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, load voltage and limited winding temperature 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 evaluation of the windings temperature and 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 highly efficient system with fewer losses, which can be used in several different implanted artificial organ applications.

In this paper an optimization method associated with Finite Element (FE) software is used to define a TET 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 power will be supplied even if the coils are separated by distance up to 25 mm, with an increase of winding temperature less than a defined limit.

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

A sensibility analysis may prove that when a certain misaligned TET is at certain distance between the coils, it can have 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. Thus, the constraints of this project are supplied power higher than a required value, load voltage within a certain range, and winding temperature increase smaller than a given value. These constraints must be maintained for all coupling condition defined by the distances between coils up to 25 mm.

It is important to mention that the considered TET, with 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 highest separation between coils because the worst case can be at any position. For this reason, all the constraints should be calculated in a set of distances between coils.

The TET parameters that could help to meet the demands of this project are the primary and secondary windings number of turns and wire gauge (defined by the type of wire) and power supply voltage and frequency. 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 stochastic method for solving both constrained and unconstrained optimization problems. Although the algorithm will never produce the same results, its advantage is that it has more chance to not get stuck in local minimums.

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 also defined as integers since there is no advantage in specifying them with decimal places.

The type of wire was used based on a table of Copper AWG properties. Thus, the optimization generates the GA 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]. This simulation generates information such as voltage, current and power at the source and load. The GetDP software simulates the FE equation, considering the source with voltage and frequency defined by the individual selected by the GA and the load as a regulator that absorbs a fixed power even if the voltage is varies. If the maximum power that the individual can transfer is smaller than the required fixed power, GetDP will simulate the system with any load. However, this is not critical because one of the constraints in the GA is the power absorbed by the load and thus such individual will not be accepted as a valid individual.

The constraints were computed as a non-linear function for all positions and are used by the GA algorithm to calculate the new individual. Although the temperature is very complicated to compute, it cannot be neglected. Thus, few coils were physically built to evaluate the relation between dissipated power, coil area and temperature of the coil. Thus, the optimization function was constrained with temperature calculated from the power loss, the area of the coil and this factor measured by experimentation.

The TET system to be optimized was considered to use serial resonant capacitors to compensate the self-inductance. In this way, at each individual created by the optimization software, it is necessary to determine the values of the new resonant capacitors. This enforces the optimization 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 between coils and between the centers of the 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.

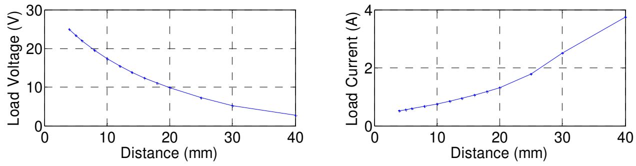

Fig. 1. Load voltage and current of the selected TET with the coils aligned at different distances between coils.

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 increase of temperature would be higher due to the higher current passing through the secondary winding.

IV. Conclusions

This paper proposes an optimization method to define a TET as small as possible meeting the requirements of power transfer, load voltage and windings temperature. 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 with the problem of increasing windings temperature. This suggests the use of multi-objective optimization algorithms, adding another objective function to decrease the gain of winding temperature.

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