Modeling of resonant electric power conversion for wireless power transfer systems

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Summary

Wireless power transfer (WPT) is important for charging the battery in hybrid vehicles with an electric motor. The design and optimization of WPT-systems is non-trivial and one particular challenge is the modeling of non-linear components that are featured in power inverters and rectifiers. In this project, we develop and test models for these non-linear components in the setting of a WPT-system and, in particular, we focus on techniques that can be used for gradient-based optimization of the WPT-system. First, we have implemented and simulated accurate models of the circuit in SPICE and performed successful comparisons with measurements to validate this model. We have demonstrated that the Rectifier-Compensated Fundamental Mode Approximation Analysis (RCFMA) can be a useful technique to incorporate the rectifiers in frequency-domain analysis of WPT-systems. However, we find that Modal Analysis (MA) is a more attractive approach and we have successfully implemented and tested this approach for simple rectifier circuits. In the context of the WPT-systems of interest in this project, it is also demonstrated that the magnetically coupled resonant circuits require a more sophisticated version of MA that accounts for the entire system and we have derived such a formulation, which is currently implemented and tested. The project started 2015-03-30 and ends 2015-06-26.

General project description and background

A main difficulty in future WPT-applications is the relatively large air gap between the primary and secondary side of the WPT-system, which results in a low coupling-coefficient. An attractive approach to mitigate problems with a low coupling-coefficient is to use resonant circuits on both the primary and secondary side. Simple time-harmonic models for the fundamental mode demonstrate that it is possible to achieve high efficiency for reasonably good power transfer levels despite an air gap distance of 30 cm. However, such circuit models are not sufficiently accurate for modeling and design of an actual WPT-system, which involves power converters and rectifiers. Thus, we have tested Rectifier-Compensated Fundamental Mode Approximation Analysis (RCFMA) and Modal Analysis (MA) in this context and we find that MA is a more attractive technique. The Modal Analysis is based on a set of different time-domain solutions that is used to form combined trajectories (based on time-continuity of currents and voltages) that occur after transients in the system have vanished. This approach is known to be accurate for systems with high coupling-coefficient but may be challenging to use in its basic form for low coupling-coefficient systems that require highly resonant circuits with possibly different resonance frequencies.

Achieved results

The Modal Analysis (MA) is based on a set of different time-domain solutions that is used to form combined trajectories (based on time-continuity of appropriate currents and voltages) that occur after transients in the system have vanished. The MA leads to a set of non-linear equations and their solution correspond to the times when the diodes in the rectifier are switched on and off. This approach is known to be accurate for systems with high coupling-coefficient. In this project, we have extended this technique for low coupling-coefficient systems that require highly resonant circuits with possibly different resonance frequencies. Tests of MA for simple circuits are successful and we currently implement and test MA for the complete WPT-system.

Timing and finance

The project started 2015-03-30 and ends 2015-06-26. The total project budget is SEK 0.3 million, which is funded by SHC.

Executors and collaboration

Yinan Yu (60%), Johan Winges (35%), Thomas Rylander (20%), Tomas McKelvey (10%) during 3 months. We have a fruitful collaboration with QRTECH, which provides measurement results for validation of the models.

Dissemination of Results

We will write a technical report on the work for the SHC and this report will also be submitted as an article to an appropriate journal/conference.

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