Wireless Power Transfer System Design

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WPT System

\[ V_2 = M \frac{dI_1}{dt} \]
Wireless Power Transfer (WPT)

Near-Field (Inductive coupling, resonant)

• Do not rely on propagating EM waves
• Operate at distances less than a wavelength of transmission signal
• Resonance obtained by use of external circuit capacitor
• Electric and magnetic fields can be solved separately

Focus of this presentation

Far-Field (resonant)

• Operating range to ~10 meters
• Self capacitance of coil turns are of importance
• Requires full wave solver with coupled electric and magnetic fields
Design Challenges

Magnetic Analysis
- Inductance/Resistance calculations versus frequency
- Ensure linear mode operation
- Relative Position sensitivity study
- Loss evaluation
- Effect of temperature on magnetic performance

Circuit Analysis
- Operate in resonant mode, considering magnetic results
- Compute efficiency considering relative position
- Transient simulation considering frequency dependent effects

Thermal Management
- Consider local losses distribution in thermal evaluation
- Consider changing of electrical properties with temperature
Outline

- Large Gap Transformer Design Using Computational Electromagnetics
- Combination of Circuit and Magnetic Analysis for Resonance
- Thermal Management
Large Gap Transformer Design Using Computational Electromagnetics
• Low reluctance flux path is available
• Mutual Coupling between the coils can be easily determined using Magnetic Circuit approach
• Leakage flux can be considered to be negligible
• Mutual inductance can be derived using flux balance
• Analytical solution possible within permissible level of accuracy
Large Gap Transformer

- No Specific path for the magnetic flux
- Leakage flux is significant enough and cannot be neglected
- Analytical methods are proposed for calculation of Mutual inductance using Maxwell’s formula for two coaxial circular coils

\[
M = \frac{2\mu_0\sqrt{R_p R_s}}{k} \left[ \left(1 - \frac{k^2}{2}\right) K(k) - E(k) \right]
\]

Application of these formulas to real life cases is almost impossible

Computation Electromagnetics can help to reduce problem complexity significantly
Maxwell

Maxwell is the electromagnetic field analysis software using the Finite Element Method.
Transformers

Insulation – Dielectric Withstand, Maximum E-field

Losses and Temperature in Ferrite Core

Load Analysis Foil Losses

Inductance

Lorentz Force

Creep Stress

Converters

Tank Wall Losses Bus Bars
WPT Magnetic simulation Flow Chart

Magnetic Field Solver
+
Circuit / System Simulator

Magnetostatic

Core, Winding

Eddy Current (time harmonic)

Impedance Model

Eddy Current

Gap

Sliding

Circuit / System Simulator (AC / TR)

Circuit / Drive / Controller design
Waveform, Efficiency, Power factor, Response

Fields, Losses
Magnetostatic Analysis

- Saturation
- Magnetic shielding
- Self and Mutual Inductance
- Coupling Coefficient
Parametric Analysis using Maxwell
Eddy Current (Frequency domain)

- Impedance vs frequency
- State Space Model for Circuit Analysis
- Losses
- Eddy current shielding

Core (Power Ferrite)

Shield Plate (Aluminum)
Combination of Circuit and Magnetic Analysis for Resonance
Inductive Type Coupling – Near Field

1) Electromagnetic analysis to determine $R$, $L$, $M$

2) Resonant circuit realized by a lumped capacitance parameter in the circuit simulator
System Approach with Simplorer

Secondary Coil

Primary Coil

Reduced Order Model (ROM)
Frequency Domain Analysis: System Level

AC Analysis Setup
- Analysis Setup Name: AC
- Analysis Control:
  - Disable this analysis
- Start frequency: FStart: 50 kHz
- Stop frequency: FEnd: 300 kHz
- Frequency step: FStep: 1 kHz
- AC sweep type: Linear
- Enable continue to solve

Bode Plot 2
Parametric Analysis: Frequency Domain

**Bode Plot: Load Voltage vs Gap**

**Bode Plot: Load Voltage vs Slide**

Geometric parameters are Available in the circuit environment
Transient Analysis
Efficiency Map

Output/Input Power

Tuned capacitance for each conditions

\[ P = VI \cos \theta \]
\[ \eta = \frac{P_{out}}{P_{in}} \times 100[\%] \]
Optimize the Design: Various Shape Types

Disk Coil type

Solenoid Coil type
Efficiency as a function of sliding direction and distance

- Gap between coils kept constant
Efficiency as a function of gap between coils

- Zero sliding
System Simulation – WPT

AC200V
Rectify
Inverter

Controller

Wireless Power Transformer

Battery

Motor
Inverter
Charging Circuit

Contactless Power Transfer
Thermal Management
Temperature in ANSYS Mechanical or CFD

Ohmic Loss

Core Loss

Temperature
Summary

ANSYS offers a comprehensive modeling solution for Wireless Power Transfer systems:

- Magnetostatic
- Frequency domain
- Circuit and system level
- Thermal

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