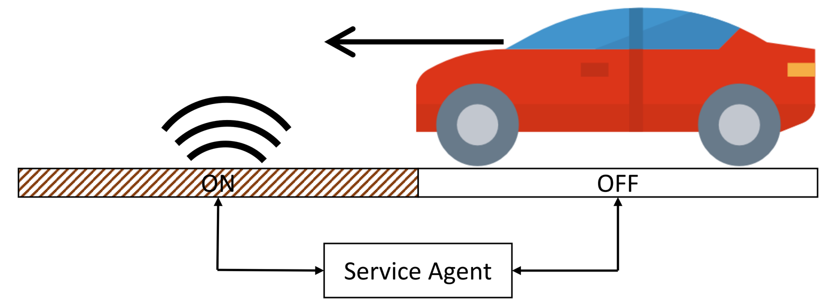
An AI-Enabled Control for Dynamic Wireless Power Transfer

Muhammad Enagi Bima, Bhattacharya Indranil
Electrical and Computer Engineering Department



Objectives

- Minimize the primary-secondary coil communication.
- Estimate the mutual inductance between participating coils using a Neural Network based algorithm.
- Implement a control scheme to enable efficient wireless power transfer.

Introduction

- Dynamic Wireless power transfer (WPT) is a technology that would enable the charging of electric vehicles, pace makers and other consumer electronics while they are in motion.
- This requires WPT system to be aware of its environment and adapt parameters to it.

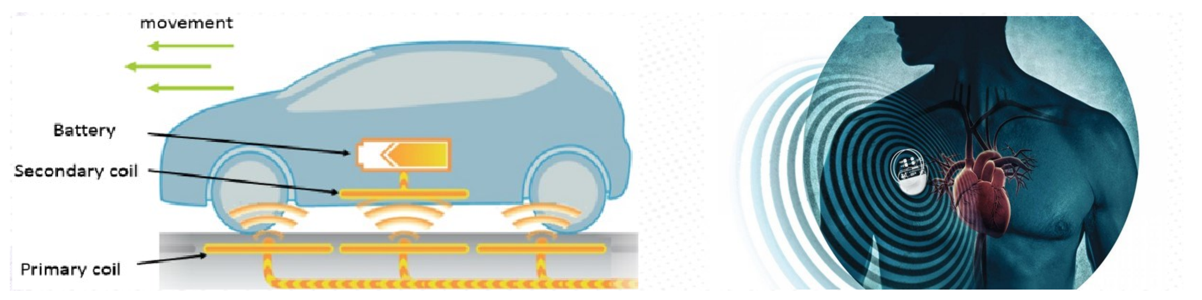


Figure 1: Dynamic Wireless Power Transfer for EV and powering pacemaker

Challenges:

- Amount of power transmitted over a long distance
- Estimating the mutual inductance fast enough to ensure enough power is transferred

Proposed Solution:

- Implment an artificial intelligence based system that is aware of its encironment
- Coupling coefficent estimation using distance information

Shielding

Involves providing an alternate path for magnetic field to pass through thereby protecting the intended object or region. Typically done by using a magnetic material with high permeability.

Magnetic Field line constructive adding up

Is achieved by the use of coil structures that provide more constructive interaction between the magnetic flux lines. Various coil structures have been use din literature which include: circular, square, helical and Double D [1].

Novelty

A novel AI powered WPT scheme is presented in this project. Location data is generated and used to train a Neural Network which in turn estimates the coupling coefficient between P-S coils.

Methodology

Figure shows the method adopted in actualizing this project. ANSYS Maxwell software package was used for generating location data. It is based on Finite Element Analysis (FEA) method.

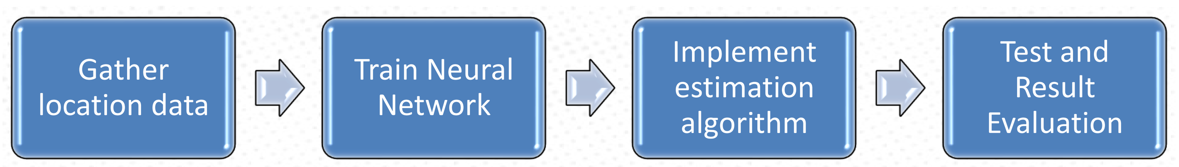


Figure 2: Block diagram for this research showing key steps adopted in its actualization

Modeled coil structure is tested using various parameters. These include:

- coupling coefficient linked to Location
- Implemented optimization algorithms
- Used layered DD coil [2]

Implementation of estimation is in two steps:

- Implement Maximum power point tracking
- Tune voltage

Modeling

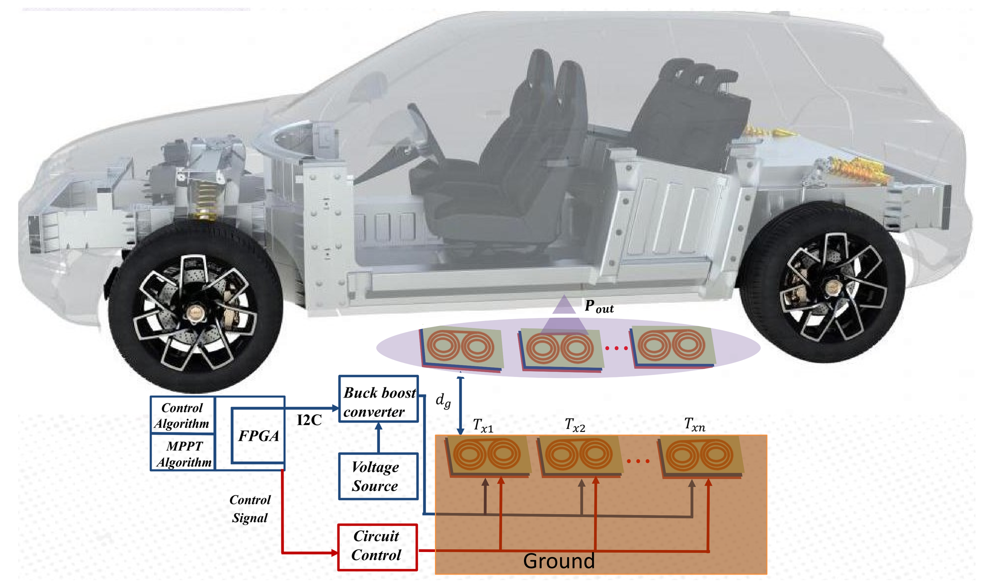


Figure 3: Schematic of proposed control scheme for DWPT

The control system tunes circuit prameters such as transmit voltage and load by using received signals from embedded sensors.

$$k_m = \frac{-j \times \omega M_{mn}}{Z_{transm}} \quad (1)$$

$\omega = 2\pi * frequency$, Mmn Mutual inductance between coil m and n

Efficiency of Power Transfer

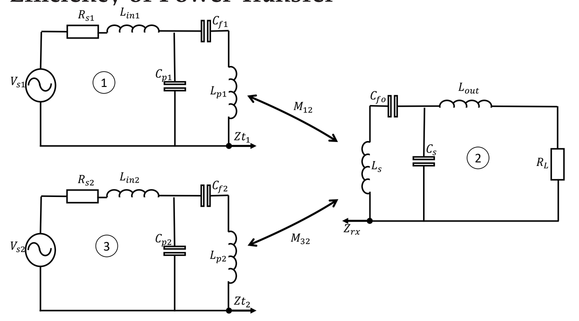


Figure 4: Resonant WPT circuit diagram

Consider Fig. 4 Output Power:

$$Pout = \left(\frac{I_{receiver} \times Z_{st}}{Z_{Lout} + R_L}\right)^2 \times R_L \quad (2)$$

Input Power:

$$P_{in} = I^2_{ipm\_eq} - \times Z_{in_m} \quad (3)$$

Transfer Effciciency:

$$\eta = \frac{P_{out}}{P_{in1} + P_{in2}} \times 100\% \quad (4)$$

Where Z_{st} is the impedance of the CCL tank in the circuit. Z_{in_m} is input impedance of circuit m, I_{ipm} is the current at the source side of the ciruit as a result of its own source.

Source Voltage Control

$$PI = \begin{bmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \end{bmatrix} \begin{bmatrix} W_1 \\ W_2 \end{bmatrix} + \begin{bmatrix} J_{12} \\ J_{21} \end{bmatrix} \quad (5)$$

Where PI is a ratio between the input power and the product of the source voltages. W is the ratio of the two source voltages to each other. H and J are factors of the impedance and resistance in the source circuits.

Efficiency Control

$$\eta = \frac{PO}{PI} \times 100\% \quad (6)$$

Where PO is a ratio between the output power and the product of the source voltages. The values of W are critical in tuning to the right values

Data Generation

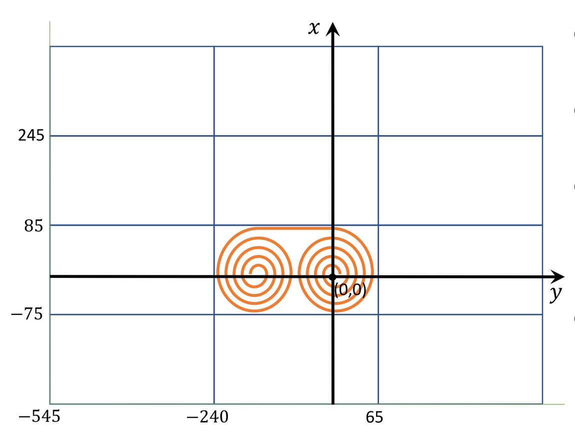


Figure 5: Location data generation

- 3 Layers of Layered DD coils
- $160mm \times 305mm$ [2]
- Receiving coil (x, y) moved relative to transmitter$(0, 0)$
- Coupling Coefficient is recorded

Neural Network Training

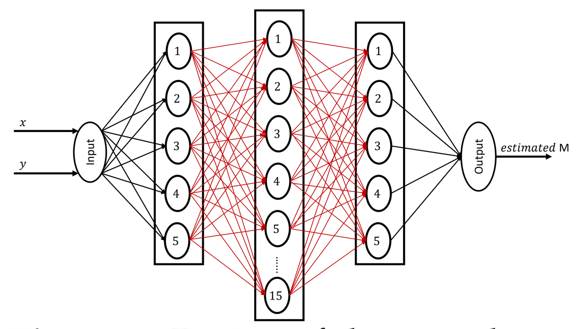


Figure 6: Design of the neural network

- Cleaned data is used to train the Neural Network (NN)
- Three hidden layers $5mm \times 15mm \times 5mm$
- Input location in x and y axes
- Output Mutual indctance

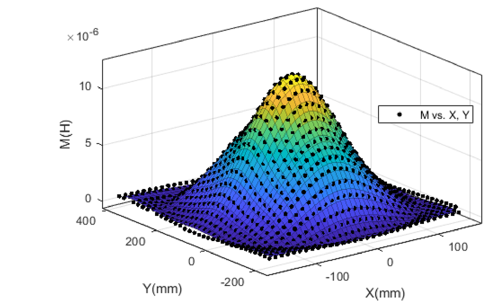


Figure 7: M distribution

$$coupl = \frac{M}{\sqrt{L_p \times L_s}} \quad (7)$$

$coupl$ is the coupling coefficient

Coupling Coefficient

Table 1: Estimated values of Coupling coefficient based on location

Label	$X1\ (mm)$	$Y1\ (mm)$	$X2\ (mm)$	$Y2\ (mm)$	$coupl1$	$coup2$
S1	−85	85	75	85	0.034355	0.034941
S2	−85	−67.5	75	−67.5	0.01597	0.016942
S3	−85	237.5	75	237.5	0.01439	0.014388
S4	−80	−445	80	−140	0.00854	0.00605
S5	−80	−445	−80	165	0.0085	0.0283

Simulation Parameters

Two optimization algorithms are used for MPPT:

- Jaya Algorithm: Based on a Teaching-learning optimization algorithm
- Crow Search Algortihm (CSA): based on the behavior of crows in hiding their food storage from being detected.

Table 2: Circuit parameters

Parameter	Value
Frequency	$85\ kHz$
L_s, L_p	$158\ \mu H$
L_{out}	$1.75\ \mu H$
C_s,C_p	$25\ nF$
C_f,C_{fo}	$22.3\ nF$

Maximum power point

Table 3: Using Jaya algorihtm

Label	JAYA		LTSPICE	
	$Pout(W)$	Eff	$Pout(W)$	Eff
S1	811.71	100	811.49	99.9
S2	2357	99.87	2360	99.98
S3	2475	99.82	92375	100
S4	23944	34.36	2405	26
S5	1293	99.19	1301.38	99.98

Table 4: Using CSA algorihtm

Label	CSA		LTSPICE	
	$Pout(W)$	Eff	$Pout(W)$	Eff
S1	1066.56	99.5	1121.3	99.7
S2	2408.08	97.38	2458.4	99.5
S3	2358.93	95.4	2392.4	96.97
S4	12	21	12.63	6.1
S5	1173.51	97.29	1203	95.2

Control Scheme

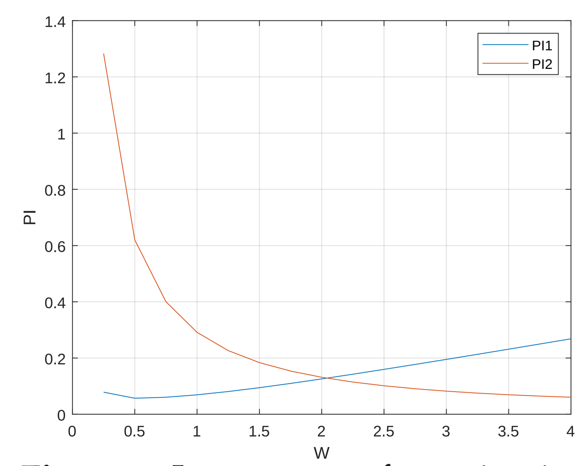


Figure 8: Input power from circuits

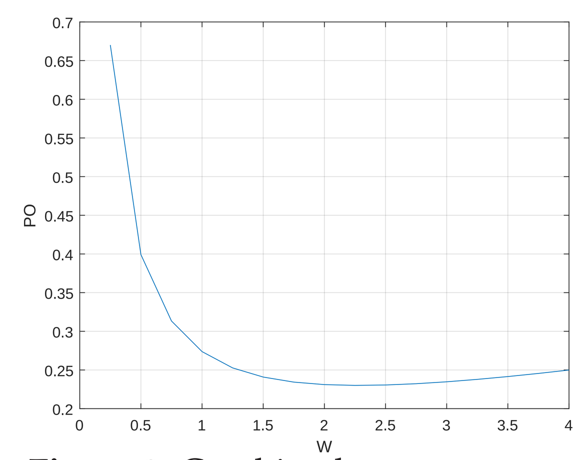


Figure 9: Combined output power

Transfer Efficiency

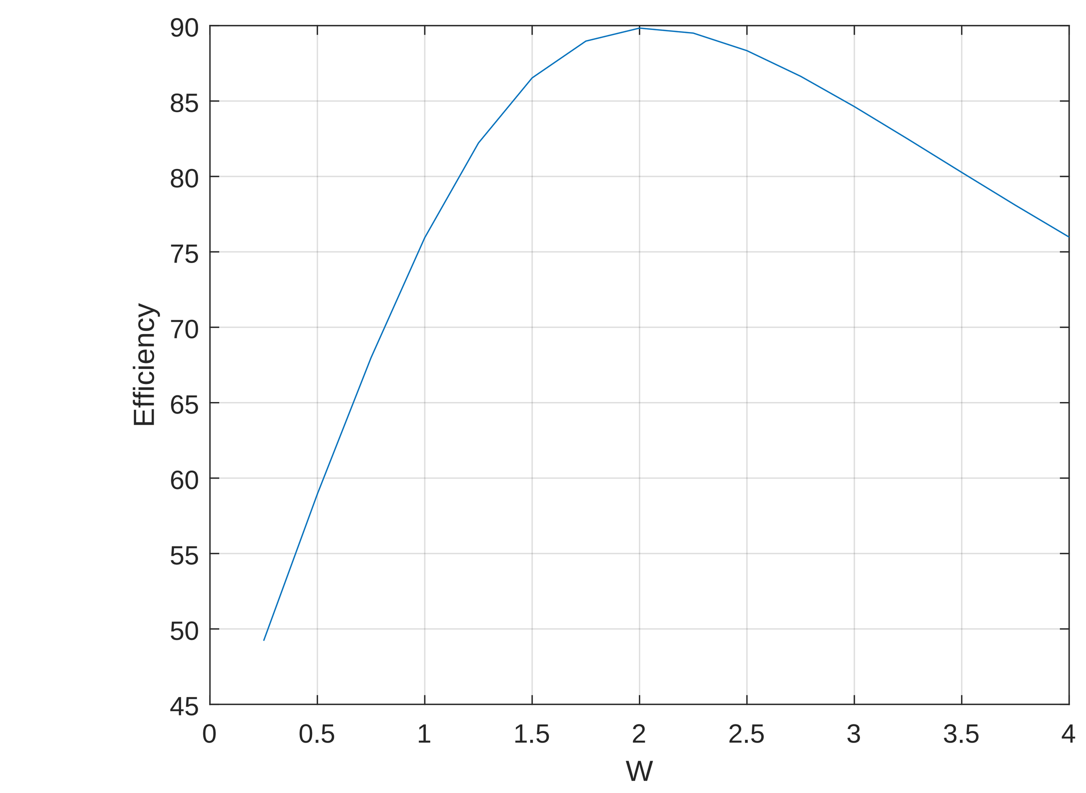


Figure 10: Transfer efficiency

Discussion

1. Point of maximum power (**See Fig. 9**) does not always fall at point of Maximum efficiency (**See Fig. 10**) which is very important to avoid power wastage.
2. The feedback control scheme can be used to make the WPT system operate within the target transmit power range and at a point between maximum efficiency and maximum power.
3. Equation (1) shows the transmit circuits not only have an impact on the receiver, but even on each other. A fraction of the impedance of circuit 1 gets translated into circuit 2 and vice versa.

Conclusion

- Transmit power fluctuates significantly as coupling coefficient changes
- Adopting a control scheme can be used to keep the power within intended operating range and
- Maintain an optimal maximum efficiency maximum power tradeoff

Future Research

- An optimized implementation of the algorithm on a hardware such as an FPGA.
- Integration with Metamaterials.
- Tunable inductors and resistors at high operating frequency

These will further drive the prospects of having an efficient dynamic wireless power transfer.

References

[1] Sadeque Reza Khan, Sumanth Kumar Pavuluri, and Marc P. Y. Desmulliez. Accurate Modeling of Coil Inductance for Near-Field Wireless Power Transfer. *IEEE Transactions on Microwave Theory and Techniques*, pages 1–12, 2018.

[2] M. E. Bima, I. Bhattacharya, W. O. Adepoju, and T. Banik. Effect of coil parameters on layered dd coil for efficient wireless power transfer. *IEEE Letters on Electromagnetic Compatibility Practice and Applications*, pages 1–1, 2021.

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