Wireless Electric Vehicle (EV) Chargers – Challenges and Solutions

Seminar instructor: Miroslav Vasić, miroslav.vasic@upm.es
Nikola Mirković, nikola.mirkovic@ieent.org

Short

This seminar “Inductive Power Transfer (IPT) Chargers for Electric Vehicle (EV) Applications – Challenges and Solutions” explores the cutting-edge design and implementation of Inductive Power Transfer (IPT) systems, a key technology driving the future of electric vehicle (EV) charging. As transportation shifts toward sustainable energy, IPT chargers provide a contactless, efficient solution for powering EVs. The seminar addresses the core challenges of IPT, such as optimizing the inductive coupler, managing compensation techniques, and implementing advanced converter topologies. Emphasis is placed on practical strategies for achieving high power transfer efficiency, particularly for systems operating at frequencies between 80 and 90 kHz, in line with SAE J2954 standards. Power ratings of the IPT chargers that will be presented and analysed range from 3.3 kW up to 30 kW.

Attendees will gain foundational insights into IPT system design, including the selection and optimization of coil geometries and ferrite tiles, and the tuning of resonant networks. The seminar also introduces novel solutions such as three-winding topologies and single-stage matrix converters, which offer improved efficiency and compactness but present their own design and control challenges. Special attention is given to bidirectional charging for modern EV batteries, as well as achieving reliable system performance under conditions like misalignment and high ground-to-vehicle clearance.

The seminar is divided into two sections. The first part covers the theoretical modeling and design of the IPT system, including compensation strategies and coil design. In the second part, practical implementation challenges are addressed, with real-world examples such as a 30 kW three-phase IPT charger prototype, highlighting synchronization issues, system losses, and control strategies. The seminar also provides hands-on guidance on modulation techniques for matrix converters, with experimental results to validate the discussed approaches.

This seminar is designed for researchers, PhD students, and professionals in power electronics who are interested in advancing their knowledge of IPT systems for EV applications. It offers a blend of theoretical principles and practical design insights, ensuring that participants can tackle the challenges of high-efficiency, high-power IPT system design.

Detailed Synopsis

The transport sector is responsible for close to a quarter of global energy-related CO_2 emissions due to its heavy reliance on fossil fuels. In order to successfully perform the energy transition of our society, and stay on 1.5°C pathway, the transport emissions must be reduced from 8.2 $GtCO_2$ in 2018 to 0.4 $GtCO_2$ in 2050. Consequently, electric transportation has become one of the pillars of our society for a sustainable energy future, and electric vehicles (EVs) and efficient battery chargers are the key elements for the development of efficiently electrified society.

As a response do these challenging tasks, Inductive Power Transfer based EV chargers have emerged as a focal point of research and innovation in the field of power electronics, as they enable seamless battery charging, without any physical contact between the charging infrastructure and the EV, and as, additionally, these chargers can offer smart charging techniques and services.

The objectives of this seminar are:

- To provide the attendees with the fundamental knowledge about the functionality and design of IPT EV chargers, focusing on both design of the inductive coupler as well as the converter topologies that are used for powering the system.

- To explain the requirement and importance of compensation of the inductive link in IPT systems, giving a thorough overview of the existent compensation techniques and their functionality and draw the attention of the listeners to possibilities opened by introducing an additional coil to the classical system.
- To present novel concepts for efficient and compact IPT solutions based on three windings topologies and single-stage matrix converter topology, outlining the practical challenges related to the implementation of these novel ideas, as well as the ones related to the control of the system.

In this way this seminar offers a great educational part that covers the two fundamental aspects of our engineering work: **theoretical analysis of the IPT system operation**, and **practical and descriptive design examples** used to illustrate the design problems and limitations of this power transfer technology, including the geometry constraints and the desired power transfer capability. Additionally, the seminar presents novel design concepts (the auxiliary compensation winding) and a novel modulation of advanced converter topologies such as **matrix converter (Fig. 1)**, that may be interesting for researchers and professionals who would like to know how to implement an IPT system that relies on such a topology.

This seminar focuses on IPT systems intended for EV applications. For this reason, and according to the SAE J2954 standard proposal, the operating frequency range of the examples that will be analyzed during the seminar will be between 80 and 90 kHz. Both low power (**3.3 kW, Fig. 2**) and high power (**30 kW, Fig. 4**) chargers will be analyzed, outlining the adequate application for each of them. Ground to vehicle clearance distances of up to 250 mm present a challenging barrier for transferring high power levels efficiently, so in our seminar we will present design techniques for the inductive link that allow system to reach its full potential in terms of efficiency. Achieving efficiencies between 90% and 97% cannot be solely accomplished by optimizing the inductive link, thus, we will emphasize the way of properly choosing the strategy to compensate the IPT coils and the converter topology that will energize the entire system. Due to the massive energy capacity of contemporary EV batteries going to more than 100 kWh, significant attention will be dedicated to bidirectional IPT chargers, as they provide a possibility to fully utilize the capabilities of the EV battery. In the end, compact **three-phase IPT (Fig. 3) systems** will be disseminated as a gateway for achieving high power transferring capability.

Our tutorial is divided into two sections. In the first part, we delve into the fundamental principles of wireless power transfer, exploring the modelling and design of the inductive link, focusing on optimal coil design and tuning of the resonant network and outlining the existing challenges in the domain of IPT. Afterwards, the practical segment proposes solutions to the previously stated challenges, providing attendees with hands-on knowledge on how to design and build high-power, highly efficient IPT chargers. Both DC/DC and AC/DC chargers are encompassed in this part, with detailed guidelines on implementation of both systems, going from converter design and optimization of the inductive link, over the control algorithm of the system, up to the modulation of the utilized converters.

The main results that we aim at with this seminar are:

1. Demystify the operating principles of IPT chargers and provide clear guidance on how to design and build such a system.
2. Explain where are the research challenges and opportunities of further improvement.
3. Demonstrate possible solutions for the identified challenges, pointing out to the hidden "obstacles" in their implementation and how to successfully tackle them.

This seminar is intended for researchers, PhD students and corporate employees working in power electronics related areas, who want to augment their knowledge in inductive power transfer. It assumes a working knowledge of electronics engineering and a familiarity with power conversion technology. The seminar is intended to cater to a wide audience level, from the junior workers to the experts.

Table of Contents

- Inductive Power Transfer - IPT
    - Operating principles
    - Wide specter of different applications with examples: Electrical transportation, Biomedical applications, Space technology, Consumer electronics
- IPT EV Charging
    - Motivation and benefits
    - Important achievements from the current state-of-the-art
    - Challenges: efficiency, synchronization, system and field control, winding technology, bidirectionality

2. **Modeling of an IPT system (30 minutes)**
    - IPT system – A coreless transformer
    - Compensation topologies
        - Constant-current and constant-voltage topologies
        - Gyrator – a fundamental building block
        - Complex topologies
3. **Design of the inductive coupler (30 minutes)**
    - Coil design: geometry, power losses
    - Ferrite optimization: position and quantity of ferrite tiles
4. **Three-coil IPT charger for EV applications (30 minutes)**
    - Motivation and the basic idea
        - Losses and control
        - Idea behind the utilized three-coil system
    - Auxiliary (intermediate) coil in details
        - Model of the three-coil system
        - Design procedure
        - Control of the system
    - Synchronization of the converters
        - Requirement for synchronization
        - Possible solutions for achieving synchronous operation
    - Experimental validation on a 30 kW prototype
5. **Single-stage IPT chargers (45 minutes)**
    - State-of-the-art topology overview
    - Matrix converter
        - Different variants of the topology
        - Design considerations and challenges
    - Modulation of the matrix converter in IPT charging applications
        - Classical SVM modulation
        - Improved SVM modulation
        - Modulation with the flipping pattern
    - Single-stage, three-phase IPT charger
        - Coupler topologies and operating principles
        - Matrix converter powering a three-phase IPT system
        - Balancing the system under misalignment
    - Hands-on Demonstration
        - Experimental results
        - Losses dissemination and system efficiency
        - System reliability
6. **Conclusions (15 minutes)**
    - Summary and discussion
    - Future points for the research

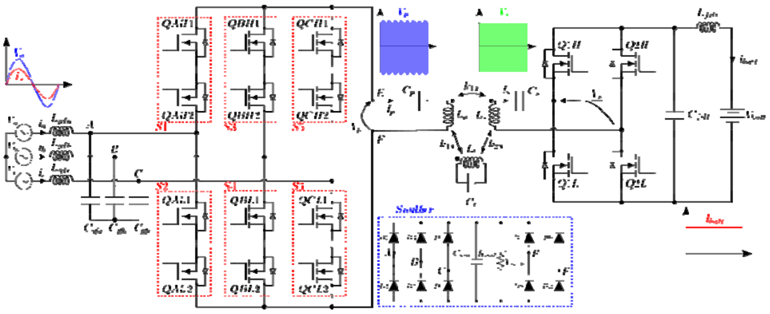

Fig. 1 Matrix converter topology

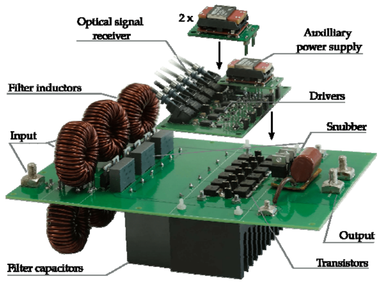

Fig. 2 Low power matrix converter prototype

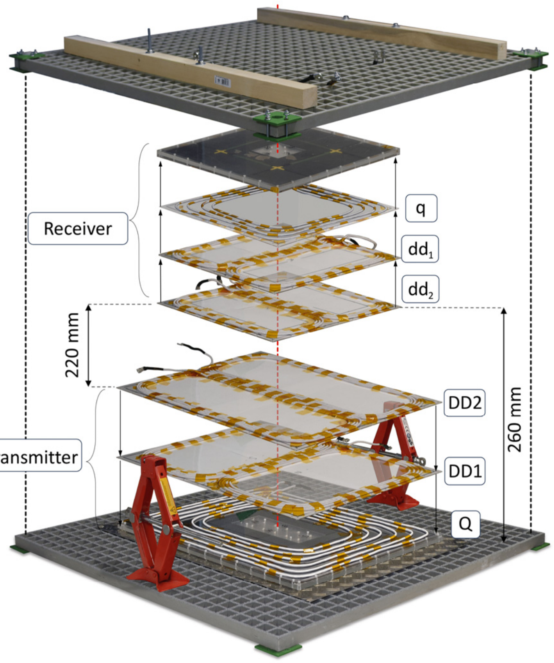

Fig. 3 Three-phase coil structure for IPT EV charging

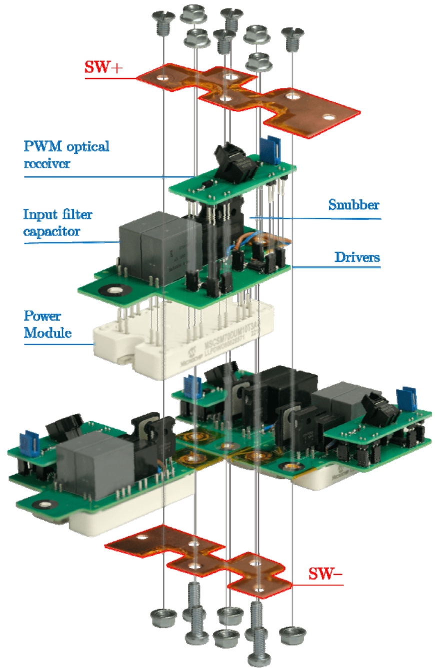

Fig. 4 High power matrix converter prototype