DESIGN OF BI-DIRECTIONAL POWER CONVERTER FOR VEHICLE-TO-GRID CAPABILITY OF REACTIVE POWER COMPENSATION

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ABSTRACT
The main objective of the paper is to design an Power transfer from Vehicle-to-Grid which consists of a bi-directional ac <-> DC bridge. The paper is divided in two parts: Reactive Power compensation and Bi-directional Conversion. Typically, the bidirectional power transfer stands for two-way transfer of active power between the charger and the grid. The general term of sending active power from the vehicle to the grid is termed Electrical Vehicle (EVs) to Grid (V-G). This revision shows the effect of reactive power operation on the design and operation of single-phase charger that are suitable for reactive power support. Moreover, the interface between the power grid and the EV, instead of using typical power converters that only work on unidirectional mode, need to use bidirectional power converters to charge the batteries Grid-to-Vehicle (G2V) mode and to distribute part of the stored energy in the batteries back to the power grid Vehicle-to-Grid (V2G) mode. With the bi-directional power converter topology presented in this paper, the consumed current is sinusoidal and it is possible to regulate the power factor to control the reactive power, targeting to contribute to moderate power quality problems in the power grid. To consider the behaviour of the presented bi-directional power converter under different scenarios, are presented some computer simulations and experimental results obtained with a prototype that was developed.

Keywords — Reactive power control, Bi-directional Battery Charger - Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) charging.

INTRODUCTION
Nowadays, the modern and enormous investments in electric flexibility, mainly in Electric vehicle sales are estimated to increase in the upcoming years as a cost-effective another to conventional internal combustion engine vehicles. EVs present a more efficient operation and thereby, have increased fuel cost savings. However, huge number of EV connection to the electricity network increases concerns about reliability of the grid especially at the low voltage distribution network due to substantial increase in the peak load.

The explosion of EVs will underwrite do reduce the strong dependence from oil and other fossil fuels, allowing an actual reduction in the emissions of greenhouse gases. This way the influence of the vehicles sector in the climate change will be reduced. However, for the electrical power grids EVs will be extra loads, which will consume energy to charge their batteries, and in many cases at the same time, and connected to the same distribution transformer.

With the electric stored energy in the batteries of EVs, rises a new concept in the electrical power grid market denominated Vehicle-to-Grid (V2G). In this logic, besides the battery charging mode, denominated as Grid-to-Vehicle (G2V). Aboard chargers convert the ac grid voltage into dc, and they normally have unidirectional power transfer capability. Using a more advanced topology and controller compared to conventional methods available in the market, the charger can also supply power quality functions such as reactive power
compensation (inductive or capacitive), voltage regulation, harmonic filtering, and power factor correction. The combination of EVs in the power grid, in order to implement the V2G concept, it is necessary the use of bidirectional power converters.

The concept of the bidirectional charger with V2G technologies is introduce in Fig. 1. When the EV is connected to the power grid the energy can flow to or from the EV batteries (G2V and V2G). In the absence of power grid or power outages, the EV can operates as voltages source to feed the desired loads. Today, in the utility grid, reactive power consumed at the residential load is compensated using capacitor banks, static VAR compensators, static synchronous compensators, etc. But, benefit of the reactive power very close to the residential load is more efficient and reduces the installation and maintenance costs associated with the said devices.

In this paper is presented the development of a bi-directional power converter to charge the batteries through the concept Grid-to-Vehicle (G2V), and to deliver back to the power grid a small amount of the stored energy in the batteries, according to the power grid requirements and with the user agreement, through the concept Vehicle-to-Grid (V2G). The bi-directional power converter was designed to preserve the power quality of the electrical power grid through sinusoidal current consumption, with controlled power factor, allowing the control of the active and reactive power. It also was designed to allow charging the batteries with different modes, based on different voltages and currents levels, marking to preserve the batteries lifetime. In order to confirm the different modes of operation, in a first stage the bi-directional power converter topology and the control algorithms were validated by computer simulations and then were validated through experimental results with the developed prototype.

BIDIRECTIONAL BATTERY CHARGER TOPOLOGY The presented battery charger is composed by two power converters that share a DC link. One is to interface the power grid and the other is to interface the power batteries. In order to interface the power grid is used a full-bridge AC-DC bidirectional converter. This converter can operates as active rectifier with sinusoidal current and uniform power factor during the G2V operation mode. During the V2G operation modes this power converter operates as inverter. In the V2G mode the converter operates as controlled current source to inject the required power in the power grid.

In order to interface the batteries is used a reversible DC- DC converter. In the G2V operation mode this converter operates as buck converter to control the current and voltage during the current and voltage batteries charging stages, respectively. During V2G the converter operates as boost converter to raise the batteries voltage to an adequate DC link voltage aiming to agreement the proper operation of the full-bridge AC-DC bidirectional converter. The complete electric diagram of the bidirectional battery charger is presented in Fig.

2. Although using two bidirectional converters, the required hardware is equivalent to a controlled bridge.

With Energy Storage Systems (ESS), such as chemical batteries, compacted air tanks, it is possible to maintain the stability of the power grid, mainly to improve the use of renewable energy sources it is possible to store the energy produced when the demand is low in order to be used later when the demand increases. Since in average most of the vehicles, are parked for long time periods, their batteries can be used as ESS, receiving energy during the excess of production and delivering energy back to the electrical grid during the period of great demand, balancing the energy production and consumption. In this context, these vehicles are also useful to stabilize the intermittent production and
A. Power regulator

It is an electronic circuit that delivers a stable dc voltage independent of the load current, temperature and ac line voltage variations. Its designed to automatically maintain a constant voltage level. They may use a simple feed-forward design or may consist of negative feedback. It may use an electro-mechanical mechanism, or electronic components. Depending on the design, it may be used to regulate one or more AC or DC voltages. In regulation is a measure of change in the voltage magnitude between the sending and receiving end of a component, such as a transmission or distribution line. Voltage regulation describes the capacity of a system to provide near constant voltage over a wide range of load conditions. The term may refer to a passive property that results in more or less voltage drop under various load conditions, or to the active interposition with devices for the specific purpose of adjusting voltage.

\[ I_d = \frac{2}{3} \text{[cos}\theta \cos(\theta-2\pi/3) - \cos(\theta+2\pi/3)] [a b c] \]
\[ I_q = \frac{2}{3} [-\sin\theta - \sin(\theta-2\pi/3) - \sin(\theta+2\pi/3)] [a b c] \]

B. Current regulator

The control of voltage and reactive power is a major issue in power system operation. This is because of the topological differences between distribution and transmission systems, different approaches have changed. This contains contributions of unique reactive power control and voltage stability schemes for distribution and transmission systems.

dq reference frame will be change into

1. SIMULATION OF THE V2G REACTIVE POWER CONTROL

The total controller of the system should contain various additional controllers in adding to the previously defined current controllers for dc-ac converter. The leading goal of the controller is to follow active and reactive power instructions that are sent by the value. So, additional controller loops are required to make sure that the charger always consumes the active power and reactive power levels requested by the utility.

![Overall Stimulation diagram of Reactive power control](image)

If the dc-link voltage drops below \( V_{dc \text{ ref}} = 120 \text{ V} \), the

\[
\text{abc} = i_d *(k_p e + k_i \theta e dt)
\]

\[
\text{Sin}_\text{cos} = 2\pi ot*(i_q *(k_p e + k_i \theta e dt)
\]

They gives to abc frame then control frequency, abc

\[
= 60+(\pi/180)
\]

battery charging current decreases to increase the dc-link voltage back to 120 V. Consequently, when the dc-link voltage stays at \( V_{dc} \), A synchronize with the grid voltage phase angle and instantaneous pq power theory is used to compute the average active and reactive power value including their directions. To achieve both operations, quadrature axis is required.

Table 1. The parameters used in system
II. DEVELOPMENT OF THE BI-DIRECTIONAL BATTERY CHARGER PROTOTYPE

Thus, in this section is described in detail the bidirectional power converter and the digital control system developed.

A. Bi-directional Power Converter

As discussed before, the presented battery charger is composed by two bidirectional power converters, one DC-DC and the other AC-DC. To the AC-DC bidirectional power converter was used the switching method Periodic Sampling based on the Direct Current Control. This technique does not work at fixed frequency, but it establishes a maximum frequency limit, which in this case. On the other hand, to the DC-DC converter was used the switching technique Pulse Width Modulation (PWM), which works with a fixed frequency. The bidirectional flow of energy is obtained through the adequate control of the MOSFETs.

B. Digital Control System

The control system, which equipment the algorithms during the operation as G2V and V2G, is composed by several electronic circuits with analogue and digital signals. The control algorithms of the developed digital control system were implemented in a Microcontroller. The internal ADCs receive the voltages and the currents signals that are provided by the signal conditioning circuit, and in conjunction with the external interface, generate the control signals to the understanding circuit.
### III. EXPERIMENTAL RESULT

In this Section are presented the experimental result obtained with the developed battery charger with bi-directional power converter considering the operation.

![Switching mode of operation](image1)

**Fig. 12. Switching mode of operation**

![Inverter output](image2)

**Fig. 13. Inverter output**

### IV. CONCLUSIONS

In this paper was presented a battery charger allows the interaction with the power grid to charge the batteries Grid-to-Vehicle (G2V) mode and to deliver part of the stored energy in the batteries back to the power grid Vehicle-to-Grid (V2G) mode. In description the bidirectional power converter topology that was presented in this paper, the consumed current is sinusoidal and it is possible to control the reactive power, leveling to give to moderate power quality problems in the power grid.

In a first section, the behavior of the bidirectional power converter was evaluated under different settings through computer simulations. Then the performance of the bidirectional power converter was evaluated with a prototype. In this paper were presented the simulations and experimental results obtained.

### REFERENCES


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