http://dx.doi.org/10.5755/j01.eee.19.2.3466 ELEKTRONIKA IR ELEKTROTECHNIKA, ISSN 1392-1215, VOL. 19, NO. 2, 2013

Self-tuning Core-less Serial Resonant DC/DC Converter for Powering Loads on Rotating Shafts

P. Apse-Apsitis[1], A. Avotins[1], L. Ribickis[1]
[1]*Institute of Industrial Electronics and Electrotechnics, Riga Technical University,*
Kronvalda 1-315, LV-1012 Riga, Latvia
peteris.apse-apsitis@rtu.lv

***Abstract*—To feed sensors on different turning or rotating shafts of electrical motors, like servo, stepper or DC motor shafts, pan/tilt and different robotic system rotating parts, especially where rotations are up to 3600 and more turns of rotation, conventional wire loop cannot be applied. The same problem also lies with data transmission from sensor. The article describes a way to transfer energy wirelessly from stationary part to rotating (moving) part to solve the problem with power supply and proposed topology allows wireless data transmission, allowing significantly reduce total systems overall complexity and price.**

***Index Terms*—DC-DC power converters, power MOSFET, self-tuning, rotating shaft.**

I. INTRODUCTION

To feed sensors on different turning or rotating shafts of electrical motors, like servo, stepper or DC motor, or pan/tilt and different robotic system rotating parts, especially when rotations are up to 3600 and more turns of rotation, conventional wire loop cannot be applied. The same problem also lies with data acquisition from sensor.

Resonant circuits (resonant tanks) are well known and widely used in different power supplies, for example [1], [2], or core-less power supplies [3], as well as in different applications of radio communications.

Steady state operation and characteristics of LLC converter is described in many papers and topologies are shown in references, for example [1] shows the main properties of LLC converter. Power resonant converters typically contain in series connected coil, represented as inductance L and coil active resistance R, capacitance C, transformer, represented as inductance Lt and transformer winding active resistance R_t, forming resonant tank.

For radio wave radiation - core-less (air core) or high frequency ferrite core inductance and tuned antenna are applied as resonant tank. A capacitive power transmission show potentially good results, but it is not well-suited for low resonant frequencies due to large capacitor plate size to achieve inductances at least 10uF.

Self-tuning core-less serial resonant DC/DC converter contain two coupled core-less inductance resonant tanks. Both tanks are deployed using similar (+/- 5%) L and C values, similar air-core coil design, have the same coupling inductance and coupling coefficient.

Converter doesn't utilize transformer for energy transfer (known from the basics) - both inductances are used instead of that. In spite of the mentioned above same values, resonant tanks are asymmetric due to filter capacitors and load resistance. Self-tuning work frequency allows achieving the best possible energy transfer from power supply to load.

Described converter system is just one part of the whole system, where secondary voltage regulator as well as implemented data transmission over wireless power line is possible. Secondary voltage is regulated in primary side by means of measured value of secondary voltage, which is sent back to primary side via wireless power line.

II. CONVERTER DESCRIPTION

Converter is divided in two parts (Fig. 1), where static part includes half -bridge switches, comparator to control half -bridge MOSFET switches according to the resonant tank current direction, clamp diodes, current direction detection shunt resistor and primary core-less LC circuit.

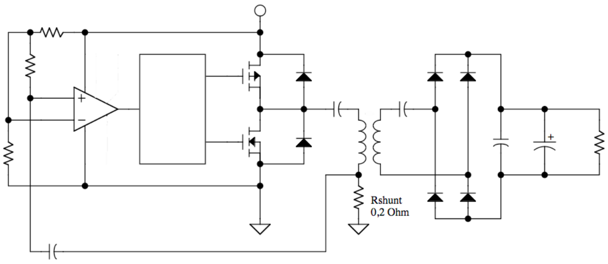

Fig. 1. Simplified diagram of self-tuning core-less serial resonant DC/DC converter.

Rotary part includes secondary core-less LC circuit, full bridge rectifier, filter capacitors and load - for example step or DC motor, or LED lights. Primary and secondary resonant circuits are inductively coupled via air-core transformer - coupled inductances.

Switches are commutated on coupled resonant tanks current zero-crossing – zero current switching (ZCS).

Manuscript received March 11, 2012; accepted May 30, 2012..
Authors work is supported by Latvian State Research Funding Project Nr. 6.

Different versions of ZCS converters are widely described, for example [2], [3].

Resonant converter operates on low resonant frequency - below 120 kHz, determined by coupled LC resonant tanks. Resonant frequency is influenced by load resistance as mentioned above.

III. AIR-CORE INDUCTANCES/TRANSFORMER

Air-core inductances utilize flat coils (Fig. 2, Fig. 3). Coils are axially aligned and placed close to each other and arranging core-less transformer.

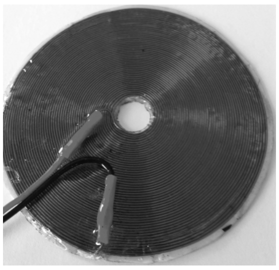

Fig. 2. Experimental flat coil with enameled copper wire (on left) and litz wire (on right).

Fig. 3. Experimental flat coil with enameled copper wire (on left) and litz wire (on right).

Two types of coils are experimentally tested: enameled cooper wire and litz wire. Litz wire coil has lower inductivity for the same inner diameter (12mm) and outer (75mm) coil diameters of enameled copper wire coil, due to larger litz wire outer diameter for the same cross-section. Distance between these coils is in approx. 1-2 mm, which depends from coil base plate thickness. In-spite of the fact that enameled copper wire based coil inductance is 82 uH and lower capacitor values can be applied this design was excluded due to high active resistance at frequencies more than 100 kHz.

Litz wire coil inductance is 21uH and this coil type was used in experimental tests.

Overall design of core-less transformer is shown in Fig. 4. Lower coil is mechanically fixed to step motor (in this design for continuous rotation step by step), upper coil is fixed to step motor shaft (in Fig. 4) mechanical fixings are removed for better observation).

Fig. 4. Design of overall core-less transformer.

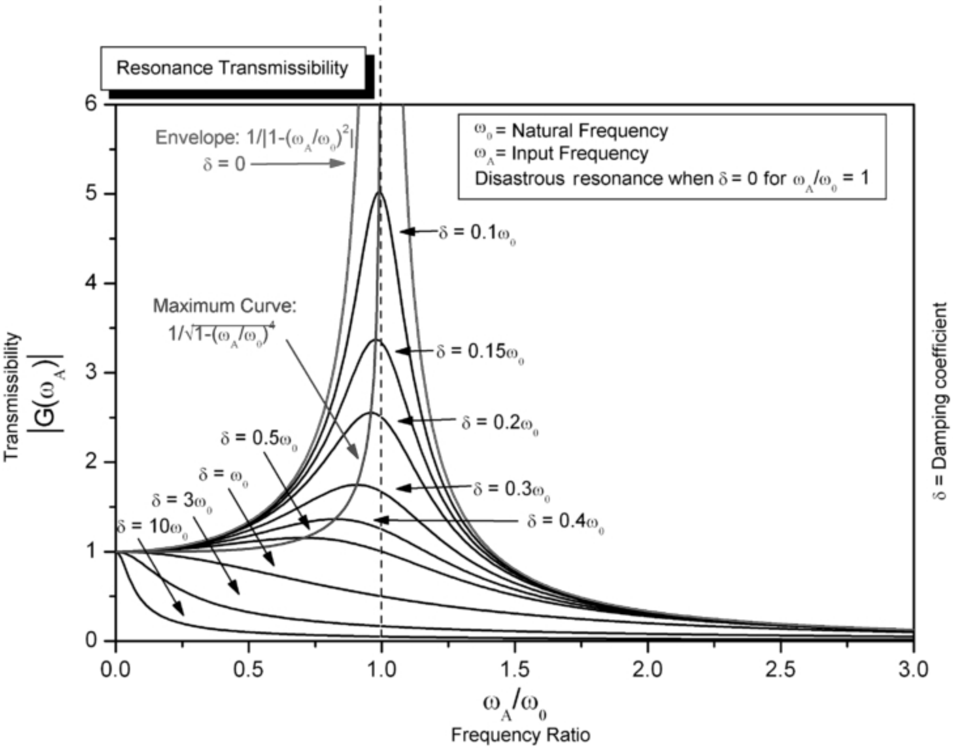

Fig. 5. Design of overall core-less transformer.

IV. THEORETICAL BASE

Resonant circuits are well described in literature starting from Tesla coil (year 1897) [4]. Development of radio communication and intensive research and development in this area describe all characteristics of resonant circuits etc.

For wireless power transmission resonant frequency shift under tank load change via direct influence on quality factor Q (1) and damping coefficient d (2):

$$Q=\frac{1}{R}\sqrt{\frac{L}{C}}\ , \tag{1}$$

$$d=\frac{R}{2L}\ . \tag{2}$$

Graphical representation is shown on Fig. 5, where the main graph illustrates experimental results. Graph in concentrated way show maximum transmissibility (resonance) shift under different Q and d.

Mentioned before is applicable for one resonant tank. In two tank circuit instead of resonant frequency we use partial resonant frequency, frequency between two tanks resonant frequencies (Fig. 6).

Second tank resonant frequency decrease under increasing load and partial resonance increase (shift from point A to B, Fig. 6). More increase of load causes partial resonant frequency shift to point D or point C - closest to the partial frequency at point A.

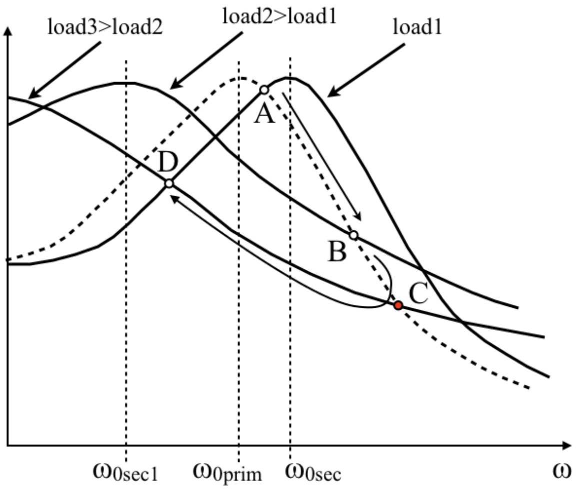

Fig. 6. Design of overall core-less transformer.

All mentioned are well described and known from overall AC circuits and amplifiers development during the time.

V. RESONANT TANKS

Measured tank coil inductivity is 23 uH (placed free air, measurement frequency 100kHz), capacitance - 100 nF, calculated resonant frequency is 104,94 kHz. Secondary resonant tank capacity is lower than 100 nF due to connected in series filter capacitance (2200 nF) - approx. 95,65 nF. Calculated secondary resonant frequency thereby is 107,3 kHz.

Experimental test results (Table I) prove two coupled resonant tanks characteristics according to Fig. 6.

TABLE I. EXPERIMENTAL TEST RESULTS OF CONVERTER.

Load Type	**Secondary**			**Primary**			**η, %**	**Resonant frequency, kHz**	**Comment**
	I, A	**U, V**	**P, W**	**I, A**	**U, V**	**P, W**			
Active load	0	73,2	0,00	1,73	15,54	5,77	0,00	106,5	no load
	0,19	33,8	6,42	1,1	15,54	17,09	0,38	108,0	
	0,24	26,2	6,29	0,93	15,54	14,45	0,44	109,0	
	0,28	21,7	6,08	0,8	15,54	12,43	0,49	110,0	
	0,31	18,7	5,80	0,72	15,54	11,19	0,52	111,0	
	0,34	16,5	5,61	0,65	15,54	10,10	0,56	112,0	
	0,36	14,6	5,26	0,59	15,54	9,17	0,57	113,0	
	0,38	12,9	4,90	0,54	15,54	8,39	0,58	114,0	
	0,39	11,3	4,41	0,49	15,54	7,61	0,58	115,0	
	0,42	9,3	3,91	0,43	15,54	6,68	0,58	116,0	
	0,43	8,9	3,83	0,43	15,54	6,68	0,57	116,4	
	0,44	7,7	3,39	0,39	15,54	6,06	0,56	112,2	
	0,45	8,1	3,65	0,44	15,54	6,84	0,53	96,4	
	1,35	0	0,00	0,94	15,54	14,61	0,00	80,7	short circuit
Permanent magnet DC motor load	1,22	0	0,00	0,91	15,54	14,14	0,00	80,8	motor stopped
	0,36	14,62	5,26	0,6	15,54	9,32	0,56	113,2	motor free run

VI. CONCLUSIONS

Design of proposed converter is simple and is low cost solution for wireless energy transfer, especially for applications with rotating joints, like robotics, special measurement stands in optics and material testing laboratories.

Achieved efficiency (58%) is acceptable for low (6W and less) power transmission.

Future tasks include testing of other coil designs, Hall-effect current sensor application in converter design - to exclude shunt resistor, as well as energy transfer efficiency measurements using data transmission over wireless power line conditions (using Manchester encoding).

Before industrialization, the final design of the multi-parameter system will also need analytical estimation of different electronics quality parameters, with methods well described in research done by authors [5], [6].

REFERENCES

[1] P. Špánik, P. Drgoňa, M. Frívaldský, A. Príkopová, “Design and Application of Full Digital Control System for LLC Multiresonant Converter”, *Elektronika ir Elektrotechnika (Electronics and Electrical Engineering*), no. 10, pp. 75–78, 2010.

[2] Bo-Tao Lon, Yim Shu Lee, „Novel actively-clamped zero current switching Quasi resonant converters“, in *Proc. of the IEEE International Symposium on circuits and systems,* Hongkong, 1997.

[3] K. H. Liu, F. C. Lee, „Quasi resonant converters topology and characteristics“, *IEEE Transactions on PE,* pp. 62–74, 1987.

[4] Tesla Nicolas, „Electrical Transformer“, U.S. Patent 593,138, 1897.

[5] D. Eidukas, V. Stupak, “Efficiency of Electronic Devices for Unsteady Flow of Failures”, *Elektronika ir Elektrotechnika (Electronics and Electrical Engineering*), no. 4, pp. 57–60, 2011.

[6] D. Eidukas, R. Kalnius, “Models Quality of Electronics Products”, *Elektronika ir Elektrotechnika (Electronics and Electrical Engineering*), no. 2, pp. 29–34, 2010.