

A Design Proposal for Optimal Transcutaneous Energy Transmitters

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Abstract—The use of artificial organs completely implanted in the body of the patient requires a design of a Transcutaneous Energy Transmitters (TET) as small as possible and that meets several project requirements. In this paper, an optimization method is used to minimize the volume of the TET assuring the transmission of power and load voltage at distances between coils up to 25 mm. In order to best represent the real load with regulator circuit, a load that absorbs a defined active power is used instead a fixed resistor. Moreover, the paper discusses model issues such as the influence of the displacements between the coils in the coupling of the TET.

Index Terms— Inductive Power Transmission, Finite Element Methods, Optimization

I. INTRODUCTION

With the evolution of medicine, more and more artificial organs are completely implanted in the patients requiring the supply of power to be internal to the body. This fact intensifies the need of optimized Transcutaneous Energy Transmitters (TETs) which are devices to transfer energy from outside the body to inside the body without the need of wires trespassing the skin. This technology has been studied by several researches and normally uses inductive link between a primary coil external to the body and a secondary coil underneath the skin, similar to a coreless transformer providing power to these artificial organs and their internal backup battery [1]-[3].

Since the skin of the patient is part of the magnetic coupling between the windings, the design of the system should instigate the least discomfort to the patient without losing reliability in unsteady situations. Therefore, a proper design allows obtaining a system that supplies the required power at different specified situations.

In this paper an optimization method associated with Finite Element (FE) software is used to define TET coils as small as possible that supply the power necessary to feed a ventricular assistive device totally implanted into the patient. This method guarantees that the needed power will be supplied even if the coils are separated by distance up to 25 mm.

II. METHODOLOGY

In order to minimize the discomfort of the patient, the TET was optimized to have the smallest possible size while taking in consideration the undesirable conditions to which the TET could be subjected in addition to the constraints of the project.

Since the TET is positioned in the body of the patient, it is subjected to different kinds of undesired coupling situations such as different distances between coils and/or misalignments

between the centers of the coils. Thus, the TET must supply the required power at any of these situations.

The TET, with serial resonant capacitors compensating the self-inductance, has an optimal coupling position that entails the maximum transfer of power which is different than the highest coupling [4]. This enforces the need to simulate in different positions instead of only the lowest coupling between coils because the worst case can be at any position even at better coupling. For this reason, all the constraints should be calculated in a set of distances between coils.

Initially, this paper made a sensibility analysis to prove that when a certain misaligned TET is at certain distance between the coils, it has the same coupling factor as when it is aligned at further distance between the coils. This simplifies the optimization process since the TET can be simulated through FE in axisymmetric 2D when the coils are aligned, avoiding the expensive computations of the FE 3D to simulate the misalignment.

A study on the device to be supplied by the system requires necessarily 13 W. A converter electronic circuit will regulate the voltage to supply always the required voltage at any situation. However, it works only with voltages above 8 V and accepts maximum of 30 V, decreasing its lifetime if more than 28 V is submitted for long time. Hence, if the smallest TET coils found supply the required power at the required voltage range for the specified coupling situations, the system is considered the optimal.

Thus, the constraints of this project are supplied power higher than a prescribed value (13 W) and load voltage within a certain range [8 V – 28 V]. These constraints must be maintained for all coupling condition defined by the distances between coils up to 25 mm.

The TET parameters that could help to meet the demands of this project are the primary and secondary windings number of turns [20 - 65] and wire gauge [AWG 14 - AWG 32] and power supply voltage [12 V - 36 V] and frequency [50 kHz - 400 kHz]. These parameters, except for the voltage and frequency, should be integer numbers.

For the process of optimization, the genetic algorithm (GA) was used because it is a reliable stochastic method for solving both constrained and unconstrained optimization problems. Special mutation and initial population functions were created to generate populations satisfying the range and integer constraints on decision variables. In these functions, similar to the number of turns and type of wire of the coils, the supply voltage and frequency were defined as integers since there is no advantage in specifying them with decimal places.

Although the algorithm will never produce the same results, its advantage is that it has more chance to not get stuck in local minimums.

The type of wire was used based on a table of Copper AWG properties. Thus, the GA generates individuals with integer type of wires, which are used to compute the diameter of the wires that affects the TET geometry, inductance, resistance and the volume of the coil. The selected individual is then drawn in the software Gmsh [5] and its FE equations are simulated by the software GetDP [6], which allows easy interface with Matlab that runs the GA algorithm. GetDP simulates the FE equation, considering the source with voltage and frequency defined by the individual selected by the GA. Then, it supplies information such as voltage, current and power at the source and load.

The load was implemented not to be simulated as a fixed resistor load, but as a regulator that absorbs a fixed power even if the voltage varies. That means that, the load resistor value depends on the value of the voltage supplied by the system. If the maximum power that the selected individual can transfer is smaller than the required fixed power, the simulated load value will be a resistor that absorbs the maximum power that the individual can supply. This fact adds a complexity to the process, since the regulation of the system is variable and searching the exact value of the load resistor to absorb the required power inserts a non-linearity to the FE equations. However, it is important to take in consideration because simulation using a fixed resistor value may present non-acceptable values of power for a valid individual that supplies the required power for a different value of load resistance.

Note that the objective function in this case is very simple, since it is only the size of both coils. However, the constraints add a non-linearity and complexity to the process since they are computed as a non-linear function for all positions and are used by the GA algorithm to calculate the new individual.

Moreover, each individual at a generation has its own serial resonant capacitors to compensate the self-inductance. This enforces GA to know the complete equivalent circuit for each individual before simulating the TET with the proper resonant capacitor. Thus, for each individual, the optimization executes the following procedure: i) GetDP calculates the equivalent circuit parameters of TET at the initial distance between coils; ii) MatLab calculates the value of the resonance capacitors; iii) GetDP simulates the TET with these resonant capacitors, obtaining the value of constraints; iv) MatLab stores the results; v) If the actual distance between coils is the last to be analyzed, the data is supplied to GA and the calculation for this individual ends; otherwise, GetDP calculates the new mutual at the next distance between coils and the steps after step iii) are executed again.

Furthermore, the optimized configuration that meets the requirements was analyzed with different load resistances and at different distances and displacements between coils.

III. RESULTS

The optimization resulted in an individual which the primary and secondary windings have respectively diameters around 100 mm and 30 mm. Fig. 1 shows the behavior of the

load voltage and current when the coils are aligned for different distances.

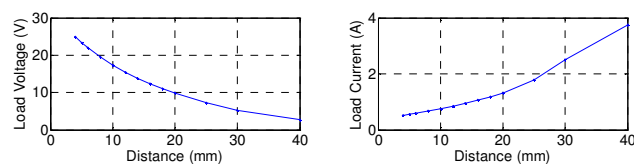


Fig. 1. Load voltage and current of the selected TET with the coils aligned at different distances between coils.

Note that the farther apart the coils are, the bigger the load current is and the smaller the load voltage is. This configuration does not meet all the requirements of load voltage for distances greater than 30 mm, but even at these distances, it can supply the required power. This means, if the load regulator was designed to work with smaller voltages, this TET would be useful to the artificial organ, however the winding temperature would be higher due to the higher current passing through the secondary winding.

IV. CONCLUSIONS

This paper proposes an optimization method to define the smallest TET coils possible meeting the requirements of power transfer and load voltage. Since the load absorbs a constant active power when activated, the results of the selected optimal configuration present the required power at all distances between coils limited by the constraints of the optimization. The paper shows that if the regulator electronics at the load allows lower voltages, the selected configuration could work at the required power even at larger distances, however increasing windings currents, which would affect their temperatures. This suggests the use of multi-objective optimization algorithms, adding another objective function to decrease the windings temperatures rise.

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