Transcutaneous Energy Transmission Based Wireless Energy Transfer To Implantable Biomedical Devices

[1] Anand Garg [2] Lakshmi Sridevi
Department of Electronics and Instrumentation Engineering
SRM University Kattankulathur, Chennai-Tamil Nadu-INDIA

Abstract— **Transcutaneous energy transmission (TET) plays an important role in providing power to implantable biomedical devices such as total artificial heart and heart assist devices through wireless power transmission. The system can provide a power varying from 5-15W. The paper deals with certain challenges like i) temperature rise due to power loss which may have direct effects on the skin. ii) positioning of external and internal coils which may also disturb the operation. It also deals with methods of optimal power transfer capabilities with considerably high transmission efficiency thereby decreasing the losses.**

Index terms- **Transcutaneous power transfer, Wireless transmission, time varying magnetic field, optimal power transfer.**

I. INTRODUCTION

The transcutaneous energy transfer (TET) system is designed to deliver power from a primary source to a secondary implantable device through a dermal skin. It has been shown to provide an effective means of supplying power to the high power implantable devices such as total artificial heart and heart assist devices by avoiding the risk of infection associated with wires passing through the skin. The system consists of an implanted secondary coil and an external primary coil along with supporting electronics. A TET system could be used to power ventricular assist systems and eliminate driveline infections. There are both direct and indirect safety concerns that must be addressed when continuously transferring power through the skin. Direct safety concerns include thermal tissue damage caused by exposure to the electromagnetic fields, coil heating effects, and potential unwanted nerve stimulation. Indirect concerns are those caused by potential interference of the TET system with other implanted devices. The power can be provided by time varying magnetic field and also by using a closed loop frequency based power regulation method with right amount of power to load under variable coil coupling. To minimise power loss a resonant capacitor can be used. A zero voltage switched TET system may dissipate different amounts of power while delivering the required amount of power. TET coils are characterized by self inductance operating coupling range and equivalent series resistance profile. The system has to provide improved heating performance and frequency stability to the system over the power requirements and over the range of coupling ratio. For instance a power of 15W over a coupling range of 0.55 with a separation of 25mm may improve the heating performance hence providing a good frequency stability. Improvement in power transfer can be achieved under the optimal power transfer methods but this might have drastic effects on the efficiency of the system. To increase the transmission efficiency losses in the system has to be reduced. High operating frequencies may have terrible effects on the skin as it generates more heat flux. So the operation may be performed under low operating frequencies. To eliminate the skin effect and proximity effect Litz wire made of many thin wires covered by an insulating film and twisted together is used that carries the alternating current.

II. OPERATION

TET systems work by transferring energy from the transmitter to the implanted receiver over distance made up by the skin, fat, blood and possibly other biological tissue and clothes as well. Most TET systems consist of two inductively coupled coils: one at the energy transmitter side and one at the implant side. The energy is transferred over the distance by a alternating magnetic field. It is not possible for the patient to hold the coil of the energy transmitter always exact over the coil of the implant and the energy transmitter might be moving over time. In order to protect the implant against high voltage or temperature rise, power delivery should be adapted to the situation. Control of power supply or providing the energy transmitter with information from the implant, has been mostly done by using a dedicated second channel for data communication via high frequency radio communication. To drive the power in the TET, the device makes use of a N-MOSFET (Negative-Channel Metal-Oxide-Semiconductor Field-Effect Transistor) H-bridge inverter.
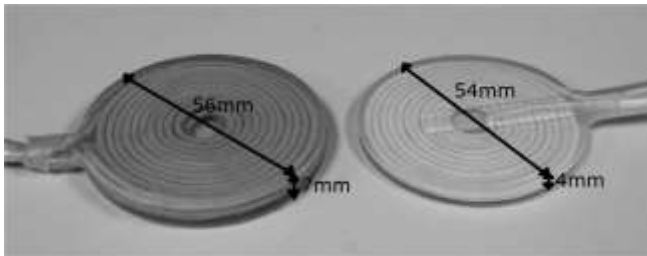
Fig 1. Transcutaneous energy transfer coils.

Left: Primary coil. Right: Secondary coil.

I. Basic operation of magnetic coupling

Moving electrical particles induce a magnetic field H. The magnetic field induced by a current 'l' in a coil with a radius 'r', 'N' turns and a winding length 'd' at a distance 'x' can be calculated as

$$H = \frac{INR^2}{2(R^2+x^2)^{\frac{3}{2}}}]\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

The voltage induced in the secondary coil is given by

$$V_2 = M\frac{di_1}{dt} + L_2\frac{di_2}{dt} \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

In this equation:

V_2 is the voltage induced in the secondary coil or the implanted coil
i_1 is the current flowing in the primary coil
i_2 is the current through the secondary coil
M being the mutual coupling inductance in the coils
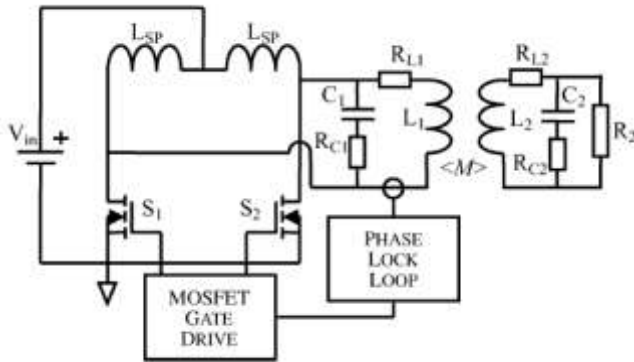L_2 is the self inductance linked with the secondary coil

Fig 2.Push–pull parallel resonant converter with parallel resonant pickup

The mutual inductance is proportional to the coupling factor K which is dependent on the transmission channel quality(the distance and the material used between the coils). To increase the energy transfer between two coils, capacitors need to be placed in parallel or in series with each inductance L1 and L2. An inductively coupled system provides the highest energy at resonance frequency which in turn can be roughly calculated for low coupling factors. The frequency is given by the expression

$$\frac{1}{2\pi\sqrt{L_1 C_1}}$$

A microcontroller can be used to control the transmitting frequency and load modulation. It also measures the current in the resonant circuit which consists of the transmitting coil in series with a capacitance. On implant side a parallel resonant circuit is connected to a rectifier circuit and provides the load with a smoothed voltage.

III. POWER TRANSMISSION

The power levels in this system have to be maintained for its continuous operation. In the Transcutaneous method inductive power transfer technology is used for delivering power. A TET system must be able to adapt to the prevailing coupling conditions. The separation of the coils depends on the tissue thickness of the patient and surgical placement. In addition to this, the system should be able to tolerate slight changes in coupling, due to movement from physical activity and repetitive activity such as respiration. Size and weight of the power transfer coils is another important factor. The heat generated by the power transfer coils must not cause damage to the surrounding tissue.

The transfer of power is achieved through the use of two LC resonant circuits, where the coils are mutually coupled together via the interaction of oscillating magnetic fields. The strength of the coupling is determined by a coupling co-efficient K. A half-bridge resonant converter can be used to drive the power transfer coils, and power flow control is performed on the external primary side via feedback through wireless communication.

A.-Optimization in power transfer capability

Due to a large winding separation, the TET system has relatively large leakage inductance, reduced magnetizing flux, and the mutual coupling is generally weak. Compensation for loose coupling can be achieved through the use of resonance circuits which enable the boosting of voltage or current in the secondary to usable levels. Consequently, the inductance and the capacitance values of the primary and secondary windings need to be optimized to achieve maximum power transfer capability. The constraints with regard to optimization are

1. *Inequality based on bifurcation phenomenon:*
   When the TET system is optimized, the bifurcation region based on stability consideration is analyzed. In such a region, the operating frequency will either drift away from the ideal operating point or move in an unstable state. Therefore, the

optimization parameters operate out of the bifurcation region.

2. Inequality based on components peak over-voltage and peak withstand current:

Each component in the system must function properly throughout the operation period. The components of the system should be operated under the peak over-voltage and peak-withstand current.
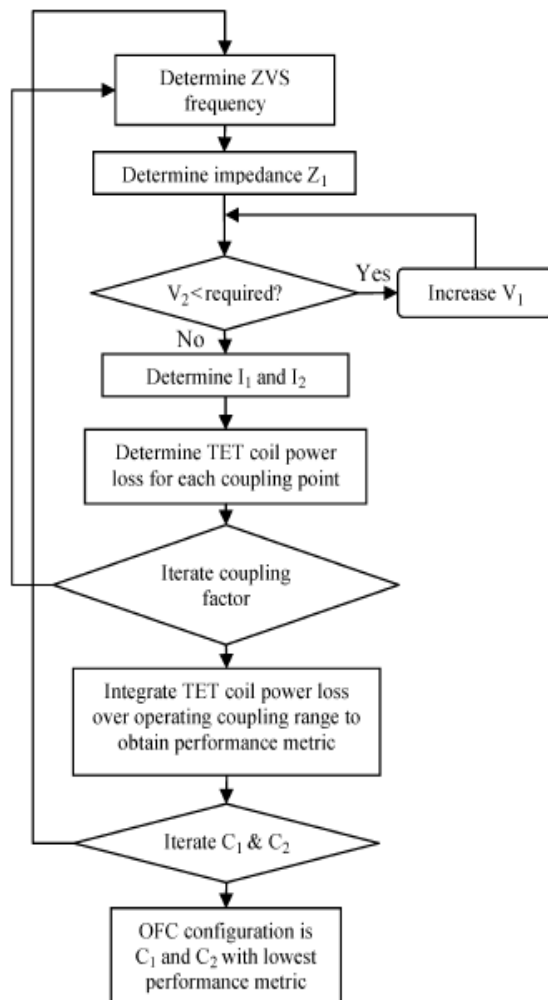

Fig 3.Flowchart of minimal coil loss optimization procedure.

IV. CHALLENGES

The Transcutaneous energy transmission faces the following challenges which may affect the operation of the system.

1. Temperature rise due to power loss which may have direct effects on the skin

The tissue starts damaging when the temperature reaches 42°C. The implantable device(secondary coil) is placed in soft tissue just underneath the skin and the primary coil is placed above the skin. the primary coil temperature is very important. the human tissues are non-magnetic and conductive so the magnetic field radiation are not altered as it encounters the tissue. so without any attenuation it can penetrate the tissues. TETs will generated eddy currents that interact with tissues. at low frequency the body appears transparent to many fields and at higher frequencies there are tendencies for the magnetic fields to get attenuated which disturbs the operation. The most desirable way to minimize heat generation resulting from power losses is to maximize efficiency. Although it is particularly important in the secondary circuit, efficiency is also important in the primary side to minimize radiation of heat from the primary coil into the skin tissue and to maximize the life span of the external battery source.

2.Positioning of external and internal coils which may also disturb the operation

To avoid disturbances due to positioning of the TETS, the coupling limitation can be tightened. The controller tolerance is increased to decrease the coupling factor. By making use of pressure sensors and flow sensors the operation can be monitored at periodic intervals and the patient is alerted appropriately.

V. CONCLUSION

TET coils in a system for powering implantable devices may generate heat in the tissue through two main mechanisms: conduction losses caused by equivalent series resistance (ESR); and core losses (hysteresis and eddy current).Due to the high frequency magnetic field generated. A

good TET system should have a wide operating coupling range without generating sufficient heat to cause tissue damage. For efficient operation of a TET system,soft switching techniques such as zero voltage switching (ZVS) or zero current switching (ZCS) are implemented. At low coupling factors (when coil separation is large) the natural resonant frequency is mainly governed by the impedance of and as the effect of the secondary reflected impedance is negligible. at high coupling factors multiple natural resonant frequencies may exist. The minimal coil loss (MCL) optimization procedure determines the capacitor values of the primary and secondary resonant tanks which give minimum power loss in the TET coils.

REFERENCES

1. Transcutaneous Energy Transfer System Incorporating a Datalink for a Wearable

2. Autonomous Implant-2012 Ninth International Conference on Wearable and Implantable Body Sensor Networks

3. Optimization Model of the Transcutaneous Energy Transmission System for Achieving Maximum Power Transfer Capability-JOURNAL OF COMPUTERS, VOL. 6, NO. 2, FEBRUARY 2011

4. Wireless Power System for Implantable Heart Pumps Based on Energy Injection Control-Progress In Electromagnetics Research Symposium Proceedings, Moscow, Russia, August 19-23, 2012

5. Minimizing Power Loss in Air-Cored Coils for TET Heart Pump Systems-IEEE JOURNAL ON EMERGING AND SELECTED TOPICS IN CIRCUITS AND SYSTEMS, VOL. 1, NO. 3, SEPTEMBER 2011

6. Experimental Study of a TET System for Implantable Biomedical Devices-IEEE TRANSACTIONS ON BIOMEDICAL CIRCUITS AND SYSTEMS, VOL. 3, NO. 6, DECEMBER 2009