Design Simulation of a 2-Kw Single Phase Inductive Power Transfer Systems

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Abstract- The aim of the paper is to have an overview of the inductive power transfer for electrical vehicles with a special concentration on coil design and power converter simulation for static charging. There were some advances in this area as to know more about microwave systems. However, this subject has recently become very attractive due to their practical systems. There are low power applications such as charging the batteries of contactless tooth brushes or implanted devices, and higher power applications such as charging the batteries of electrical automobiles or buses. In the first group of applications operating frequencies are in microwave range while the frequency is lower in high power applications. Coil design is very important for an efficient and safe power transfer. The converter on the primary side is used to generate a high frequency voltage to excite the primary coil. The purpose of the converter in the secondary is to rectify the voltage transferred from the primary to charge the battery. Finally, the simulation of a single phase 2 kW system and results were presented.

Indexed Terms- Coil design, single phase, simulation, contactless charging, electrical automobiles, inductive power transfer, and operating frequency.

I. INTRODUCTION

This has compelled engineers and scientists together with researchers to find an accurate and sustainable alternate solution to these natural energy sources. The advent and electric vehicles (EVs) integration has been received by all as a present solution to the depleting assets (petroleum), which are mainly used in the automotive applications. The trend in the development of these advanced energy systems can be analysed carefully. The concept of EVs was developed, through initiation of the "HEV" stands for hybrid EVs. Shortly afterwards, engineers took another step forward, with the invention of plug-in hybrid (PHEVs) or connect HEV's. Nonetheless, PHEVs were accepted, but the applications were associated with a lot of disadvantages. EV also has limitations. Batteries used to store energy are heavy and expensive. Time is needed to fully charge the batteries, and the driving range is still limited. Also, batteries need to be replaced in a few years. A recent topic of interest for EVs is wireless charging. It is also called inductive charging technology (IPT). Through IPT, it is possible to charge batteries in shorter time without any physical correction. IPT can be used for static and dynamic charging.

II. LITERATURE REVIEW

The study was related to the design techniques for magnetic coupler, mechanisms for control, detection-algorithms, compensation topologies, as well as safety issues (radiation). Amongst the several issues addressed above, researchers concluded on the design of magnetic coupler and compensation circuits. Loosely coupled transformer formed the magnetic couplers of 5 WPT chargers [1]. They have their primary and secondary coils linked across a relatively large air gap in a fixed charging system. Having a higher efficiency and tolerance to misalignment with maximum dimensions is always preferable. In some other kinds of couplers, the geometries along with configurations have been proposed by researchers [3]. Circular design has been well researched and optimized.

III. COMPENSATION TOPOLOGIES

An air cored transformer results in low efficiency, because of large leakage inductances in both primary and secondary windings. There is a smart method to solve the problem presented here, by using capacitors in order to compensate the reactive current. We can use shunt and series compensation in power system, while capacitive compensation is applied to power system for reactive compensation [4].

a. In the case of shunt compensation, this leads to an increase in power transfer ability and reduction in the reactive voltage drop across line.
b. In the case of series compensation, the maximum power transfer capability of the line is better, because of partial compensation of series inductance, and reduction in load angle results in enhancement of system stability [4].

In order to overcome system losses, capacitors can be connected in series and parallel to both coils. The secondary capacitance is selected as the first step. There are two different ways to connect the compensation capacitors in series and parallel to both sides of inductors. The methodology given in the mentioned paper is based on the algorithm given in flow chart. It starts with the selection of coil geometry, maximum current density for the coils, and maximum number of turns allowed. In the iteration process, first, the number of turns for each coil is assumed to be 1, and some initial values are assigned to coil cross-section areas. Also, a frequency factor which determines the operation frequency is started at 1. In the first step, inductance values are calculated for the given initial and sections of the windings for a desired transferred power. Two design procedures are presented, but there remain many design decisions that depend on the actual case and the experience of the designer [6].

Based on current, voltage, power values and quality factors are calculated for the compensation topology of choice. If the load power is less than the targeted value, frequency is increased and calculations are repeated for the same coil size. This iteration is repeated until the desired power level is reached. Once the power level is reached, the current density values of the coils are checked to see if this is an acceptable operation point. If the current density is above the defined limit at a coil, corresponding cross-section area is increased and the iteration is repeated.

TABLE 1 FOUR DIFFERENT TOPOLOGIES

Topo-logy	Acts like Sources	Indepen-dent of changes	Power factor small distance	Total impedance at resonant	Efficiency
SS	Current	C_2	low	low	Very high
SP	Voltage	C_2	Low	low	medium
PS	Voltage	C_2	High	High	medium
PP	Current	C_1	Very high	High	High

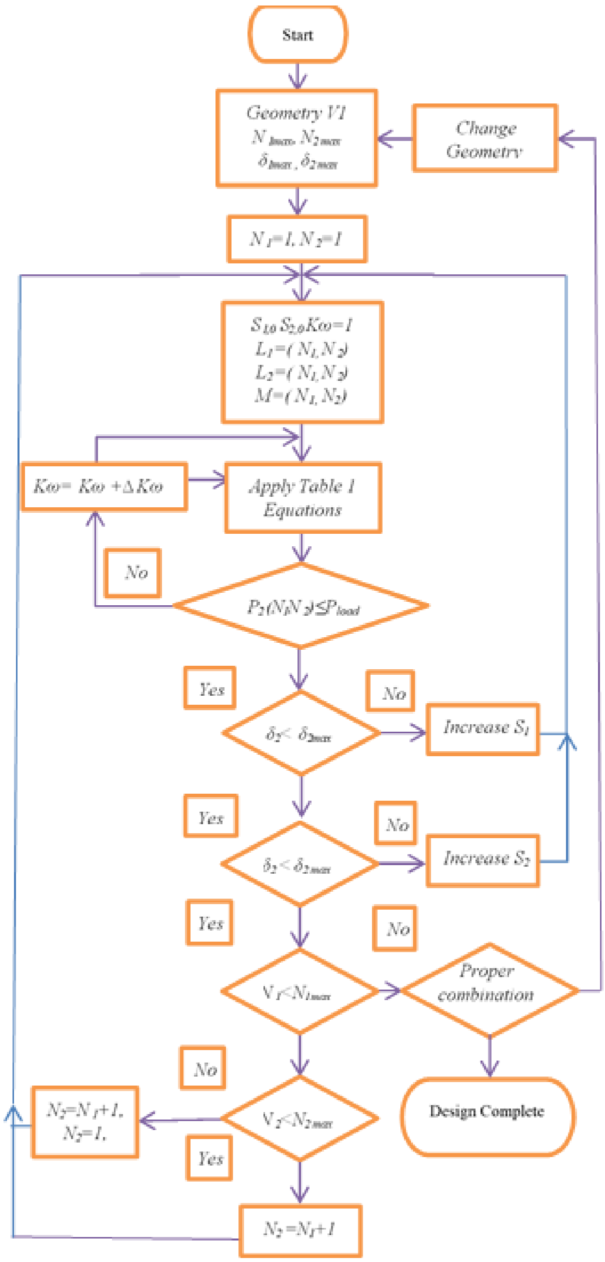

Fig.1. Flow Chart of the System

IV. RESULTS AND DISCUSSION

The iterative technique described above was tested in computer via MATLAB software. Maximum number of turns was defined to be 30 and 10 for the primary and secondary, respectively. For each pair of turn numbers, a solution was found iteratively, starting from an initial cross section and by changing the frequency. Figs. 3-7 show the results.

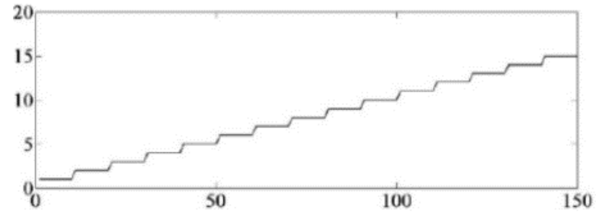

Fig.2 Turn number variation for the primary at each step

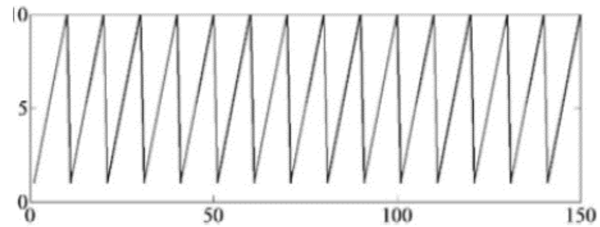

Fig.3 Turn number variation for the secondary at each step

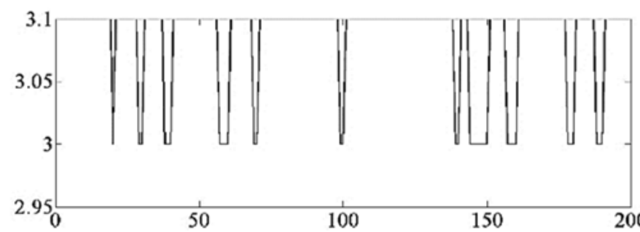

Fig.4. Cross-sectional area variation for the primary for each step (mm^2)

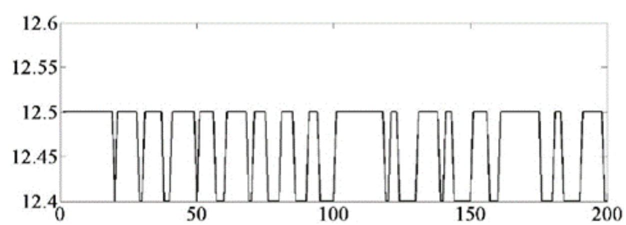

Fig.5. Cross-sectional area variation for the secondary for each step (mm^2)

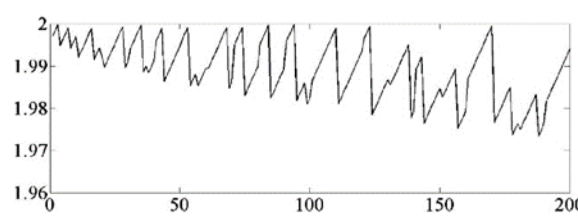

Fig.6. Power output variation for each step (kW)

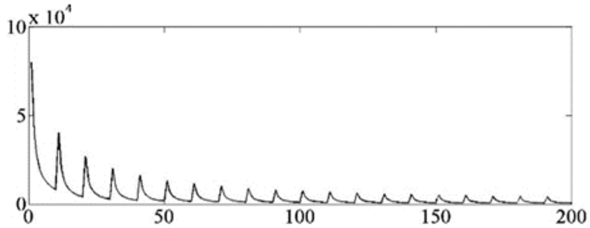

Fig.7.Variation of resonance frequency (kHz)

Results show that the technique produces possible solution for each set of turn numbers. A true solution should be selected among these results to build the real system. Therefore, the data given in [7] will be used in the remaining of the paper.

V. DESIGN OF A 2-kW SYSTEM

The topology is selected as rectangular coil structure with a maximum frequency of 20 kHz. When the methodology presented applied, the optimum solution was obtained with S-S compensation, as shown in Table II. The coil dimensions were found to be a_1=0.4 m, b_1=0.8 m, and h= 0.15 m by using

MATLAB Code (coil parameters given in Table II).

A. Simulation of the System

The operation of single-phase full bridge DC-DC converter is described, and the simulation results obtained by MATLAB Simulate were presented. The full wave bridge inverter includes two arms, two switches, and anti-parallel (freewheeling) diodes as shown in Fig. 8. These are used to provide paths for the reverse currents. The switches are represented here by name of T1, T2, T3, and T4, respectively. For each branch, the upper and lower switches are turned on and off alternating, with a brief dead time in between the transitions. There is 180° phase shift between the two legs which means diagonal switches conduct together to apply square wave voltage across the load [3].

TABLE II COIL PARAMETERS

Parameters(Units)	Values
N_1	27
N_2	7
V_l(V)	50
S_1(mm^2)	2.5
S_2(mm^2)	10
R_1(Ω)	0.4
R_2(Ω)	0.02
L_1(H)	0.0146×10^3
L_2(H)	0.006×10^3
P_l	2000
F_0(kHz)	19.8
η(%)	95
V_{C1}(V)	2019
V_{C2}(V)	305
I_p(A)	10.5
I_s(A)	40
C_2(μF)	0.0043×10^3
Q_p	10.7
Q_s	6.1

VI. SIMULATED CIRCUIT AND RESULT

The circuit used in the simulations is shown in Fig. 8. The circuit parameters are as follows: L_1= 1.46 mH, L_2 = 61 μH, C_1= 43.7 nF, C_2 = 1.05 nF. These parameters are part of those given in Table II. The switching frequency is 20 kHz, which is equal to the resonance frequency of the LC circuits; the primary capacitor is in resonance with the inductance of the transformer. The transformer is defined as a coupled inductor with the inductance parameters given above. The coupling factor is taken as 0.5.

The square wave voltage generated by the inverter is shown in Figs. 9-13. The frequency of this voltage is 20 kHz, which is the resonance frequency of the primary. In Fig. 10, the currents in the primary and secondary are shown. As seen in the figure, the currents are nearly sinusoidal at the resonance frequency of 20 kHz. In Fig. 11, primary capacitor voltage is shown; Fig.12. The secondary side capacitor is given. As expected, the voltages can increase significantly meaning special capacitors are required for this application. Finally, output voltage is shown in Fig. 13. The load of this circuit can be replaced with a battery charging system to simulate the real one.

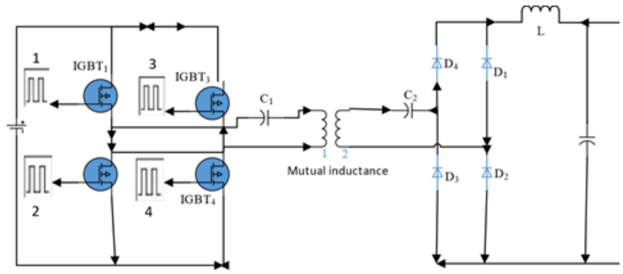

Fig.8.Simulated Circuit

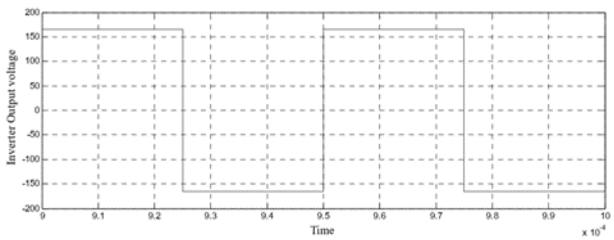

Fig.9. Inverter output voltage

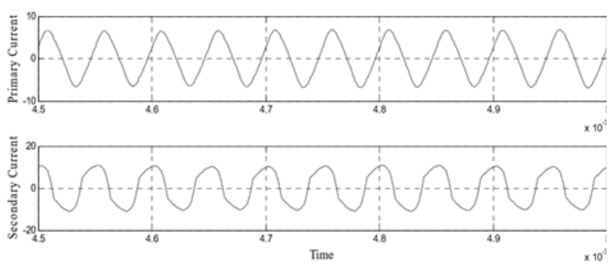

Fig.10. Primary and Secondary Currents

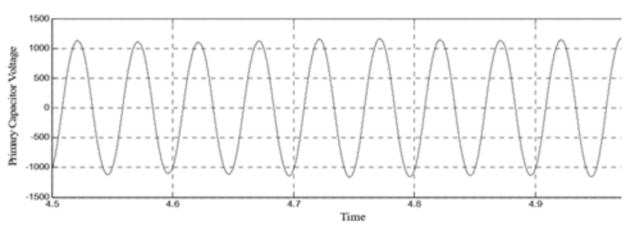

Fig. 11. Primary Voltage

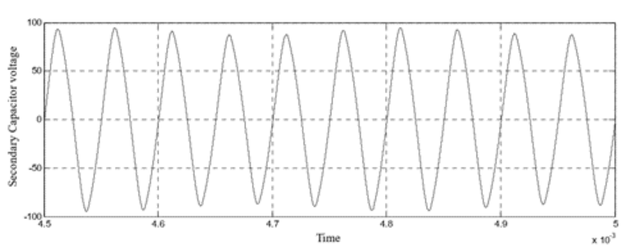

Fig. 12.Secondary Voltage

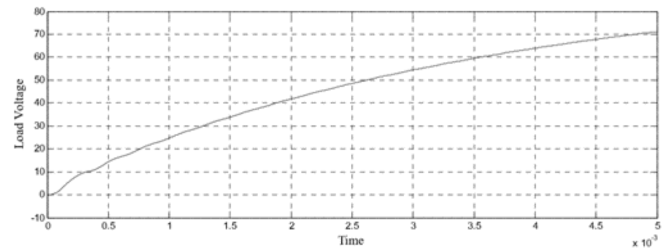

Fig. 13. Load Voltage

VII. CONCLUSION

In IPT systems, power is transferred between the coils of the system. The coils are not around the same core, and there is a distance between the coils making the system a loose coupled one. In order to transfer the power efficiently resonance concept should be utilized. There are four classical topologies and also the new proposed ones such as LCL topology. The one presented here uses series-series compensation topology, which is adequate for battery charging applications. However, the results show that capacitor voltages increase tremendously, and this requires special capacitors. Therefore, LCL topology needs to be utilized instead of the classical series one. Another subject that should be studied is the control of the system. The system was run on open-loop control, but it needs to be improved. There are different control topologies presented in the literature and double-side control seems to be very promising. Also, hybrid control algorithms, taking care of the duty cycle control and zero phase angle control at the same time can be very interesting. There are already published papers investigating this issue. One final possibility for the future is investigating the operation of different converter topologies, especially multilevel converter topologies as they could provide a good power factor and high powers necessary for some applications

REFERENCES

[1] Wu, H. H., Golchrist, A., Sealy, K. D. & Bronson, D. (2012). "A high efficiency 5kW inductive charger for EV using dual side control". IEEE Transactions on Industrial Informatics, + (3), 585-595.

[2] Kalwar, K. A., Amir, M., & Mekhilaf, S. (2015). "Inductively coupled power transfer (ICPT) for

electric vehicle charging-A review". Renewable and Sustainable Energy Reviews, 47, 462-475.

[3] Li, S., & Mi, C. C. (2015). "Wireless power transfer for electric vehicle applications". IEEE journal of emerging and selected topics in power electronics, 3(1), 4-17.

[4] Hingorani, N. G., & Gyugyi, L. (2000). "Understanding FACTS: concepts and technology of flexible AC transmission systems". United States: Wiley-IEEE press

[5] Chao, Y. H., Sheih, J. J., Pan, C. T., & Shen, W. C. (2007). "A closed-form oriented compensator analysis for series-parallel loosely coupled inductive power transfer systems". In Proceedings of IEEE International Conference on Power Electronics Specialists Conference (pp.1215-1220). Orlando: IEEE.

[6] Lee, B. S. & Han, K.H. (2005). "Modeling and analysis of IPT system used for PRT". In Proceedings of IEEE International Conference on Electric Machines and Systems (pp. 839-842). Perth: IEEE.

[7] Sallán, J., Villa, J. L., Llombart, A., & Sanz, J. F. (2009). "Optimal design of ICPT systems applied to electric vehicle battery charge". IEEE Transactions on Industrial Electronics, 56(6), 2140-2149.