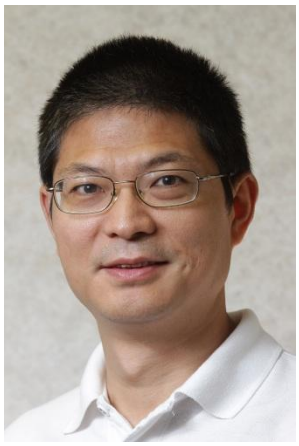
Wireless Power Transfer Technology for Electric Vehicle Applications

Instructor: Prof. Chris Mi

Fellow of IEEE, Professor of Electrical and Computer Engineering at the University of Michigan, Dearborn, and the Director of the US DOE funded GATE Center for Electric Drive Transportation.



Electric vehicles and plug-in hybrid electric vehicles (PEVs) have attracted worldwide attentions because their capabilities to displace petroleum usage and improve energy and environment sustainability. One of the key constraints for the mass market penetration of PEVs is the inconvenience and safety concerns associated with charging. Wireless charging using Wireless Power Transfer (WPT) Technology, as an alternative to conductive charging or battery-swapping, can provide the convenience and safety requirements. Recently, EV battery wireless chargers have been realized at large power levels (>50kW) with reasonable sizes, distance in excess of 200 mm, DC-to-battery efficiency of 96.5%, and a misalignment of up to 600 mm, using magnetic-resonance technology. This breakthrough will have strong impact on PEVs and a variety of other applications, including consumer electronics, home appliances, medical implant devices, and some industry applications. This tutorial focuses on the key technical challenges of WPT, including coil design, system analysis using analytical methods, simulations of the WTP system; resonant topologies suitable for various applications, and power electronics topologies associated with WPT. The presentation will be mostly focused on high power applications in the kilowatts and tens of kilowatts range but other wireless power transfer technologies and applications of WPT, as well as environment safety, will be briefly discussed.

Topical Outline

Module one: Introduction of wireless power transfer

There have been dramatic progresses in wireless power transfer (WPT) in terms of power level (>50kW); efficiency (>90%), transfer distance (>300 mm) and misalignment tolerance (>300mm), thanks to optimized coil design, magnetic resonance tuning ability and soft switching of power converters employed in the WTP systems. This is the first tutorial of five in a series developed on the topic of wireless power transfer by Prof. Chris Mi, fellow of IEEE and Professor of University of Michigan-Dearborn. In this first tutorial, Dr. Chris Mi provides an overview of wireless power transfer technology and its application in electric vehicle charging. Different terminologies in wireless power transfer will be explained. Various methods for wireless power transfer will be discussed. Magnetic resonance and compensation methods will be introduced.

Topics:

- Conventional charging methods: conductive charging and battery swapping
- Issues of conventional charging
- History of WPT
- Method of WPT: microwave, laser, ultrasound, magnetic resonance
- Application of WPT
- State of the art of WPT
- Limitations of current WPT in EV applications
- Resonant topologies of WPT: series-series; series-parallel, and parallel-series

Module 2: Method of study of WPT Systems

This is the second tutorial of five in a series developed on the topic of wireless power transfer by Prof. Chris Mi, fellow of IEEE and Professor of University of Michigan-Dearborn. In this tutorial, Dr. Chris Mi discusses the different method that can be used to study wireless power transfer systems, including equivalent circuit method, two-port network theory, S-parameter analysis with the help of a network analyzer, and numerical methods.

Topics:

- Analytical method approach: equivalent circuit analysis
- Two port networks
- S-Parameter analysis
- Transmission efficiency
- Impedance matching

Module 3: Coil design and analysis

This is the third tutorial of five in a series developed on the topic of wireless power transfer by Prof. Chris Mi, fellow of IEEE and Professor of University of Michigan-Dearborn. In this tutorial, Dr. Chris Mi discusses the various types of coil design for maximum coupling coefficient, including circular, rectangular, flux pipe, double D, and DDQ coils. Measurements of coil inductance will be discussed.

Topics:

- Coil layout structures
- Field analysis and numerical analysis
- Calculation of mutual and self inductance
- Measurement of coupling coefficient
- Design for handling of misalignment

Module 4: Power electronics circuit design and control

This is the forth tutorial of five in a series developed on the topic of wireless power transfer by Prof. Chris Mi, fellow of IEEE and Professor of University of Michigan-Dearborn. In this tutorial, Dr. Chris Mi discusses the elements needed for a complete EV wireless charger. Rectifier, power factor correction, and resonate topologies will be discussed.

Topics:

- AC-DC rectifier and power factor correction stage
- DC-AC resonant stage
- Soft switching
- AC-DC output stage
- Resonant topology
- Frequency tuning and adaptive control for misalignment compensation

Module 5: Other issues in WPT

This is the last tutorial of five in a series developed on the topic of wireless power transfer by Prof. Chris Mi, fellow of IEEE and Professor of University of Michigan-Dearborn. In this tutorial, Dr. Chris Mi discuss other aspects of wireless chargers, such as safety issues, switching frequency band requirement, SAE WPT J2954 standard, object detection methods, communication methods between transmitter and receiver, some testing results of foreign object inserted between the transmitter and receiver are shown.

Topics:

- Human, animal and environment safety
- Object detection
- SAE J2954 standard for WPT
- Wireless communication between the transmitter and receiver
- Inductive coupling vs. capacitive coupling
- In-motion charging vs. stationary charging
- Other applications of WPT: medical, appliance, consumer electronics
- References for further reading

About the Instructor

Dr. Chris Mi is a fellow of IEEE, Professor of Electrical and Computer Engineering at the University of Michigan, Dearborn, and the Director of the US DOE funded GATE Center for Electric Drive Transportation. He received the B.S. and M.S. degrees from Northwestern Polytechnical University, Xi'an, China, and the Ph.D. degree from the University of Toronto, Toronto, Canada, all in electrical engineering. Previously he was an Electrical Engineer with General Electric Canada Inc. He was the President and the Chief Technical Officer of 1Power Solutions, Inc. from 2008 to 2011. He is the Co-Founder of Gannon Motors and Controls LLC and Mia Motors, Inc.

His research interests are in electric and hybrid vehicles. He has taught tutorials and seminars on the subject of HEVs/PHEVs for the Society of Automotive Engineers (SAE), the IEEE, workshops sponsored by the National Science Foundation (NSF), and the National Society of Professional Engineers. He has delivered courses to major automotive OEMs and suppliers, including GM, Ford, Chrysler, Honda, Hyundai, Tyco Electronics, A&D Technology, Johnson Controls, Quantum Technology, Delphi, and the European Ph.D School. He has offered tutorials in many countries, including the U.S., China, Korea, Singapore, Italy, France, and Mexico. He has published more than 100 articles and delivered 30 invited talks and keynote speeches. He has also served as a panelist in major IEEE and SAE conferences.

Dr. Mi is the recipient of "Distinguished Teaching Award" and "Distinguished Research Award" of University of Michigan Dearborn. He is a recipient of the 2007 IEEE Region 4 "Outstanding Engineer Award," "IEEE Southeastern Michigan Section Outstanding Professional Award." and the "SAE

Environmental Excellence in Transportation (E2T) Award." He was also a recipient of the National Innovation Award (国家发明奖二等奖) and the Government Special Allowance Award (政府特殊津贴) from the China Central Government. In December 2007, he became a Member of Eta Kappa Nu, which is the Electrical and Computer Engineering Honor Society, for being "a leader in education and an example of good moral character."

Dr. Mi was the Chair (2008-2009) and Vice Chair (2006-2007) of the IEEE Southeastern Michigan Section. Dr. Mi was the general Chair of the 5th IEEE Vehicle Power and Propulsion Conference held in Dearborn, Michigan, USA in September 6-11, 2009. Dr. Mi is one of the three Area Editors of the Editor of IEEE Transactions on Vehicular Technology, associate editor of IEEE Transactions on Power Electronics, Associate Editor of IEEE Transactions on Industry Applications, Senior Editor, IEEE Vehicular Technology Magazine, Guest Editor, International Journal of Power Electronics, Editorial Board, International Journal of Electric and Hybrid Vehicles, Editorial Board, IET Electrical Systems in Transportation, and Associate Editor of Journal of Circuits, Systems, and Computers (2007-2009). He served on the review panel for the NSF, the U.S. Department of Energy (2007–2010), the Natural Sciences and Engineering Research Council of Canada (2010), Hong Kong Research Grants Council, French Centre National de la Recherche Scientifique, Agency for Innovation by Science and Technology in Flanders (Belgium), and the Danish Research Council. He is the topic chair for the 2011 IEEE International Future Energy Challenge, and the General Chair for the 2013 IEEE International Future Energy Challenge. Dr. Chris Mi is a Distinguished Lecturer (DL) of the IEEE Vehicular Technology Society.

He is also the General Co-Chair of IEEE Workshop on Wireless Power Transfer sponsored by PELS, IAS, IES, VTS, MAG, and PES, Editor of IEEE Journal of Emerging and Selected Topics in Power Electronics - Special Issue on WPT, and steering committee member of the IEEE Transportation Electrification Conference (ITEC- Asian).

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