A Plug-In Hybrid "Blue-Angel III" for Vehicle to Grid System with a Wireless Grid Interface

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Abstract— **Vehicle to grid (V2G) concept is becoming increasingly popular, but it essentially requires some form of a power interface between the electric vehicle (EV) and the grid. In contrast to wired power interfaces, a user-friendly and secure wireless interfaces with no physical contacts are preferable. This paper presents a V2G system that comprises of a plug-in hybrid vehicle, called Blue-Angel III, and a wireless power interface for grid integration. Blue-Angel III uses a Li-Ion-Supercapacitor energy storage and a wireless power interface, which is based on inductive power transfer (IPT) technology, facilitates the power exchange between the grid and Blue-Angel III. This paper details the structure, control, energy storage and management, and communication protocols of the hybrid Blue-Angel III, and discusses design aspects of the 2kW bi-directional IPT power interface of the proposed V2G system. Simulation results under various conditions are presented to show that the proposed wireless and bi-directional IPT interface is ideal for the grid integration of Blue-Angel III and EVs.**

I. INTRODUCTION

Decentralized energy production or Distributed Generation (DG) and use of vehicle-to-grid (V2G) plug-in electric vehicles can be considered as partial solutions to the global energy crisis at present. The benefits of DG, even at residential power levels, have become more and more apparent and are widely accepted, and as such their usage has risen and is expected to continue [1-5]. One major outcome of the wide acceptance and usage of DG is the vehicle to grid (V2G) concept, which uses plug-in electric vehicles (EV) to store and supply energy to the grid. EVs are becoming increasingly popular but essentially require some form a power interface to be used in the V2G concept. Most existing systems use a 'hard-wired' power interface to couple the EV to the grid but such systems pose many disadvantages. For this reason, the focus is now for the use of wireless power transfer techniques for the grid integration of EVs. Amongst the limited 'wireless or contactless' power transfer techniques that are available, the inductive power transfer (IPT) technology can be regarded as a technique that has been widely accepted for numerous industry applications [6-10].

This paper presents a V2G system with a wireless power interface for grid integration. The proposed V2G system consists of a hybrid car, called Blue-Angel III, and a 2kW bi-directional IPT power interface to facilitate the grid integration. Blue-Angel III uses a Li-Ion and Supercapacitor system as its energy storage, and the IPT technology to realize the 'wireless' grid interface. A super-accumulator-module (SAM), located inside Bleu-Angel III, oversees the overall operation of the proposed V2G system, which is intended for residential use.

II. BLUE-ANGEL III

Blue-Angel III, shown in Fig. 1(a), is a custom made hybrid electric vehicle, which has only two seats. It is ultra-light in weight in comparison to similar sized car in the market. Blue-Angel III is powered by an energy storage, comprising Li-Ion batteries and Supercapacitors, which has a capacity to commute for 64 km. The energy storage, shown in Fig. 1(c), is managed by a Super Accumulator Module (SAM), shown Fig. 1(d), which also oversees the operation of the 2kW bi-directional IPT interface, which is described in Section III.


(a)


(b)


(c)

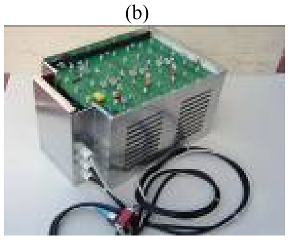
(d)

Fig. 1 (a) Blue-Angel III (b) MMI in Blue-Angel III (c) battery module for SAM 4th Generation. (d) SAM for Blue-Angel III

As a plug-in-hybrid electric vehicle (PHEV), Blue-Angel III is intended to facilitate the actual and future storage capacity. The user is expected to enter his intentions, by using MMI with Touch screen in Blue-Angel III, shown in Fig. 1(b), for the usage of the car: for example, entering the

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approximate time and duration/distance of the next trips for the entire day.

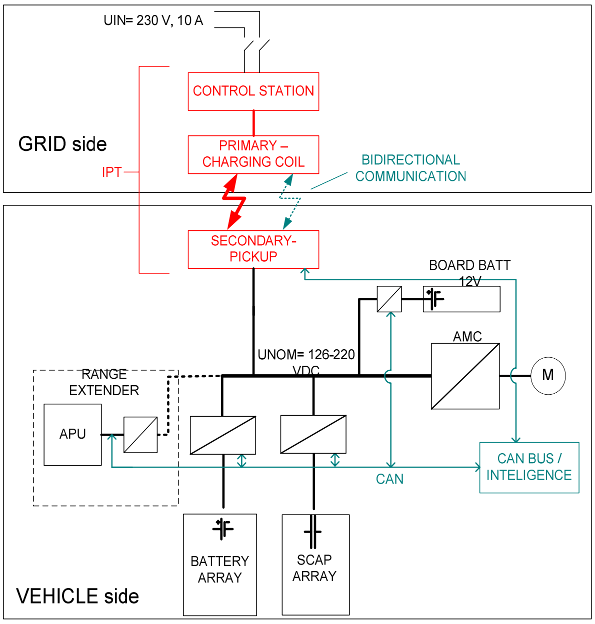


Fig. 2 The V2G system of Blue-Angel III with an IPT interface.

A minimum capacity, which should always remain in the SAM, is also entered. This data, together with actual capacity and status data of the car as well as its position, is periodically and wirelessly transferred to a server, which holds a database of a cluster of PHEVs. In the same database, data from relevant DGs are regularly updated. All these data will be accessible through a web interface. The PHEV user can log in to the server to modify his own usage pattern of the vehicle. At the same time, the utility supplier may offer different tariffs for sold or bought energy by the user. The tariffs may not only be related to the time of the day at which the energy is consumed or produced, but also to the maximum power or energy that is available or consumed. All these possibilities will provide many new market possibilities for the energy suppliers, which, in turn, will result in benefits for the user. By adapting his usage pattern, the user can optimize his cost for PHEV mobility. Based on the server information, the regional energy supplier can decide, which storage capacity of which PHEV should be used to regulate the grid. The commands to discharge or charge the battery of a PHEV is again transferred via the wireless data link. Communication between Blue-Angel III and EEMU (located in the building, part of the power module) is performed via a CAN protocol. The vehicle integrates Li-Ion-batteries with high specific energy and electric double layer capacitors (Supercapacitors) with high specific power in a combined energy buffer called "Super Accumulator Module" (SAM) [12]. Peak power transients are covered by the Supercapacitors while the batteries deliver the required base energy at lower power compared to the Supercapacitors. An alternative power unit (APU), formed by an internal combustion engine acts as a range extender and delivers additional "base" energy.

Unlike batteries, supercapacitors themselves cannot be integrated into the drive system. It is necessary to have well developed modules that control over voltages, fulfill charge balancing and have adequate supervision circuits. The advantage of very high power density of Supercapacitors often has to be combined with those of batteries. Therefore, the possibility of combinations of batteries with Supercapacitors is important, too. Furthermore, the mounting and packaging have to be performed in a way to minimize the maintenance, and these aspects are managed by the SAM [13-16].

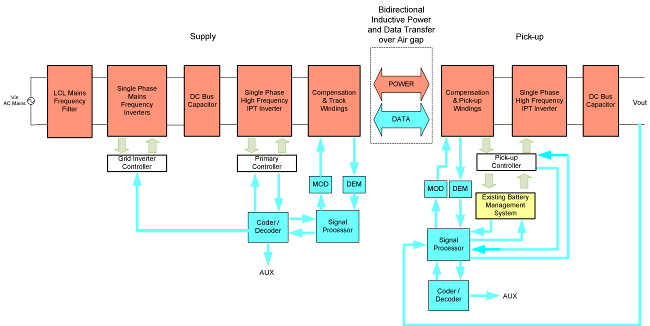
As already mentioned, SAMs cannot be considered to be isolated elements. They are only parts of several sources and drains. To control the energy flow of the drive system in the electric vehicle, SAMs must interact with other sub-systems, and this is achieved through energy management. A schematic of the proposed V2G system is shown in Fig. 2. Together with the proposed IPT unit, Blue Angel III is currently equipped with 4th generation SAM, which is a further improvement of the 3rd generation SAM [17]. SAM 4th generation implements an advanced state of health SOH determination.

III. IPT WIRELESS POWER INTERFACE

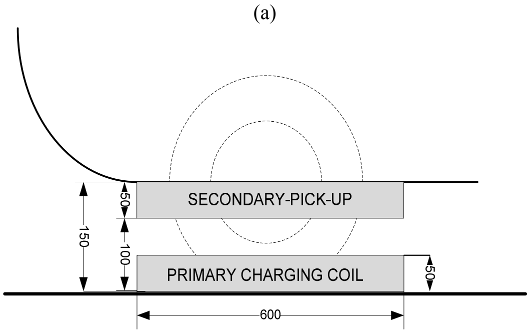
The proposed bi-directional IPT system, shown in Fig. 3, consists of two sub-modules, a primary charging coil or pad located on the grid side and a secondary pick-up coil, which is placed under the electric vehicle or Blue-Angel III. The power is transferred from the grid side coil to pick-up across an air-gap. The primary coil is placed on the grid side and is connected to the grid via an appropriate power converter while the pick-up coil is connected to the vehicle's DC-link, V_{DC}, via an appropriate power converter. The specifications of the proposed 2 kW IPT system are given in Table 1.

The driver takes the first step in charging cycle by parking the vehicle in a charging station and aligning the primary charging coil in the station and the on board secondary pick-up coil accurately enough to allow effective power transfer. A number of steps can make the alignment easier and more precise, for example, the driver brings vehicle in optimal position with help from position sensors. Several types of digital communication links between the vehicle and the charging station (e.g. infrared, RF, ultrasonic) can be used to identify the vehicle in the station. This control function needs only a low-level signal to activate (turn on) or deactivate (turn off) the charging station.

When the vehicle is parked at a charging station, the on-board charging system initiates a charging cycle and, when the whole charging cycle started, rectifies the incoming power from AC to DC which comes through the inductive power coupling. The charging station on grid side monitors and regulates the charging voltage, and terminates the charging cycle when the battery is fully charged or when the vehicle prepares to leave the charging station.



(a)



(b)

Fig. 3 The IPT system (a) schematic (b) physical layout

Table 1 : System parameters

Input voltage	V_{in}	230 VAC
Input current	I_{in}	10 A
Power factor	cosφ	>0.95
Output voltage	V_{out}	126…220 VDC
Output power	P_{out}	2 kW
Charging current	I_c	~ 10A
Load regulation range	-	10…100%
Efficiency	η	0.85 (50mm air gap)

A bi-directional communication system is required between the charging station and the pick-up to allow the charging station to control the charging process based on battery parameters from the SAM and vehicle's management system. Previous solutions of the bi-directional communication have used radio or infrared links for communication between the pickups and the charging stations or a separate coil for the communication integrated in the same core with power coil. This system attempted to reduce the component count by modulating the data on the same signal as the power. The two different modulating processes are used. Communication from the primary to the secondary is achieved by a process called Amplitude Shift Keying and from the secondary to the primary by a process called Load Shift Keying. Signals are decoded by filters and comparators, which feed a digital signal to the microcontrollers.

A manually operated switch in the driver's control display allows the driver to stop a charging cycle for any reason. The panel graphically displays the degree of battery charging level. The charger controls on the vehicle will include programmable logic that will accommodate additional control functions (e.g. charging only during hours of low demand on the utility system, when electricity rates are lowest).

IV. Results

A 2 kW bi-directional IPT system, as shown in Fig. 4, is designed for the specifications given in Table 1.

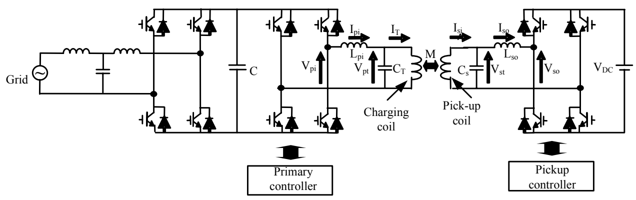
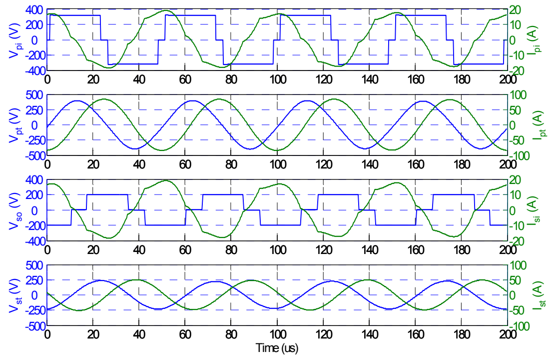
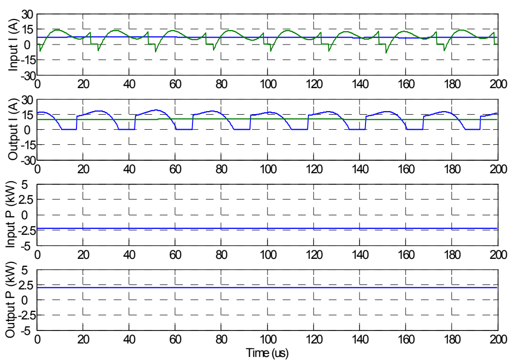


Fig. 4: A 2kW bi-directional IPT system

The simulated performance of this system under various conditions is presented below.



(a)



(b)

Fig. 5 Waveforms when Blue Angel III is charged at the rated power

Fig. 5(a) shows the resonant voltage and current waveforms of the IPT system when the batteries and Supercapacitors are charged at full power. The pick-up side controller is operated at the unity power factor and. A constant current of 65A is maintained in the primary track by the primary controller while the pickup controller is operates pick-up side inverter at unity power factor to maintain the output at rated value. The power flow is regulated through the control of the voltage magnitude. The power output and charging current are shown in Fig. 5(b) to show that Blue-Angel III is charged at 10A.

Operation of the system at 50% of the rated charging rate is shown in Fig. 6. In this situation, during which the SAM module decides to charge Blue-Angel III at a lower charging rate, the output current reference has been changed from 10A to 5A, and the primary track current has been reduced to 35 A to reduce the standing losses of the system under this low power conditions. It is assumed that both the track and the pickup has equal conduction losses and therefore the optimum operating point is achieved when both coil windings share equal currents.

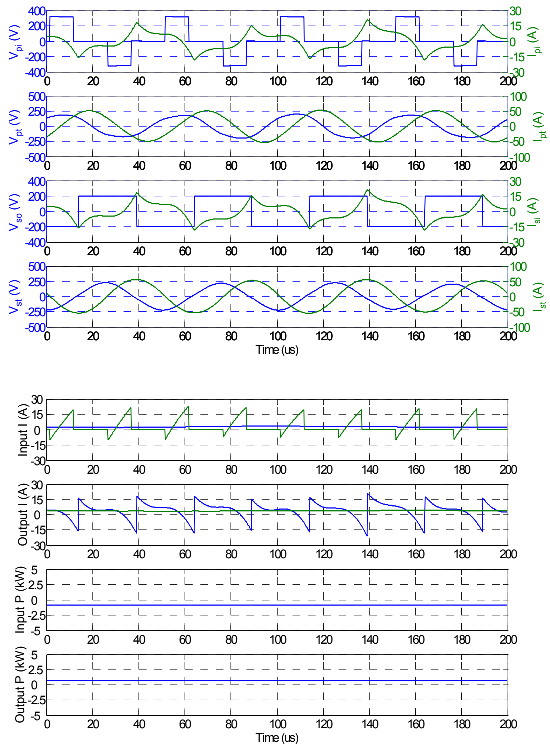


Fig. 6 Waveforms when Blue-Angel III is charged at 50% of the rated power

Fig. 7 shows the waveforms of the system during the reverse power flow, which is realized by controlling the phase angle between the primary and pick-up side inverters. In this situation, the battery discharges, supplying power to the grid.

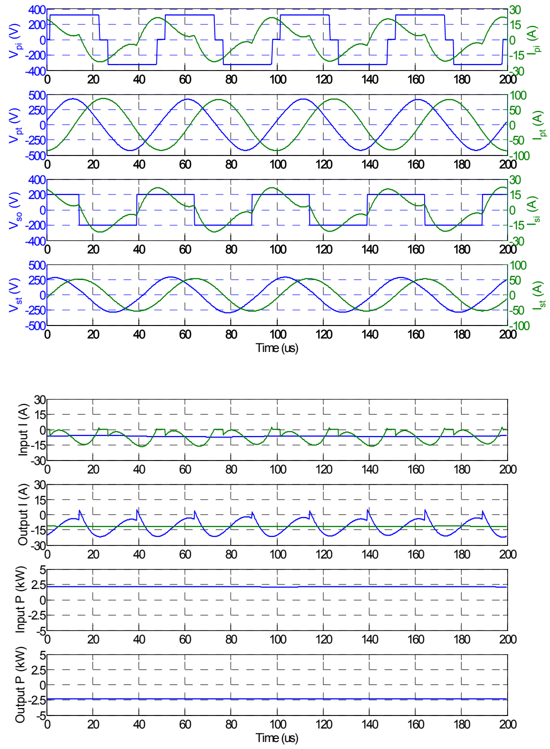


Fig. 7 Waveforms when Blue-Angel III supplies power to the grid

V. Conclusion

A V2G system with Blue-Angel III as the EV has been presented. Such a system is a part of a ‘living & mobility’ system, which has a novel multi-purpose in-house power interface with plug-in hybrid vehicle Blue-Angel III. The ‘living & mobility’ project represents one of the core strategies of the “Lucerne University of Applied Sciences and Arts”. The proposed V2G system uses a bi-directional and wireless power interface, based on IPT technology, to facilitate the controlled power flow between Blue-Angel III and the grid. Simulated performance of the bi-directional power interface has been presented to viability of the proposed V2G system.

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