Hydrogen Supplied Wireless Charging System for Electric Vehicles

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***Abstract*—The aim of this work is the experimental characterization of a Wireless Charging System based on IPT (Inductive Power Transfer) supplied by a PEMFC (Proton Exchange Membrane Fuel Cell) in order to verify the possibility of its installation in not electrified areas. A hydrogen-based supply system is designed and assembled with the purpose of having an EV (electrical vehicle) charging station not connected to the main power grid. An efficiency analysis of the wireless transmission system is carried out taking into account external parameters such as distance and misalignment between the transmitter coil and the receiver coil, verifying the integration potentialities of both IPT and fuel cell for the automotive field.**

Keywords—IPT, Wireless Power Transfer, PEMFC, Fuel Cells.

I. Introduction

Urban mobility is changing and both public and private transportation is going to be closed to the internal combustion vehicles and more opened to the eco-friendly ones, most of all with electric supply. One of the great challenges for the development of the electric vehicles (EV) is the storage of energy. As a matter of fact, most of the research is focused on new technologies that allow EVs being more attractive. In order to increase the number of EVs and their massive utilization, infrastructural works are required and it is due first of all to the lack of charging stations. For this reason, in order to decrease the so-called range anxiety, that is one of the causes of the slow development of the EVs, new technologies must be implemented. The IPT systems can be introduced as a good solution. They represent an innovative approach for the EV battery charging, due to the possibility of wireless operations.

In fact, IPT systems bring benefits not only in terms of comfort, but also in terms of safety. In [1] an overview of the main IPT technologies of EVs is given. Different issues and technical limits based on human safety implications are discussed in [2] and several power efficiency optimization methods for different fields of application are proposed in [3-23]. In particular, a specific focus on the effects of misalignment and distance on the efficiency is presented in [24].

The only usage of eco-friendly vehicles is not sufficient enough to reduce CO_2 emissions and pollution in general. As a matter of fact, although a correct use of energy is assuming more importance, a green generation has not to be neglected.

Wind-turbines and photovoltaic are nowadays the principal technologies in the field of generation, but technologies such as that of hydrogen are equally valid.

Fuel cells are the base of this technology. They are electrochemical devices able to dispense current like a traditional battery, but external reagents are provided to the systems, in particular hydrogen and oxygen. In [25] the generalities and the working principles of the fuel cells are presented. The main characteristics of the different types of fuel cell are described in [26-28] and in [29] a focus on their applications is provided.

Even though fuel cells are one of the best solutions to generate electric energy from renewable sources, they have several technical limits that cannot allow them to be used directly EVs. One of these is their slow response time that does not pair well with the dynamics of the EVs without high performance power converters. Another one is related to the safety because of the presence of massive quantities of hydrogen on board. For this reason, they can be used for residential applications or in general for the generation of electric energy in low dynamic systems. In this paper, a low power prototype of a hydrogen supplied WCS is presented. It is composed by a fuel cell whose purpose is the supply of a wireless charging system based on IPT. The whole system can be used in not electrified areas such as rural areas or car garages. The hydrogen can be also generated locally thanks to an electrolyser supplied by a low photovoltaic panel.

II. Supply System Description

In this paragraph the hydrogen-based supply system is described.

A. Electric energy generation by hydrogen

Fuel Cell is composed by two electrodes where a redox reaction between fuel and combustive happens. An electrolyte is placed between the two electrodes [30]. An external electric circuit allows the flow of the electrons produced by the redox reaction from an electrode to the other [31]. Based to the different types of electrolyte, working temperatures and fuels employed, different types of fuel cell exist. For our purpose, a PEMFC (Polymeric Exchange Membrane Fuel Cell), whose schematic is presented in fig.1 is used. It is characterized by:

- Low working temperatures;
- High efficiency;
- Low requirement of maintenance;
- Auto-humidification of membrane;
- High ratio power/dimensions.

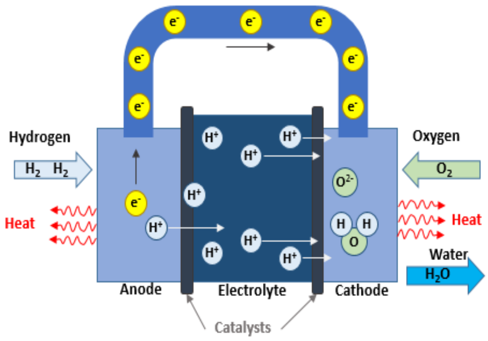

Fig.1 Schematic of a PEMFC [32]

In the PEMFC, hydrogen is used as a fuel and oxygen taken from the air as combustive. The electrolyte employed is a solid polymeric membrane made by Nafion 177. It allows a perfect separation between the elements reacted at the electrodes, as shown in the following equations:

$$2H_2 \longrightarrow 4H^+ + 4e^-$$

$$O_2 + 4e^- + 4H^+ \longrightarrow 2H_2O$$

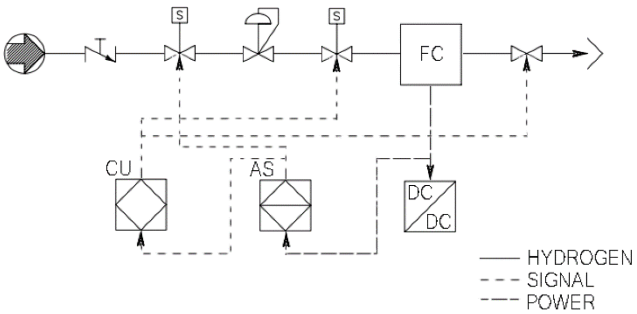

Fig 2 Schematic circuit of the hydrogen-based supply system.

B. *Design of the hydrogen based supply system*

The devices employed for the realization of the hydrogen-based supply system whose scheme is shown in fig.2 are described below.

- 300 W PEMFC (FC), 69V maximum voltage;
- Purge valve;
- Inlet valve;
- Solenoid electro valve to avoid hydrogen peaks;
- Pressure regulator to avoid high pressure at the entry of the fuel cell;
- Alarm system (AS) composed by: hydrogen sensor, high temperature sensor, high voltage sensor;
- Control unit (CU);
- DC-DC converter.

The hydrogen is stocked thanks to a hydride metal storage. With difference to the conventional hydrogen storage systems, the hydride metal technology can allow the stockpile of 900 litres of hydrogen at the pressure of 10 bar in a 5 kg compact tank [33]. The assembled supply system is shown in fig. 3.

Fig.3 Hydrogen based supply system

III. IPT SYSTEM

The proposed IPT system was designed and realized entirely in laboratory. In this paragraph, the proposed system is described.

A. *Inductive Power Transfer System Description*

Fig 4. Shows the circuit schematic of the proposed wireless charging system, consisting of the two coupled inductors and two symmetrical sides, referenced as primary

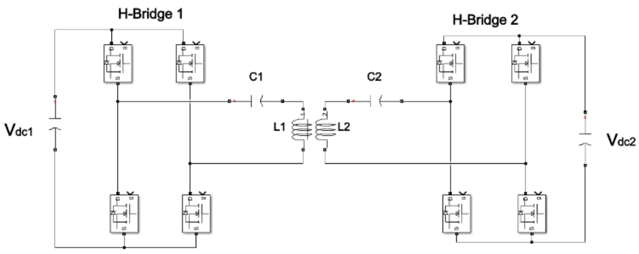

Fig.4 Schematic of an IPT based on SS compensation

and secondary side. Each side consists of a DC source, a H-bridge converter and a capacitor. The IPT system is based on the magnetic coupling between the two coils. The capacitors are used for the reactive power compensation and along with the self-inductances, determine the system resonant frequency. This proposed system is based on a Series-Series compensation, which provides advantages in terms of power regulation facility, as a matter of fact, the resonant frequency depends only on the self-inductance [33].

The primary H-bridge converter provides to the alternate voltage having frequency equal to the resonance one. The secondary side converter is used as a rectifier in order to supply the load.

B. *Design and Realization of the IPT system*

The H-bridge converters were studied in simulation, designed and realized in laboratory, using the IRFB4410Z power N-Channel MOSFETs for high frequency [34]. The N-Channel MOSFETs are driven by the HIP4081A [35]. For a proper operation of the driver, an external bootstrap circuit with capacitors and diodes are needed. The inductors employed for the system are circular planar coils with 13 μH auto-inductance, the series compensation circuit is composed by a PET capacitors bench equal to 250 nF. For this reason, the resonance frequency is equal to 94,1 kHz. The control of the system is given to the shield Arduino DUE. In fig. 5 the structure of the coils is shown.

IV. Experimental Tests

In order to evaluate the proposed system, simulations in Matlab/Simulink and experimental tests have been carried out, concerning a power transfer from the primary to the secondary side.

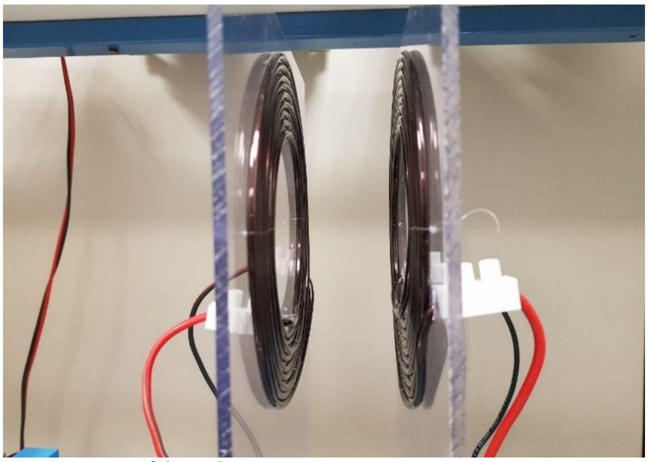

Fig.5 Structure of the coils

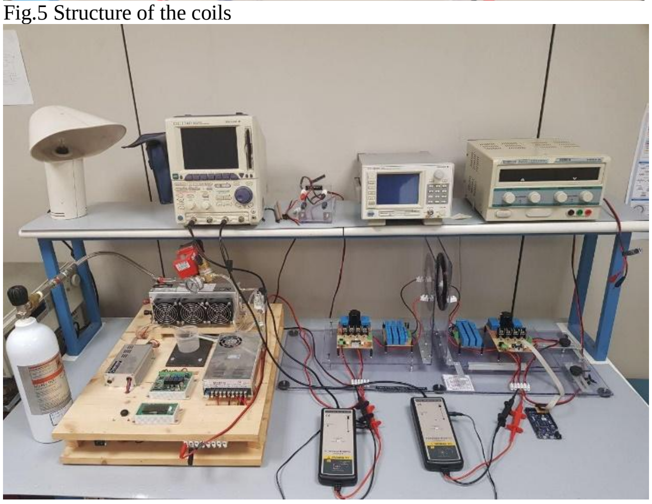

Fig. 6 Assembled system

In fig. 6 the test bench is shown. It is composed by the hydrogen-based supply described in paragraph II , the IPT system described in paragraph III, an oscilloscope Yokogawa DL 1790, two differential voltage scopes, two current scopes and an electronic load.

The goal of the tests is the efficiency characterization of the IPT system when supplied by a fuel cell, in order to verify the employment possibility of such kind of apparats in no electrified areas. Wireless power transmission strongly depends on the distance between the two coils and on the misalignment. For this reason, the tests are carried out with distances variable between the two inductors from 1 cm to 4 cm with steps equal to 0,5 cm and misalignment from 0 to 4 cm with steps equal to 0,5 cm in different load conditions set on an electronic load, from 1 Ω to 20 Ω with steps equal to 1 Ω . The output voltage of the supply system is equal to 24 V given by a DC-DC interposed between the supply system and the IPT system.

The DC-DC converter has also a second important scope. In order to have an auto-humidification of the membrane of the fuel cell, a short circuit unit is installed. It allows to the short-circuit of the cells for 200 ms every 10 s. For this reason, the DC-DC converter allows to a more stabilized input voltage. In fig. 7 and 8 (CH1) the not stabilized voltage trend and the stabilized one are shown.

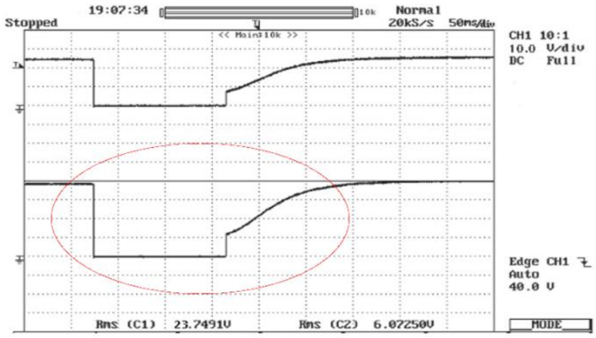

Fig.7 Not stabilized voltage trend

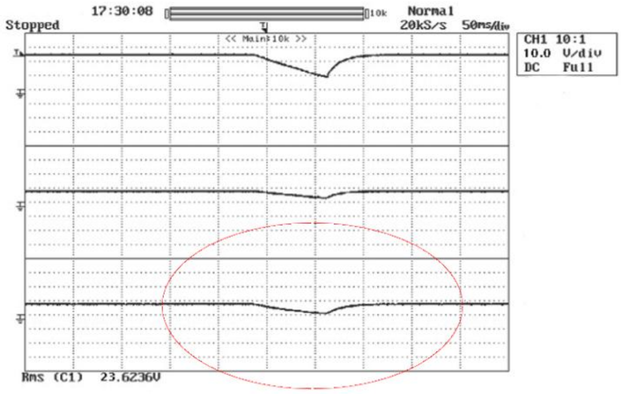

Fig.8 Stabilized voltage trend

The input and the output voltage and current of the system were measured, and the input and output power calculated, therefore the efficiency for each value of load, distance and misalignment.

V. Experimental Results

Tests carried out show how the hydrogen-based supply system presents a suitable response to the load current requirements. The maximum efficiency is equal to 76,3% and it is obtained for a load value equal to 10Ω with a distance equal to 1 cm and no misalignment. In the next figures, the efficiency is shown in dependence to the distance and the misalignment for two different load conditions. It is important to notice how efficiency decreases in general with the increase of distances and misalignment. Besides, with a load value equal to 2Ω, even though the maximum efficiency value is low, equal to 64,7%, its dependence with distance and misalignment is not significant if compared to the case of 10 Ω load, for which the system reaches its maximum value. As a matter of fact, the in the distance range from 1 cm to 4 cm, for the 2Ω load, the maximum efficiency variation is equal to 7,2%

while for the 10 Ω load, it is equal to 24,3%. As for the misalignment range from 0 cm to 4 cm, the maximum efficiency variation for the 2 Ω load is equal to 2,1%, while for the 10 Ω load, it is equal to 23,3%. It is a significant result that shows how, external factors such as misalignment and distance cannot be neglected and that a correct load matching is required in the design stage of the system.

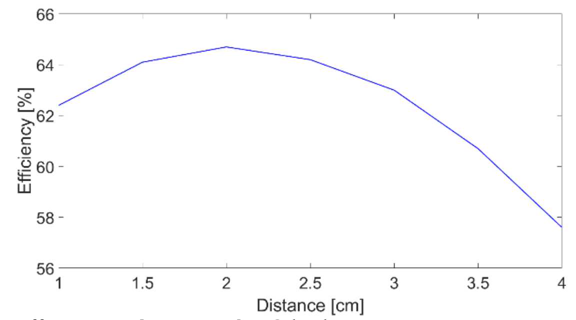

Fig. 9. Efficiency vs distance with 2 Ω load.

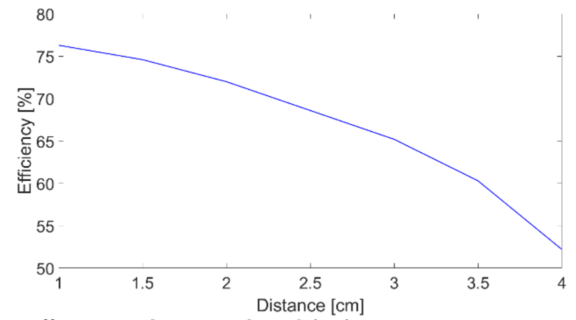

Fig. 10. Efficiency vs distance with 10 Ω load.

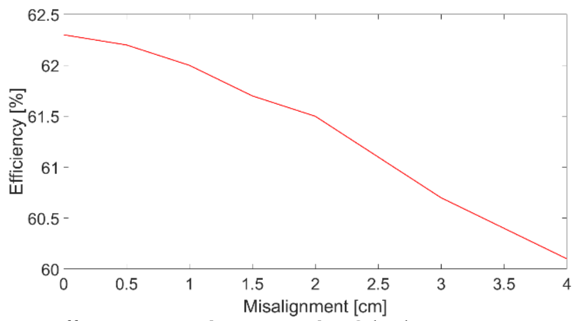

Fig. 11. Efficiency vs misalignment with 2 Ω load

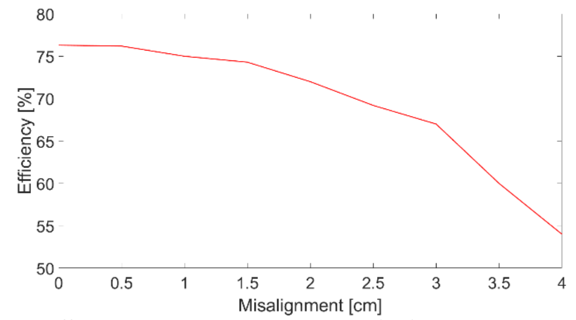

Fig. 12. Efficiency vs misalignment with 10 Ω load

VI. CONCLUSIONS

In this paper, a low power prototype of a hydrogen supplied Wireless Charging System is presented and characterized. The IPT system represents an innovative solution in terms of safety and comfort, the hydrogen-based supply system allows the installation of the whole system in not electrified areas. The hydrogen refill can be obtained thanks to an electrolyser supplied by a low power photovoltaic panel, cheaper than a traditional photovoltaic plant paired with a traditional battery. The hydrogen-based system was chosen and customized to the IPT system requirements. The experimental tests confirmed the possibility of employment of this kind of technology as a valid solution for grid-disconnected systems. An efficiency analysis of the IPT system was carried out showing how wireless charging system is a valid and concrete solution for the EVs charging, presenting high values of efficiency, even though a correct load matching is needed because external factors such as distance between coils and misalignment cannot be neglected inasmuch they affect efficiency.

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