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An Optimal Parameter Estimation Technique for Wireless Electricity Transmission

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Abstract

The wireless transmission of electricity is one of the emerging technologies which enable the wireless transmission of energy from one point to another point without using conductor wires. The technology is found very useful for various fields of engineering and medical science. The recent development in the theory of wireless electricity transmission shows that the efficient transmission over the larger air gap is also possible. Since this technology combines many fields like electromagnetic induction, radiation and resonance the calculation for the practical applications is quite difficult. This paper presents a genetic algorithm based optimal parameters estimation technique for the required transmission efficiency and to analyze the effect of parameter variations. The simulation of the proposed algorithm is performed using Matlab and the result validates the effectiveness of the algorithm.

Keywords: Wireless Electricity Transmission, Couples Magnetic Circuit, Coupled Field Theory.

Introduction

The first visions of wireless power transmission came from Nikola Tesla in the early 20th Century. In Tesla power transmission system, it is believed that the earth is a huge charged ball, which could be operated at its resonant frequency and that will form a close circuit in the Earth Ionosphere. Since most of his research was based on wireless energy transfer using radiative electromagnetic waves which are used for the transmission of information, but involves immense difficulties for the wireless power transmission. The two main problems with the above technology are 1) Omni directional Radiation is an inefficient solution. 2) Directional antenna required complex tracking system. Although the concept of wireless power transmission is proposed at early 90's, it was never gain the commercial applications because of lack of device that can be used with such technology but the recent development in the mobile technology and requirement of a system which can supply power to these devices without wires, ones again the researchers to review the technology. In year 2007, a group of researchers at MIT scored Wireless Transmission, the power of an incandescent bulb of 60W over distances of more than 2 meters with Efficiency of about 40%. [4] In its wireless power system, they use a pair of strong magnetically coupled resonator comprising a transmitter and a receiver, the resonant Pair. A lot of research since then was carried to transfer receiver pair to power wirelessly.

Related Work

This section presents some of the recent development in the field of the wireless electricity transmission. Teck Chuan Beh et al [1][3] proposed basic study for improving efficiency of wireless electricity transmission. They studies the possibility of using impedance matching networks to adjust the resonance frequency of a pair of antennas at a certain distance to 13.56 MHz is studied. The analysis of magnet resonant coupling in Restricted Frequency Range is presented in [2]. Analysis of same system using Equivalent Circuit and Neumann Formula is presented by Takehiro Imura et al [4] they presented more familiar format for electrical engineers than the coupled mode theory. In this study, they analyzed the relationship between maximum efficiency air gap using equivalent circuits and the Neumann formula and propose equations for the conditions required to achieve maximum efficiency for a given air gap. Koh Kim Ean et al [5] presented a Band-Pass Filter Model for Multi-Receiver Wireless Power Transfer via Magnetic Resonance Coupling and Power Division. The Band-pass filter model is relatively new, using this model the physical wireless power transfer system is representable in relatively simpler equations compared to coupled-mode theory and equivalent circuit model. They also proposed Methodology for multi-receiver using band-pass filter model and impedance matching. Their proposed methodology allows controllable power division among receivers. Study on Maximum Air-gap and Efficiency based on equivalent circuit is proposed in [6] they studied maximum efficiency vs air gap by Equivalent Circuit and propose simple equations about maximum efficiency of air gaps their results verifies the proposal against Electromagnetic Field Analysis. Fei Zhang et al [7] presented Mid-Range Wireless Power Transfer and Its Application to Body Sensor Networks. They presented the scope of wireless power transmission platform to permit wireless power delivery to multiple wearable sensors and medical implants on the surface and within the human body.

Wireless Power Transfer System Using Magnetic Resonance Coupling

The wireless power transfer system involves two identical antennas operating with resonating frequency power source. The power is transmitted through magnetic resonance coupling in between the two antennas. The power transmitted to the receiving antenna is then used for the required purposes.

Equivalent circuits [1]

The details for the equivalent circuit are provided in [1]. The Electromagnetic resonance coupling involves creating a LC resonance, and transferring the power with electromagnetic couplings without radiating electromagnetic waves. Hence, the magnetic coupling and electric coupling can be represented as mutual inductance and mutual capacitance respectively as shown in Figure 1. Z_{source} in figure represents the characteristic impedance, and Z_{load} is the impedance of the load. In this system, they are both considered to be the same at Z_0 , 50Ω the default characteristic of most high frequency systems. The ohm loss and the radiation loss of the antennas are represented by R. In this paper, the power is transferred via magnetic coupling. Therefore the coupling can be represented by mutual induction L_m. Next the resonance frequency is calculated based on the equivalent circuit. To satisfy the resonance condition, the reactance of Figure1 must be 0, as in equation (1). The condition in equation (1) can be satisfied by two resonant frequencies as calculated in equation (2) and (3). The coupling coefficient k can be calculated from equation (2) and (3) to become equation (4)

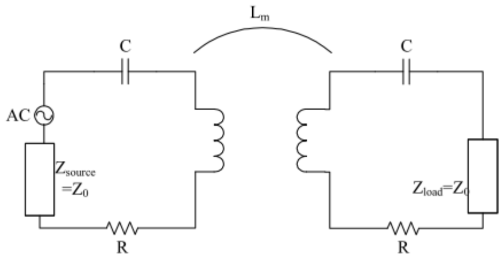

Figure 1: Equivalent Circuit of Power Transfer System.

$$\frac{1}{\omega L_m} + \frac{2}{\omega(L - L_m) - \frac{1}{\omega C}} = 0 \ldots\ldots\ldots..(1)$$

$$\omega_m = \frac{w_0}{\sqrt{(1+k)}} = \frac{1}{\sqrt{(L+L_m)C}} \ldots\ldots\ldots(2)$$

$$\omega_e = \frac{w_0}{\sqrt{(1+k)}} = \frac{1}{\sqrt{(L+L_m)C}} \ldots.\ldots\ldots(3)$$

$$k = \frac{L_m}{L} = \frac{\omega_e^2 - w_m^2}{\omega_e^2 + w_m^2} \ldots\ldots\ldots\ldots\ldots\ldots.\ldots..(4)$$

Next, the efficiency of the power transfer is calculated based on the equivalent circuit. The ratio of power reflection η_{11} and transmission η_{21} can be defined by equations (5) and (6), where S_{11} is the reflected wave and S_{21} is the transmitted wave. To simplify the calculations, R is considered to be 0Ω. Here, S_{21} can be calculated with equation (7)[2].

$$\eta_{11} = S_{11}^2 * 100\% \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. (5)$$

$$\eta_{21} = S_{21}^2 * 100\% \dots\dots\dots\dots\dots\dots\dots\dots....... (6)$$

$$S_{21} = \frac{2jL_m Z_0 \omega}{L_m^2\omega^2 - \left(\omega L - \frac{1}{\omega C}\right)^2 + 2jZ_0\left(\omega L - \frac{1}{\omega C}\right) + Z_0^2} \dots.... (7)$$

Genetic Algorithm

A genetic algorithm (GA) is a heuristic search technique that mimics the process of natural evolution. This heuristic is routinely used to generate useful solutions to optimization problems and search engines. Genetic algorithms belong to the larger class of evolutionary algorithms (EA), the solutions to optimization problems using techniques inspired by natural evolution to generate as inheritance, mutation, selection and crossover.

In a genetic algorithm to a population of strings developed (chromosomes), the candidate solutions (fitness value) to encode optimization problem to better solutions. Traditionally, solutions are represented in binary as strings of 0s and 1s, but other encodings are also possible. The development usually starts from a population of randomly generated individuals and happens in generations. In each generation, the fitness of each individual in the population is evaluated, multiple individuals are stochastically selected from the current population (based on their fitness), and modified (recombined and possibly randomly mutated) to form a new population. The new population is then used in the next iteration of the algorithm. Usually, the algorithm terminates when either a maximum number of generations has been produced, or has reached a sufficient condition for the population. If the algorithm is terminated by a maximum number of generations, a satisfactory solution may or may not be achieved.

A typical genetic algorithm steps:

1. A genetic representation of the solution domain,
2. A fitness function to evaluate the solution domain.

Generally the solution is represented as an array of bits. Arrays of other types and structures can be used in essentially the same way. The main property that makes these genetic representations convenient is that their parts are easily aligned due to their fixed size, which facilitates simple crossover operations. Variable length representations can be used, but in this case of complicated crossover. Tree-like representations are explored in genetic programming and graphic representations in the form of evolutionary programming.

The fitness function is defined over the genetic representation and measures the quality of the represented solution. The fitness function is always problem dependent. Once the genetic representation and the fitness function defined, GA is an order (usually random) initialize a population of solutions and then improved it by repeated application of mutation, crossover, inversion and selection of contractors.

Formulation of objective function

Since the objective of the algorithm is to find the optimal parameters for the wireless power transmission within required efficiency. The objective function for the proposed algorithm is formulated as given in equation 7.

$$f_{obj} = \frac{2jL_m Z_0 \omega}{L_m^2\omega^2 - \left(\omega L - \frac{1}{\omega C}\right)^2 + 2jZ_0\left(\omega L - \frac{1}{\omega C}\right) + Z_0^2}$$

Where
L_m *is the mutual inductance of the coils*
Z_0 *is the impedance of source and load*
R *is the Resistance of the coils*
L *is the inductance of tx and rx coils*
C *is the Capacitance of tx and rx capacitors*
ω *is the operating Frequency*
f_{obj} *is the required efficiency*

Proposed Algorithm

The proposed algorithm can be explained as follows
Step 1: firstly the required efficiency is provided with the parameter ranges of the available components.
Step 2: now M sets of chromosomes are generated. Where M is the population size.
Step 3: now each of M sets of chromosomes is used to evaluate the objective function.
Step 4: Calculate the fitness value for each of M sets of chromosomes using equation (3).
Step 6: Select the chromosomes with best fitness value and perform crossover to get the new generations and delete the others.
Step 7: repeat steps 3 to 7 till the maximum generations completed or the goal is found.

Simulation Results

The proposed algorithm is simulated using matlab for various objectives and the results are presented as follows

Table 1: Genetic Algorithm Parameters

Name	Value
Tolerance	0.0
Initial Population	16
Max. Generations	1000
Time Limit	30 (Sec.)

Table 2: Range of the available devices and calculated Optimum Values.

Name	Max. Value	Min. Value	Opt. Value
$Z_0\ (ohms)$	50	40	40.0
$L\ (Henry)$	2000e-9	1000e-9	1.75e-6
$R\ (Ohms)$	0.5	0.22	0.24913
$L_m\ (Henry)$	1000e-9	200e-9	5.83e-7
$C\ (Farad)$	200e-12	100e-12	1.57e-10
$f\ (Hz)$	20e6	10e6	12503427

Table 3: Required efficiency and achieved efficiency

Efficiency (η)	Required	Achieved
	80%	79.424

Effects of the variations in the component Values

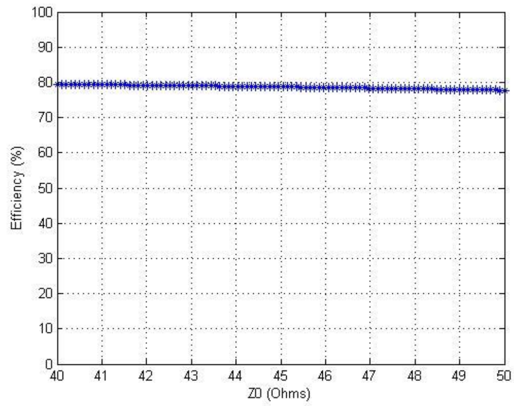

Figure 2: Effect of the variation in source and load impedance on the efficiency.

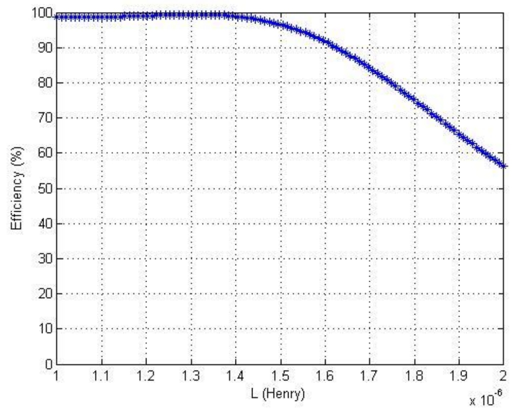

Figure 3: Effect of the variation in coil inductance on the efficiency.

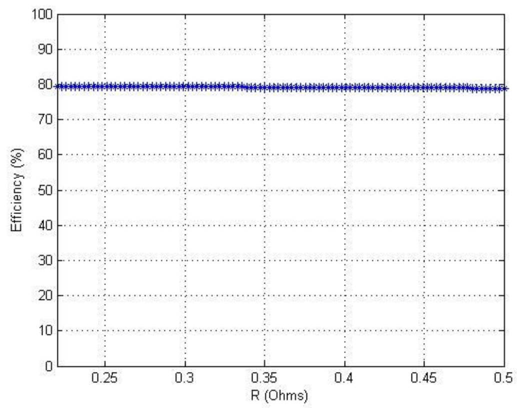

Figure 4: Effect of the variation in coil resistance on the efficiency.

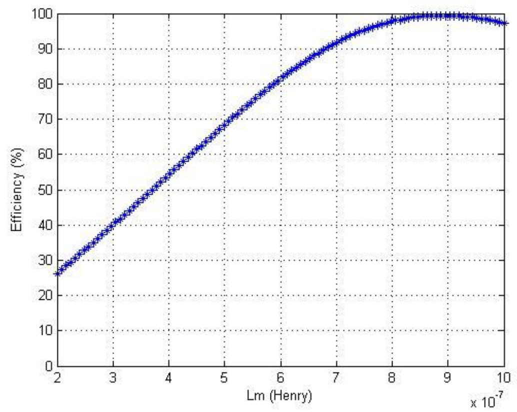

Figure 5: Effect of the variation in coil mutual inductance on the efficiency.

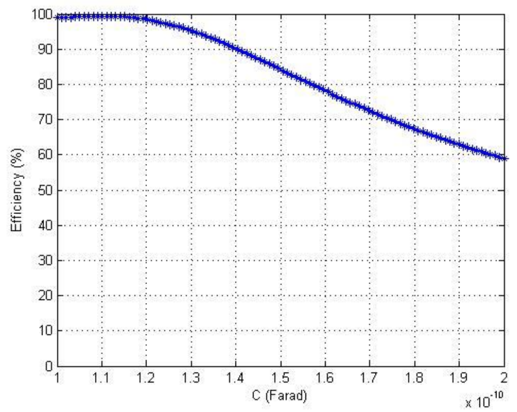

Figure 6: Effect of the variation in capacitance on the efficiency.

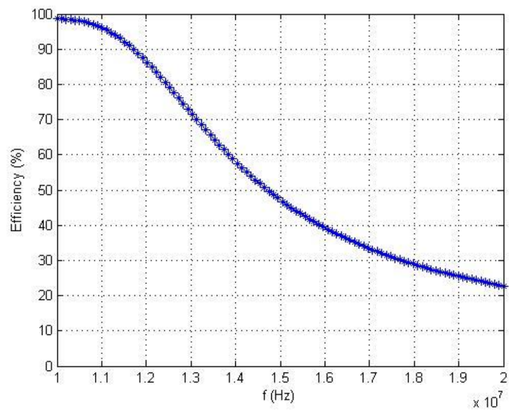

Figure 7: Effect of the variation in operating frequency on the efficiency.

Conclusion

This paper presents an optimal component value estimation method for the required efficiency and analyzes the effects of variations of component value of the efficiency of power transmission for the system designed with estimated components values. The simulation results shows that the objective is achievable up to 99.9% and while analyzing the effect of parameters variations it shows that the source and load impedances and the coil resistance slightly affect the efficiency and the variations in capacitance and inductance shows greater effect on efficiency while the mutual inductance shows highest influence on efficiency. In future the proposed algorithm can be test with the different optimization techniques and the effects of other physical parameters can also be analyzed.

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