

**DIGITAL CONTROL OF A CONTACTLESS
BATTERY CHARGING SYSTEM**

by

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Abstract

This project develops and implements a safe, reliable method for contactless charging of electric vehicle batteries. The charging system's interface to the electric utility operates with unity power factor. This system accommodates many battery types by using a novel, large signal linear digital controller that can track arbitrary current profiles. Non-ohmic charging occurs through a two part, high frequency transformer. The primary side of the charging transformer remains outside the vehicle, and mates with a secondary installed in the vehicle. The scheme for impressing an AC signal on the primary of the charging connector involves lossless MOSFET switching in a high frequency inverter, and operates in the presence of high leakage inductance. Capacitive coupling enables contactless feedback of information from the battery in the secondary to the unity power factor charging supply in the primary.

Thesis Supervisor: Steven B. Leeb

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For my mother, my father, and my sister Lauren.

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Chapter 6

Conclusions and Future Work

This project explored the design and implementation of an inductively coupled electric vehicle battery charging system. Goals included safety, reliability, and versatility. High efficiency was important with wide spread use of charging stations in mind. The prototype accomplishes these goals. The boost converter topology operates with unity power factor, facilitating maximum power transfer from the source. The model of the boost converter resulting from unity power factor leads to a robust, linear, large signal control scheme by which almost any battery with a linear model can be delivered an arbitrary charging current profile. The versatility afforded by the control scheme suggests a digital implementation whose flexibility enables easy changing of control code for different battery types. The successful magnetic coupling of energy from the charging station to the vehicle provides safety and reliability at the charging interface.

Starting from a successful unity power factor voltage loop control scheme developed by Mitwalli [34] [25, p. 396-9], an enhancement using feed forward eliminates voltage loop dependence on load. An outer current loop operates at a slower sampled data rate than the voltage loop, resulting in the simplified UPF plant delay model. With tools for developing sampled data equations for any linear load, the control scheme can be stabilized for linear controllers such as PI. Second order effects such as accumulator windup and quantization are combated through additional control features.

A half bridge inverter impresses an AC signal on the primary of a gapped core transformer. The transistors of the DC / AC circuit switch losslessly through a scheme from [35]. The

DC / AC inverter, transformer, and rectifier were built and tested. Experimental results prove that in fact the DC / AC conversion and rectification were occurring losslessly.

In order for the system to be feasible, three enhancements must be made in future work. First, the complete battery charging system of Figure 1-1 must be assembled, connected and tested since there was insufficient time during this project. The DC voltage at the half bridge inverter is the output of the boost converter. The load equations for the current loop controller will change since the battery will load the unity power factor DC supply through the DC/AC converter rather than directly. Feedback to the microcontroller is received through the capacitive coupling circuit from [43]. In short, the connection through an air gap of the UPF DC supply to the inductive and capacitive coupling systems as shown in Figure 1-1 must be made and tested.

The second improvement is to increase the amount of power that the charger can draw from the utility and efficiently supply to a battery. The prototype is designed to supply 250 Watts. Faster chargers will draw the maximum power possible from the utility, which for typical wall outlets is $2kW$. An important step towards a higher power prototype is reduction of the implementation to printed circuit boards. This improvement may provide reliability, better signal integrity, and safety to the circuit construction.

Third, the charger must take into account battery temperature and state of charge.

Another improvement may lie in developing a more sophisticated DC / AC conversion. Dividing the power to be transferred from the DC source to the battery among several bridges will reduce the size of each transformer due to smaller power demands in each branch, and increase reliability by lessening the loss when one branch fails. A “polyphase-shifted PWM” lossless switching scheme for the branch phases would need to be derived.

For commercial proliferation of this technology, the charging station will need some method for simple recognition of the electric vehicle battery type. The charging station might have a bank of controllers for the different battery loads. Alternatively, manufacturers might store charging information in the vehicle to be transmitted over the transceiver interface. The program running at the charging station will require knowledge of the optimal charging profile for the given battery. A graphical user interface for either system may be useful.