Implementation Inductive Power Transfer System with SEPIC Fed Inductive Charging Device for Electric Vehicles

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Abstract- **Actually, there is a controversial discussion in automotive industry if non-contact power supply is able to avoid the disadvantages of conductive vehicle charging systems. Beside several benefits concerning a higher charging comfort and a higher immunity against vandalism non-contact charging systems possess the drawback of a less efficiency compared to conventional charging devices. The approach described in this paper is the deployment of a SEPIC based rectifier instead of a conventional power factor correction unit. The SEPIC unit substitutes both the power factor correction unit and an also required DC-DC converter. Aim of this topology investigation is the reduction of losses within the topology chain to increase efficiency of the entire charging device.**

Index Terms- SEPIC; PFC; DC-DC converter; inductive charging; electric vehicle

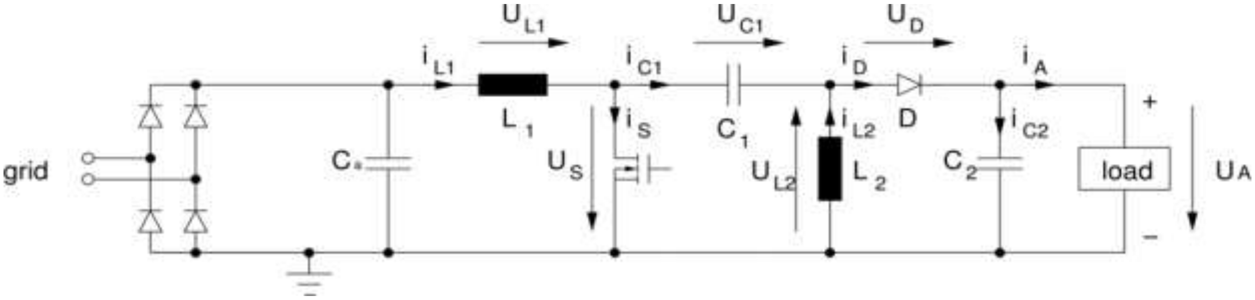
I. INTRODUCTION

The reduction of CO2 emissions by increasing the percentage of renewable energies in the federal energy mix as well as promoting electro mobility (e-mobility) [1, 2]. If charged by renewable energies, electric vehicles can significantly contribute to a reduction of CO2 emissions. Additionally, they can be employed to store and balance the fluctuating energy production of renewable sources. Therefore, a high availability of electric vehicles in the grid needs to be guaranteed.

Available charging systems for electric vehicles use wires to connect the vehicle to the grid. These systems are called conductive supply systems. Compared to conventional vehicles, driven by combustion engines, conductively charged electric vehicles feature several disadvantages. The perseverative handling with plug and cable means an additional effort for the driver. Unclean cables and plug-in activities during rainy weather at public charging stations are a permanent annoyance. Furthermore, free accessible cables are an invitation to vandalism and unplugged or broken cables are a safety risk, which is not acceptable. If the vehicle is not charged at public areas, the grid connectivity time is shorter than desired. The results are uncharged batteries, which cause a minimization of mobility and a further reduction of the available range of electric vehicles.

An alternative is non-contact charging on the basis of inductive energy transfer. This technique allows for a simple and reliable charging process. It is assumed, that automatic inductive charging will improve the user acceptance of electric vehicles in general. Furthermore, it accounts for the integration of electric vehicles into the market and supports the full exploitation of all e-mobility based benefits. Moreover, the deployment of a non-contact solution causes a low deterioration compared to plug afflicted systems.

However, the major disadvantage of an inductive power supply system remains: The transmission efficiency is significant lower than the efficiency of conductive charging devices. This is caused by the high number of current converting steps within the operation chain starting at the grid and ending at the battery's terminal clamp. This paper presents a comparison between a conventional topology and a SEPIC (single-ended primary-inductor converter) fed inductive power supply. Aim of the implementation of the SEPIC based rectifier is a perceptible reduction of the system's losses to increase the commercial viability of inductive charging stations for electric vehicles.



A SEPIC circuit is a kind of DC-DC converter, which output voltage can possess a higher or a lower amount than the input voltage. It is similar to a conventional buck-boost converter, but has advantages of having non-inverted output. Basic elements of the SEPIC circuit are three energy storing elements: Two inductivities and one capacitor. The equivalent circuit drawing is presented in Figure 1. In recent years SEPIC circuits are deployed in several applications. The scope of SEPIC circuits comprises

- pre-regulators for several LED lighting applications [3, 4]
- converter operation for photovoltaic applications [5, 6],
- various power factor control applications in all power ranges between mW and several kW [7, 8],
- and further applications.

In a first section, the setup of a conventional system is introduced. Afterwards, the SEPIC equipped system topology is presented and its operational characteristic is explained. The results of the system comparison will be presented in the full paper.

II. BASICS OF INDUCTIVE CHARGING DEVICES

An inductive charging system consists of a number of components. The power coupling between ground and vehicle is established by the stationary transmitter unit and the on- board receiver unit (called pick-up), which is directly mounted to the vehicle's under body structure. The stationary transmitter as a charging unit is linked via magnetic flux with the pick-up. According to the principle of electromagnetic induction, the pick-up can receive electric power from the stationary transmitter, without an electrical connection.

The inductive primary part consists of a flat coil with several windings, which can be mounted to a cover plate made of glass fiber reinforced plastic, which would have no influence on the magnetic field. In an exemplary system (eCPS© of Vahle Inc. [9]) this assembly group is directly placed above an aluminum plate populated with soft magnetic ferrites. Basically, the construction principle of the pick-up is the same. A difference between transmitter unit and receiver unit only exists in size, in number of windings, and in housing shape. The outer dimensions of both stationary transmitter and pick-up of the exemplary charging system are presented in Table 1. The large dimensions of the inductive units are caused by the safety limit value of the electromagnetic field defined in the German application guideline [10]. A schematic diagram of this system's cross-section is shown in Figure 2 and a photographic illustration of that part is presented in Figure 3.

The transmitter is galvanically connected to the primary inverter. This unit converts a DC voltage to a higher frequency alternating voltage with a nominal frequency of fN = 140 kHz. The advantages of an energy transfer performed at high frequencies (f>100 kHz) are already proven [11-18]. The stationary power transmitter, called primary inductor,

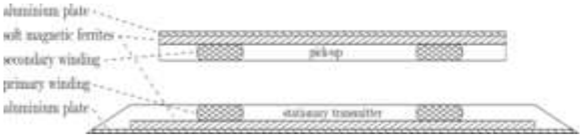


Figure 2: Schematic diagram of the inductive system's cross section

Figure 3: Stationary transmitter and pick-up of the inductive charging system.

generates a higher frequency (hf) electromagnetic field. This electromagnetic field is coupled with the windings of the pick- up.

TABLE I DIMENSIONS OF THE STATIONARY TRANSMITTER AND THE PICK-UP UNIT

	Stationary Transmitter	Pick-Up Unit
length	1089mm	825mm
width	1089mm	825mm
height	24mm	16mm
weight	approx. 49kG	approx. 14kG

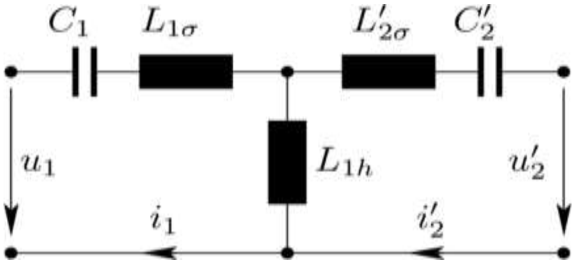


Figure 4: The inductive’s part (i.e. stationary transmitter and pick-up) equivalent circuit drawing depicting inductances and additional capacitors

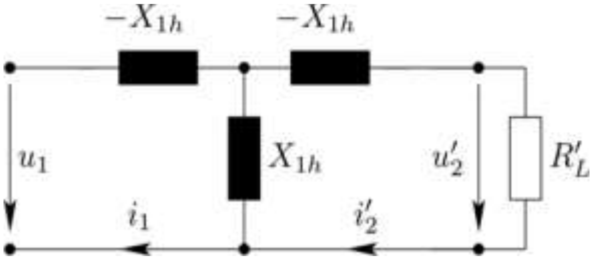


Figure 5: The simplified equivalent circuit drawing of the inductive part including load resistance RL’.

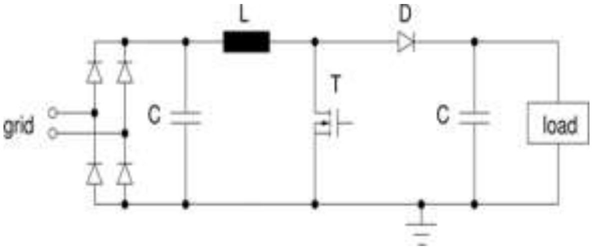


Figure 6: Equivalent circuit drawing of a usual PFC device.

To produce an appreciable part of active power in the on- board system, a compensation of the system’s inductances is required. Therefore, the stationary transmitter unit is equipped with a capacitor assembly in series connection to the primary coil. The secondary coil at the pick-up is also equipped with capacitors in series connection. Due to this compensation, the switching operation of the primary inverter is always resonant. The equivalent circuit drawing of the compensated coils is presented in Figure 4. A transformer equivalent circuit drawing is chosen to describe the electrical transmission characteristic. In this drawing, L1σ is the primary leakage inductance, L2σ’ is the secondary leakage inductance, and L1h is the mutual inductance. The capacitors C1 and C2’ are the respective compensation elements of primary and secondary winding. All values marked with an inverted comma are not the measurable values but related to the primary side by the ratio of the primary and secondary winding factors w1/w2. Due to the series compensation on both sides, the circuit can be simplified by calculating the reactances and summating the values of the series connected elements. The simplified equivalent circuit drawing can be seen in Figure 5. The absolute value of all three reactances is equal. In general, this is valid for inductive power transmission systems with compensation in series connection [19]. This passive network features a specific behavior: A voltage source connected to the primary side is transformed into a constant current at the clamps of the secondary side and vice versa. This means, the output current of the inductive transmission system does not depend on the connected load resistance. The proof of this system behavior can be found in [19]. This system behavior enables the deployment of a very simple control method for the contactless device’s power transmission value. The load current of the vehicle’s battery, which is the passively rectified output current i2 of the pick-up, can be directly adjusted by changing the primary voltage u1. The secondary current’s setpoint value can be given by the on- board battery management system. Therefore, the primary inverter can be fed by a variable DC source.

III. DC-VOLTAGE SUPPLY OF THE PRIMARY INVERTER

There are several possibilities to provide the primary inverter (hf power converter) with a variable DC source. Basically, a PFC (power factor correction) device has to be integrated into the inductive transmission system. This PFC causes the compensation of reactive power to the grid. Reactive power on the primary side of the primary inverter is usually caused by switching distortion. The deployment of such a PFC is ruled by law and therefore mandatory.

Usual active PFC circuits are based on a boost converter topology and provide a DC voltage on their secondary side [20]. A typical PFC design is presented in Figure 6. This circuit is able to provide downstream connected devices with a supply voltage of 320V < uA < 400V if connected to a standard 230Vac grid on the primary side. However, to adjust the entire power range of the non-contact transmission system a variable DC voltage of 0 < u1 < umax is required. umax = 400V is valid for the Vahle eCPS system mentioned above. This means if such a PFC device is deployed an additional DC-DC converter is required to control the transmission power. The working principle of such a PFC based inductive power supply system is presented in Figure 7. The PFC provides the DC-DC converter with a constant DC voltage. This voltage is converted to a variable DC voltage in dependence on the desired value provided by the battery management system (bms). This desired value depends on the battery's state of charge (soc) and the battery's optimum input current. Due to the proportional dependency of the compensated pick-up's output current and the input voltage of the primary inductor, the power flow can be directly adjusted by this simple feedback control.

However, the series connection of several power electronic devices will lead to a decrease of transmission efficiency. Therefore, an alternative solution for both power factor correction and DC voltage adjustment is prospected. A SEPIC seems to be an ideal solution for this. In Figure 1 can be seen that a SEPIC offers the desired behavior by utilization of only one semiconductor switch. It is assumed, that this circuit is able to substitute both PFC and DC-DC converter. An increase of the overall efficiency of the transmission system is expected. Figure 8 shows the working principle of the SEPIC driven inductive power supply system for electric vehicles.

IV. CONCLUSION

Non-contact power supply systems for electric vehicles on the basis of inductive power transmission are a reasonable alternative to conductive charging stations. The main disadvantage of the inductive system is the lower efficiency when compared to conventional plug afflicted systems. The substitution of more than one power electronic devices by one single device is one approach to decrease this disadvantage.

The comparison between the conventional PFC driven transmission system and the SEPIC driven transmission system is performed by simulation and measurement. A simple prototype of an inductive power supply system designed and constructed within the e-mobility research group of the University of Wuppertal is utilized as test carrier for all experiments. Results will be presented in the full paper.

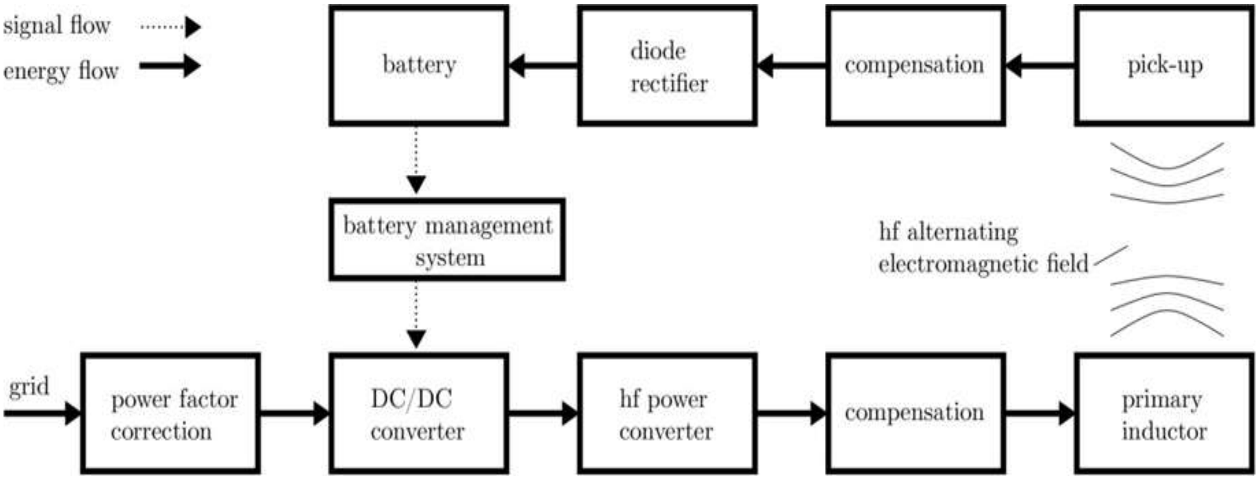


Figure 7: Working principle of a PFC based inductive power supply system

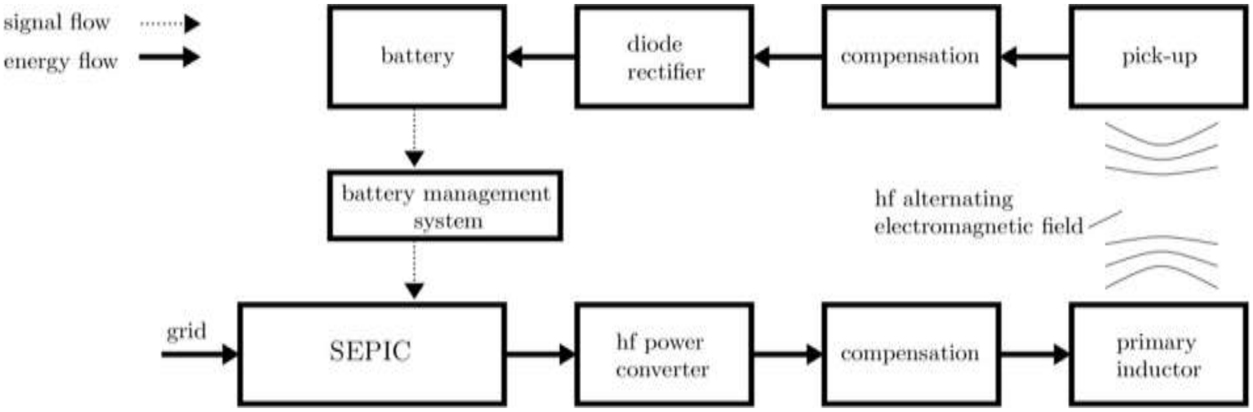


Figure 8: Working principle of a SEPIC based inductive power supply system

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