IECON 2023 Tutorial Proposal

Title of the Proposal: Research ON Key Technologies of the Inductive Power Transfer With a Long Air Gap

- Presenter(s):
  Professor, Yijie Wang, School of Electrical Engineering and Automation, Harbin Institute of Technology

  Associated Professor, Yueshi Guan, School of Electrical Engineering and Automation, Harbin Institute of Technology

  Associate Researcher, Jianwei Mai, School of Electrical Engineering and Automation, Harbin Institute of Technology

  Professor, Dianguo Xu, School of Electrical Engineering and Automation, Harbin Institute of Technology

- Brief description:
  No more than 600 words

  With the increasing development of wireless power transfer technology, academia and industry have put forward new requirements for the comprehensive performance of this technology. High power density, high transmission efficiency, long transmission distance, etc. In order to promote the digitization process of the new power system and accelerate the construction of a highly reliable energy internet, more and more monitoring and perception devices, such as sensors, cameras, and data processors, are being applied to the high-voltage side of smart substations. Inductive power transfer (IPT) system with a long air gap can meet the electricity demand of high-voltage equipment. However, how to synchronously improve the power density and transmission efficiency of the system is a major challenge. However, how to synchronously improve the power density and transmission efficiency of the system is a major challenge. In order to solve this problem, firstly, the mechanism of the parasitic capacitance of the coil was studied. The results show that the dielectric loss of parasitic capacitors is the main factor limiting the improvement of coil quality factor. By establishing a more precise distribution parameter model of the coil, the influence mechanism of the parasitic capacitance of the coil on the resonant circuit is revealed more clearly. And a segmented series compensation method is proposed to reduce the voltage of the parasitic capacitance of the coil. The loss of the coil and the influence on the resonant circuit are greatly reduced. Second, The rectifier causes the equivalent AC impedance of the load to be inductive or capacitive. In severe cases, there will be a loss of duty cycle, which will not only reduce the system efficiency, but also limit the range of load changes. In this paper, the calculation method of the equivalent AC impedance of C-filter bridge rectifier and LC-filter bridge rectifier load in continuous conduction mode is given, and an improved C-filter bridge rectifier and LC-filter bridge rectifier are proposed. Finally, in order to extend the relative distance of IPT system, a three-dimensional magnetic cubic coupling structure and an improved three-dimensional solenoid magnetic coupling structure for high-aspect ratio wireless power transfer systems are proposed. The proposed magnetic coupling structures are suitable for the application scenario of long air gap wireless power transfer, and can maintain sufficient coupling coefficient to maintain the efficiency of the system. Based on the three-dimensional solenoid magnetic coupling structure, the multi-level IPT system with long air gap was studied to improve the transmission efficiency.
In order to extend the distance of wireless power transfer, improve the efficiency of the system, a series of studies were carried out.

1. The research on the mechanism of the parasitic capacitance of the loosely coupled transformer

   Loosely coupled transformer (LCT) is the core component of IPT system, and its performance parameters have an important impact on the efficiency and output stability of the system. The high quality factor of coil is very important for the efficiency of LCT. In the limited space, close winding of coil is the main method to improve its quality factor. However, in the compact coil, the parasitic capacitor will increase the system loss, which may reduce the efficiency. Previous research work did not pay attention to the parasitic capacitance low quality factor of dielectric loss. We put forward accurate coil distribution parameter model to reveal the mechanism of parasitic capacitor. In order to solve this problem, a single-turn segment series compensation method and a single-layer segment series compensation method were proposed.

2. Research on the input impedance characteristics of bridge rectifier

   Rectifier circuit is a necessary part of IPT system. Reducing the reactive power caused by rectifier can help improve the efficiency of the system. The bridge-type rectifiers is the most widely used, which can be divided into C-filter rectifier and LC-filter rectifier according to the different filter network. The load equivalent AC impedance of C-filter rectifier is inductive when the load resistance value is large, and the load equivalent AC impedance of LC filter rectifier is capacitive when the load resistance value is small. The reactive power caused will increase the system loss, damage the resonance state of the compensation network. Previous research work is based on the ideal diode and circuit model, not considering the influence of parasitic capacitance or parasitic inductance, and the calculation and analysis are not accurate. We propose the analysis method of the bridge rectifier load, and propose the improved rectifier circuit structure and parameter design method to reduce the reactance component, which is helpful to increase the working range of the load and improve the system efficiency.

3. Research on long distance wireless power transfer systems based on multiple receivers structure

   In order to extend the relative distance of wireless power transfer, a multi-receivers structure is investigated. An optimal design for long-range wireless power transfer system based on multiple repeaters is proposed, which aims at powering high-voltage side sense module in HVdc applications. The mathematical model of the system is established. The characteristics of current distribution and impedance angle are analyzed under equally spaced situations. To further optimize the system, the optimized spaced structure with different distances is investigated, which can improve transferring efficiency under same distance requirement. The effect of load is also analyzed. A 1.5 m prototype with eight repeaters is built and the experimental results verify the feasibility of optimized coil arrangement, which can effectively improve efficiency, especially under light load situations.

Brief CV:
Photo, name, email, and short CV
Yijie Wang, wangyijie@hit.edu.cn. He was born in Heilongjiang Province, China, in 1982. He received the B.S., M.S. and Ph.D. degrees in electrical engineering from Harbin Institute of Technology, China, in 2005, 2007 and 2012, respectively. From 2012 to 2014, he was a lecturer with the Department of Electrical and Electronics Engineering, Harbin Institute of Technology. From 2014 to 2017, he was an associate professor with the Department of Electrical and Electronics Engineering, Harbin Institute of Technology. Since 2017, he has been a professor with the Department of Electrical and Electronics Engineering, Harbin Institute of Technology. His interests include DC-DC converters, soft-switching power converters, power factor correction circuits, digital control electronic ballasts, LED lighting systems. Dr. Wang is an Associate Editor of IEEE Transactions on Industrial Electronics, IEEE Access, IET Power Electronics and Journal of Power Electronics.

Yueshi Guan was born in Heilongjiang Province, China, in 1990. He received the B.S., M.S. and Ph.D. degrees in electrical engineering from Harbin Institute of Technology, China, in 2013, 2015 and 2019, respectively. Since 2019, he has been an associate professor with the Department of Electrical and Electronics Engineering, Harbin Institute of Technology. His research interests are in the areas of high frequency and very high frequency converters, single-stage AC/DC converter, and LED lighting systems. Prof. Guan has authored more than 40 conference and journal papers. He received Nomination Award of Young Engineer Award of PCIM Asia Conference in 2019, the Second Prize Paper Award from IEEE Transactions on Power Electronics, as well as Best Paper awards of ICEMS 2019, SPEED 2019, ITEC Asia-Pacific 2017. He also served as the special session Chair of IEEE ICEMS 2019 conference.
Jianwei Mai, maijianwei@hit.edu.cn. He was born in Henan, China, in 1994. He received the B.S. and Ph.D. degree in electrical engineering from Harbin Institute of Technology, China, in 2017 and 2022, respectively. Since 2023, he has been an assistant researcher with the Department of Electrical and Electronics Engineering, Harbin Institute of Technology. His research interests include inductive power transfer, and magnetic coupling structure design. He is the reviewer of IEEE TIE, IEEE TPE, IEEE JESTPE, and IET PEL.

Dianguo Xu received the M.S and Ph.D degrees in electrical engineering from Harbin Institute of Technology (HIT), Harbin, China, in 1984 and 1989, respectively. In 1989, he joined the Department of Electrical Engineering, HIT, as an Assistant Professor, where he has been a Professor since 1994. He was the Dean of School of Electrical Engineering and Automation HIT, from 2000 to 2010. He is currently the Vice President of HIT. His current research interests include renewable energy power conversion technology, multi-terminal HVDC system based on MMC, power quality mitigation, speed sensorless vector-controlled motor drives, and high performance PMSM servo system.

Prof. Xu is the winner of 2018 IEEE Industry Applications Society Outstanding Achievement Award. He was promoted as a fellow of IEEE for the contribution to control of electrical drives and power electronic converters. He was general chair of ICEMS 2019 and IEEE ITEC Asia-Pacific 2017, TPC chair of IPEMC 2012-ECCE Asia and VPPC 2008. He has published over 600 journal papers, 4 book chapters, and held 63 patents.

in Power Electronics. He is the Chairman of the IEEE Harbin Section, the vice president of China Electrotechnical Society (CES).

- Relevant publications:


