project. An impedance model of the DC transformer will be developed for the system studies, and the absence of positive feedback effects will be verified. The great unknown of this concept, is whether this is sufficient for reliable and stable operation in networks of different complexity (e.g. ring type versus radial type)?

Our laboratory is equipped with 10kV DC power supply line, allowing for realistic testing of the final *DC Transformer* prototype, while the Real-Time Hardware-in-the-Loop (RT-HIL) simulations will allow for dynamic large-scale system studies as well as research on advanced protection coordination schemes.

WP-5: Protection and Control Coordination

Zero frequency of DC systems reduces losses associated with capacitive effects in cables or inductive effects in overhead lines, but also makes fault current interruption much more difficult. We will integrate hardware and software based protection features into the *DC Transformer*, avoiding the need for a discrete DC breaker, which will significantly increase the value of project results, even though it constitutes one of the main challenges. Semiconductor based *DC Transformer* offers a fair chance to reach this goal, since fast detection of short-circuit conditions and fault current limiting can be implemented in below 1ms time range. Semiconductor devices and their characteristics will be of high importance for successful realization of this task. Coordinated operation of multiple *DC Transformers* will be verified through large-scale system RT-HIL simulations and experimentally, and should as such increase the feasibility of this project.

6. Resources

The EMPOWER project will run for five years, with a total requested budget of 2’198’145 EUR, including 200’000 EUR (with overhead) for the acquisition of the RT-HIL equipment. The PI will devote 40% of his time to this project during its full five-year duration and funding is requested for three PhD students and one postdoctoral fellow. PhD typically takes four years at EPFL.

The work split is as follows: The Post Doc will work on the platform development and system aspects of the *DC Transformer* enabled MVDC power distribution networks, stability design and assessment tools, including HIL simulation verification (WP-1, WP-5). The first PhD student will work on design, characterization and optimization of high voltage semiconductor devices for high frequency operation as well as on the electrical design and integration of the *DC Transformer* (WP-2). The second PhD student will work on numerical design tools for optimization of advanced medium/high frequency transformers, including verifications and prototyping (WP-3). The third PhD student will work on the control and protection coordination related aspects for the *DC Transformer*, implementation and verification (WP-5). This is illustrated in Table 1, where dark shading indicates primarily responsible person, while light shading represents collaborative effort. While the PI is not explicitly mentioned, it is understood that he will be involved in the support and supervision of all the mentioned activities of the EMPOWER project.

The PI’s Power Electronics Laboratory (PEL) offers sufficient space to accommodate the EMPOWER project, both in terms of research and office space for students and personnel. We already have installed MVDC feeder, with voltages up to 10kV and powers up to 0.7MVA, as well as protective test cage areas for safe experiments involving high voltages. For the early prototype testing, we have available high voltage source (20kV, 5A), as well as high current source (20V, 2250A), among other equipment.

Table 1: Distribution of tasks between the personnel linked to the EMPOWER project (*M = month*)

Work Packages	Post Doc	PhD 1	PhD 2	PhD 3
WP-1: *DC Transformer Concept*	M1 – M36	M1 – M24	M1 – M24	M12 – M36
WP-2: *High Voltage Semiconductors*		M1 – M48	M1 – M24	
WP-3: *Medium Frequency Transformers*		M1 – M24	M1 – M48	
WP-4: *MVDC Power Distribution Networks*	M12 – M48			M12 – M36
WP-5: *Protection Coordination*	M48 – M60			M12 – M60
DC Transformer Demonstration	M36 – M60			

7. Summary and Outlook

The proposal addresses groundbreaking research that will systematically develop novel, perhaps disruptive, but enabling, power electronic conversion technologies for the *MVDC power distribution networks*. We will develop a high power *DC Transformer* technology, optimally using semiconductor and magnetics materials for high power applications, providing flexible, efficient, secure and reliable energy conversion and allowing for the another (r)evolution in the power systems. Throughout conceptual and practical developments, we will demonstrate new design paradigms, developing features that provide advantageous characteristics of novel conversion system and offer benefits across a multitude of energy systems and power applications. We believe that innovative outcomes of this research will have a profound impact on the European energy landscape and its future structure.

8. References

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Section b: Curriculum Vitae

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PUBLICATIONS AND BIBLIOMETRICS (*as of February 2018*)

- 1 Book (in work)
- 11 Patents (some pending)
- 26 Journal papers
- 82 Conference papers

Source	**Web of Science**	**Scopus**	**Google Scholar**
Number of items	60	73	90
Sum of citations	806	1488	2028
Average citations	13.4	20.4	22.5
h-index	**16**	**23**	**27**

EDUCATION

11. Oct. 2008 PhD in Electrical Engineering, Liverpool John Moores University, Liverpool, UK
Thesis: *Development of pulse width modulation techniques for multi-phase and multi-leg voltage source inverters*
PhD Supervisor: Prof. Emil Levi

29. Dec. 2005 Master in Electrical Engineering, University of Novi Sad, Novi Sad, Serbia
Thesis: *Pulse width modulation for the symmetrical six phase voltage source inverter*
Advisor: Prof. Vladimir Katic

22. Aug. 2002 Dipl. Ing. in Electrical Engineering, University of Novi Sad, Novi Sad, Serbia
Thesis: *Digital control of DC motor drive*
Advisor: Prof. Vladimir Katic

CURRENT POSITIONS

2014 – *Tenure Track Assistant Professor, Head of the Power Electronics Laboratory*
Ecole Polytechnique Fèdèrale de Lausanne – EPFL, Lausanne, Switzerland

PREVIOUS POSITIONS

2013 – 2014 *R&D Platform Manager ACS 6000*
ABB Switzerland Ltd, Medium Voltage Drives, Turgi, Switzerland

2012 – 2013 *Deputy Group Leader*
ABB Switzerland Ltd, Corporate Research Center, Baden-Dättwil, Switzerland

2012 – 2013 *Principal Scientist*
ABB Switzerland Ltd, Corporate Research Center, Baden-Dättwil, Switzerland

2009 – 2012 *Scientist*
ABB Switzerland Ltd, Corporate Research Center, Baden-Dättwil, Switzerland

2006 – 2009 *Research Associate*
Liverpool John Moores University, School of Engineering, Liverpool, UK

2003 – 2006 *Teaching and Research Assistant*
University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia

2001 – 2002 *Application Engineer*
ICM Electronics (OMRON representative), Novi Sad, Serbia

AWARDS

2014 *Isao Takahashi Power Electronics Award* for outstanding achievement in power electronics, presented at the 2014 International Power Electronics Conference, ECCE-Asia, Hiroshima, Japan.

2007 *First Prize Paper Award* by the 'Electric Machines Committee' of the IEEE Industrial Electronics Society at IECON 2007, Taipei, Taiwan.

2005 *Best Paper Award* at the ETRAN Conference, Budva, Serbia and Montenegro.

SUPERVISION OF PhD STUDENTS AT EPFL (13 at the moment with 4 scheduled to graduate in 2018**)**

2018 – Mr. Milan Utvic
2017 – Mr. Miodrag Basic
2017 – Mr. Marko Petkovic
2017 – Mr. Nicolai Hildebrandt
2017 – Mr. Stefan Milovanovic
2017 – Mr. Seongil Kim
2016 – Mr. Emilien Coulinge
2016 – Mr. Dragan Stamenkovic
2015 – Mr. Marko Mogorovic
2014 – 2018 Mr. Yan-Kim Tran
2014 – 2018 Mr. Min Luo
2014 – 2018 Mr. Uzair Javaid
2014 – 2018 Mr. Alexandre Christe

TEACHING ACTIVITIES

2016 – EE-365 – Power Electronics, EPFL, Spring semester, Bachelor course
2015 – EUROTECH, Doctoral PhD School at EPFL
2015 – EE-565 - Industrial Electronics 2, EPFL, Autumn semester, Master course
2014 – EE-465 - Industrial Electronics 1, EPFL, Spring semester, Master course

INSTITUTIONAL RESPONSIBILITIES

2015 – Member of the EPFL Teaching Council
2015 – Co-Organizer of the EUROTECH Summer Doctoral School at EPFL (*eurotech.epfl.ch*)

COMMISSIONS OF TRUST

2017 – Member of the *ElectroSuisse National Committee*
2016 – 2017 Member of the *ElectroSuisse ETG Board (Energietechnische Gesellschaft)*
2015 – Member of the *CIGRE Working Group SC6.31*
2015 – Member of the *PCIM Advisory Board*
2015 – Member of the *EPE International Scientific Committee*

JOURNAL EDITORIAL BOARDS

2016 – Associate Editor for *IEEE Transactions on Power Electronics*
2014 – Associate Editor for *IET Electric Power Applications*
2014 – Associate Editor for *IEEE Transactions on Industrial Electronics*

ORGANISATION OF SCIENTIFIC MEETINGS

2018 *Technical Track Chair*, EPE'18 ECCE-Europe, Riga, Latvia
2017 *Technical Track Chair*, EPE'17 ECCE-Europe, Warsaw, Poland
2017 *Topic Chair*, Ee2017, Novi Sad, Serbia
2016 *Technical Track Chair*, EPE'16 ECCE-Europe, Karlsruhe, Germany
2015 *Topic Chair*, ECCE, Montreal, Canada
2015 *Conference Co-Chair*, EPE'15 ECCE-Europe, Geneva, Switzerland
2014 *Technical Chair*, ECCE, Pittsburgh, PA, USA
2012 *Technical Co-Chair*, EPE-PEMC, Novi Sad, Serbia

REVIEWING ACTIVITIES

Journals *IEEE Transactions on*: Industrial Electronics, Power Electronics, Industry Applications, Power Delivery, Energy Conversion, Power Systems, Industrial Informatics

IET Journals: Electric Power Applications, Power Electronics

MEMBERSHIPS OF SCIENTIFIC SOCIETIES

2003 – IEEE: Senior Member (since 2012), Member (since 2009), Student Member (since 2003)
2003 – IEEE Societies: Power Electronics, Industrial Electronics, Industry Applications
2014 – EPE Member

Appendix: All on-going and submitted grants and funding of the PI (Funding ID)

On-going Grants

Project Title	*Funding source*	*Amount (Euros)*	*Period*	*Role of the PI*	*Relation to current ERC proposal*
Galvanically isolated modular converters	CTI - Commission for Technology Innovation SCCER - Swiss Competence Centre for Energy Research	519'800	2017 - 2020	PI PhD Advisor	Research scope of the project is on the integration of a line frequency transformer into the modular multilevel converter (MMC). No overlap – complementary project and provides the funding for two PhD students at PEL.
MVDC – Protection Coordination	Hyundai Heavy Industry Industrial funding	400'000	2017 - 2020	PI PhD Advisor	Research scope of the project is on the protection concepts in LVDC marine systems. No overlap – complementary
Solid state resonant conversion	SNSF - Swiss National Science Foundation	250'000	2016 - 2019	PI PhD Advisor	Research scope is related to the optimization of IGCT semiconductors for soft switching. No overlap – complementary project and provides the funding for PhD student at PEL.
Medium voltage direct current energy conversion technologies and systems	SFOE - Swiss Federal Office of Energy	355'680	2015 - 2018	PI	Research scope of the project is on the system level comparative assessment of the MVAC and MVDC grids and associated technologies. No overlap – complementary project and provides the funding for Post Doc at PEL.
Integration of intermittent widespread energy sources in distribution networks: storage and demand response	SNSF - Swiss National Science Foundation	230'542	2014 - 2018	Co-PI PhD Advisor	Research scope of the project is on the integration of storage technologies (batteries and ultracapacitors) for rapid demand response in MV grids, under conditions of presence of short-term disturbances. No overlap – complementary project and provides the funding for PhD student at PEL.
Core loss modelling of magnetic components for dynamic system level power electronic simulations	ECPE – European Center for Power Electronics	90'000	2017 - 2018	PI PhD Advisor	Research scope is related to improvement of hysteresis models for soft materials, suitable for fast electric circuit simulations. Not related

Grant applications

Project Title	*Funding source*	*Amount (Euros)*	*Period*	*Role of the PI*	*Relation to current ERC proposal*[2]
Insulation coordination impact on design optimization of high frequency power transformers	ECPE – European Center for Power Electronics	90’000	2018 - 2019	PI PhD Advisor	Research scope is related to design optimization of high power transformers with multiple winding. Not related
GEN2TRAINS	H2020-MSCA-ITN-2018	562’553 PEL part only	2019-2022	Co-PI WP-2 leader PhD Advisor	Research scope is related to hybrid train and energy storage integration and optimization. Not related

Section c: Early achievements track-record - UPDATE

PERSONAL STATEMENT

Prof. Dujic as PI of the EMPOWER project has more than 10 years of research experience, shared between academic and industrial environment, in the fields of power electronics, spanning the range from low-voltage low-power switch-mode-power-supplies in below kW range to medium-voltage high-power converters in a MW range. Research and development work conducted by PI in the field of electrical energy conversion, has been extensively published and IP protected and in 2014 he has received Isao Takahashi Power Electronics Award for outstanding achievements in power electronics.

SELECTED JOURNAL PAPERS:

1) M.Luo, **D.Dujic**, J.Allmeling: "Modeling frequency independent hysteresis of ferrite core materials using permeance-capacitance analogy for system-level circuit simulations", *IEEE Trans. On Power Electronics*, 2018. (*Early Access*)
2) M.Luo, **D.Dujic**, J.Allmeling: "Leakage flux modelling of multi-winding transformer for system level simulations", *IEEE Trans. On Power Electronics*, vol. 33, no. 3, pp. 2471-2483, 2018.
3) U.Javaid, F.Freijedo, **D.Dujic**, W.van-der Merwe: "Dynamic assessment of source-load interactions in marine MVDC distribution", *IEEE Trans. on Industrial Electronics*, vol. 64, no. 6, pp. 4372-4381, 2017. [**cited: 6**].
4) A.Christe, **D.Dujic**: "Galvanically isolated modular converter", *IET Journal on Power Electronics*, vol. 9, Iss. 12, pp. 2318-2328, 2016. [**cited: 10**]
5) S.Kenzelmann, A.Rufer, **D.Dujic**, F.Canales, Y.R. de Novaes: "Isolated DC/DC structure based on modular multilevel converter", *IEEE Trans. on Power Electronics*, vol. 30, no. 1, pp. 89-98, 2015. [**cited: 113**].
6) T.Besselmann, A.Mester, **D.Dujic**: "Power electronic traction transformer: Efficiency improvements under light-load conditions", *IEEE Trans. on Power Electronics*, vol. 29, no. 8, pp. 3971-3981, 2014. [**cited: 37**].
7) C.Zhao, **D.Dujic**, A.Mester, J.K.Steinke, M.Weiss, S-Lewdeni-Schmid, T.Chaudhuri, P.Stefanutti: "Power electronic traction transformer – Medium voltage prototype", *IEEE Trans. on Industrial Electronics*, vol. 61, no. 7, pp. 3257-3268, 2014. [**cited: 115**].
8) **D.Dujic**, G.Steinke, M.Bellini, L.Storasta, M.Rahimo, J.K.Steinke: "Characterization of 6.5kV IGBTs for high-power medium-frequency soft-switched applications", *IEEE Trans. on Power Electronics*, vol. 29, no. 2, pp. 906-919, 2014. [**cited: 42**].
9) **D.Dujic**, C.Zhao, A.Mester, J.K.Steinke, M.Weiss, S-Lewdeni-Schmid, T.Chaudhuri, P.Stefanutti: "Power electronic traction transformer – Low voltage prototype", *IEEE Trans. on Power Electronics*, vol. 28, no. 12, pp. 5522-5534, 2013. [**cited: 106**].
10) M.Claessens, **D.Dujic**, F.Canales, J.K.Steinke, P.Stefanutti, C.Vetterli: "Traction transformation: A power electronic traction transformer (PETT)", *ABB Review*, 1/12, pp. 11-17, 2012. [**cited: 29**].

SELECTED CONFERENCE PAPERS

1) **D.Dujic**, F.Kieferndorf, F.Canales, U.Drofenik: "Power electronic traction transformer technology – an overview"; *The 7th International Power Electronics and Motion Control Conference – IPEMC*, 2012, pp. 636-642. [**cited: 67**].
2) S.Kenzelmann, A.Rufer, M.Vasiladiotis, **D.Dujic**, F.Canales, Y.R.de-Novaes: "A versatile DC-DC converter for energy collection and distribution using the modular multilevel converter"; *The 14th European Conference on Power Electronics and Applications – EPE*, 2011, CD-ROM paper: no. 0545. [**cited: 75**]
3) **D.Dujic**, A.Mester, T.Chaudhuri, A.Coccia, F.Canales, J.K.Steinke: "Laboratory scale prototype of a power electronic transformer for traction applications"; *The 14th European Conference on Power Electronics and Applications – EPE*, 2011, CD-ROM paper: no. 0023. [**cited: 49**]

PATENTS / PATENT APPLICATIONS:

1) F.Canales, F.Kieferndorf, **D.Dujic**: "Power converter system for renewable energy sources", European app. no: 14177354.9, Priority date : 2014-07-17.
2) **D.Dujic**, J.Wahlstroem: "Separately excited synchronous machine with excitation supplied from dc-link of stator inverter", European app. no: 14155964.1, Priority date: 2014-02-14, EP20140155964.
3) **D.Dujic**, A.Mester, R.Celli: "Distributed controllers for a power electronics converter", European app. no: 13164815.6, Priority date: 2013-04-23, EP2797217, US2014313789, CH104124880.
4) A.Mester, **D.Dujic**: "Controlling a modular converter", European app. no: 12188016.5, Priority date: 2012-10-10, WO2014056742
5) A.Mester, T.Besselmann, **D.Dujic**: "Controlling a modular converter", European app. no: 12182924.6, Priority date: 2012-09-04, EP2703208, US2015180352.
6) T.Besselmann, A.Mester, **D.Dujic**: "Switching a DC-to-DC converter", European app. no: 12182917.0, Priority date: 2012-09-04, EP2704302, WO2014037403.
7) F.Kieferndorf, **D.Dujic**, F.Canales: "Power distribution system for autonomous facilities", European app. no: 12183730.0, Priority date: 2012-09-10, WO2014037583.
8) **D.Dujic**, F.Kieferndorf, F.Canales: "Electrical power distribution system for data centers", European app. no: 12180679.8, Priority date: 2012-08-16, WO2014026840.
9) **D.Dujic**, A.Mester, F.Canales : "Multilevel converter and a control method for operating a multilevel", European app. no: 11180537.0, Priority date: 2011-09-08, EP2568589, US2013063981, RU2012138475, KR20130028020, JP2013059251, CH103001501, CA2787709, AU2012213942
10) S.Kenzelmann, A.Rufer, Y.de Novaes, F.Canales, **D.Dujic**, M.Winkelnkemper: "Electric energy conversion system and method for operating same", EP2458725 (A1), Priority date : 2010-11-30.
11) **D.Dujic**, R.Grinberg, F.Canales, H.Z.de la Para: "Drivsystem för en maskin", SE1000198 (A), Priority date: 2010-03-03.

INVITED TALKS

20.04.2018	Title: "*Galvanically isolated high power converters for MVDC applications*" ADCGS – Aachen DC Grid Summit. Aachen, Germany
18.04.2018	Title: "*MVDC power distribution networks and technologies for marine applications*" ECPE Workshop: DC Grids. Technologies and Systems, Aachen, Germany
19.10.2017	Seminar Title: "*Medium Voltage Direct Current – Technologies and Systems*". 19th Int. Symposium on Power Electronics, Novi Sad, Serbia.
28.09.2015	Title: "*Power electronic enabling technologies*". University of Manitoba, Faculty of Engineering, Winnipeg, Canada
12.12.2014	Title: "*Emerging power electronic conversion technologies*". Columbia University, The Fu Foundation School of Engineering and Applied Science, New York, NY, USA
11.12.2014	Title: "*Power Electronic Traction Transformer Technology*". General Electric, Global Research Center, Schenectady, NY, USA

AWARDS AND HONOURS

2016	Invited to join the *Electrosuisse National Committee*
2015	Invited to join the *EPE International Scientific Committee*
2015	Invited to join the *PCIM Advisory Board*
2014	*Isao Takahashi Power Electronics Award* for outstanding achievement in power electronics
2012	Elevated to the grade of IEEE Senior Member
2007	*First Prize Paper Award* by the 'Electric Machines Committee' of the IEEE Industrial Electronics Society Annual Conference
2005	*Best Paper Award* at the ETRAN Conference.