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POWER CONDITIONING WITH ELECTRIC CAR BATTERY CHARGING FROM RENEWABLE SOURCES

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A control method for electric car battery charging combined with small domestic power plants using renewable energy is described in this paper. This method is not only capable of optimizing the working point and charging current of the system but also implements robust energy flow control to balance the convenient process variables.The proposed controller has been investigated by simulation in Matlab environment, and as a result, succesful combination of a grid synchronised inverter and a electric car battery charger robust operation could be achieved in changing operational modes.

Keywords: power quality, electric car, battery charging, simulation, nonlinear distortion, renewable power sources

Introduction

With the price of electrical energy rising the small domestic power plants are coming into general use in the European Union too (in the range of 1–5 kVA). The isolated working mode of these plants is not an efficient way since the cost effective energy storage is not a solved problem yet. On the other hand the electric cars development turns to be general in vehicle industry.

These two problems can be handled jointly, since the optimal working point of the renewable power source (photovoltaic panel or wind generator) and the optimal charging current of the Li-ion battery can only be optimized jointly. The optimal working point is important for the economical operation, the optimal charging current is important for extending the lifetime of the expensive electric car batteries. The optimal working mode sometimes needs additional electrical power, sometimes gives remaining efficient power and theese need additional storage capacity.

Grid tie inverter systems can be used to inject the spare power to the local low voltage mains. This power is utilized in the local neighborhood, not far from the injection point so the loss is small. In addition, the construction of this type of inverters makes them suitable for conditioning the line, correcting the accurate voltage forms, and repairing the reactive power in the mains. Therefore, this additional functionality doesn't need expensive change of the constructions, we should only modify the control methods and regulators to develop the ability of line conditioning. The cost of changing the controlling processor and control software negligible to the cost of equipment.

On the other hand with high percentage of fluctuating renewable energy sources the connected electric car batteries can absorb peaks of power production or feed the power into the grid [12].

Several papers deal with power injection to the grid, see e.g. [1] for a recent survey. The possibility of power factor correction in conjunction with power injection has also been realized [2, 3, 5]. Furthermore, its connection with nonlinear distortion reduction has also been explored [6] and [8]. In [6] and [8] the authors use the DSP based current control technique for distortion reduction with active power filters (APF) for compensating an exact nonlinear load. Sensing the nonlinear current time function and the ideal sinusoid current with phase locked loop (PLL) technique, they inject the exact deviation current into the grid with radical distortion reduction.

The aim of our work has been to develop and investigate control methods for performing active power factor correction and lowering the extant harmonic distortion in the line without the need for current measurement. As our earlier papers show [9, 11], this aim can be achieved in addition to control the maximum power operating point from the renewable source (wind generator or photovoltaic panel) by adding new elements to the schematic construction designed for the built-in elements.

The aim of this paper is to develop an improved construcion of combination of a small domestic power plant and battery charger components and to investigate the robustness of the proposed method with respect to working mode changes of the system consisting of a renewable source, an electric car battery charger and the nonlinear distorted low voltage electric network.

Background and motivation

The use of low consumption equipments with simple switching power supplies (mobile phone chargers, notebooks, networking products, small variable frequency motor drives, telecommunication consumer electronics) A capacitive load with high nonlinearities creates significant 3rd and 5th upper harmonic current components, which cause serious distortion in the voltage shape. It is well-known, that it is difficult to compensate the reactive power of this type of nonlinear distorted voltage shape with traditional shunt capacitances (compensator).

The distortion of the voltage shape is commonly characterized by the overall reactive power

$$Q_B = \sum_{k=1}^{n} Q_k = \sum_{k=1}^{n} \frac{|\hat{V}_s(k)|\,|\hat{I}_l(k)|\sin\phi(k)}{2}$$

where the positive integer n is the (highest) number of harmonics of interest, Q_k, $\hat{V}_S(k)$, $\hat{I}_l(k)$ and $\phi(k)$ are the the reactive power, the source (s) peak voltage, the load (l) peak current and the phase-angle difference of the k-th harmonic, respectively. The power factor (PF) of the source is defined by [3] as

$$PF = \frac{\langle V_s, I_s \rangle}{\| V_s \| \cdot \| I_s \|}$$

where $P = \langle V_s, I_s \rangle$ is the active (real) power and the product $S = \| V_S \| \cdot \| I_S \|$ is the apparent power calculated from effective values. From the Cauchy-Schwartz inequality, it follows that $P \le S$. Hence $PF \in [-1,1]$ is a dimensionless measure of the energy-transmission efficiency. The total harmonic distortion (*THD*) is defined as [5]:

$$THD = \sqrt{\frac{\sum_{k=2}^{\infty}(|V_k|^2)}{|V_1|^2}}$$

where V_1 equals to the voltage amplitude of the fundamental frequency and V_n is the voltage amplitude of the n-th harmonic. In applications with capacitive input stage, $THD > 0$ holds.

Upper harmonic components have many undesirable effects on power grid [11] causing faulty operation of the network.

Problem statement

As it is indicated in the above discussion, it is desirable to develop a control method that can compensate the distortion caused by the capacitive nonlinear load using the built-in and available controller of electric car battery charger combined with small domestic power plants. The controller unit of these plants can be extended with three new elements to form a complex multifunctional controller unit.

The first function of this complex control unit is a conventional **maximum power controller** that is used to inject base harmonic in phase with the sinusoid current to the mains. The second function is a conventional **charger controller** that controls the convenient charging current value. The third function, that is to be implemented, is the **compensation of the undesirable effects of the linear network** with production base harmonic current being not in phase, by injecting reactive power to compensate the inductive and capacitive loads. The third function to be implemented would be the **compensation of the nonlinear distortion** that is intended to achieved by injecting upper harmonic (mainly 3rd and 5th, but possibly higher) sinusoid current components to reduce the harmonic distortion and to lower the reactive power of the upper harmonic load currents.

Our aim has been to implement the missing three elements and their relationship, the simplest possible way. The main goals of the three new elements are to approach unity power factor for the overall system for the range of the possible loads and working modes, and to reduce THD. There is a trade-off between these goals that should be taken into account. The intervention to these factors is limited by the renewable source maximum power point, the semiconductors of the bridge and the serial inductances, as well as by the speed and cycle time and the computational capacity of the control device. The optimum would be to have a unit PF and zero THD, but unfortunately, this optimum is not achievable in practice, just approachable. The practical aim is to compensate the upper harmonic component. These values will be used to reduce the nonlinear distortion at the output.

Structure of the multifunctional complex controller

A simple model of the grid tie inverter [2] is used for the controller structure design, that is shown in *Fig. 1*. It contains a simple booster stage with an IGBT bridge, connected to the grid through serial inductance.

The control system is divided to six main functional parts as shown in *Fig. 2* in shadowed boxes.

- **Maximum power controller**

It is a general part of the control system, independent from the other control parts. Its' only task is to operate the renewable power source (photovoltaic panel or wind generator) at the optimal working point in any wind and solar condition to get the maximal amount of electric power from the source.

The output of the maximum power controller is the input current setpoint of the inverter. The input current control is a simple on/off switching nonlinear hysteresis controller [6].

- **Charger controller**

This part of the control system is also independent from the other control parts. It is responsible for controlling the Bulk converter's switching element S6 *(Fig. 3)* to adjust the convenient charging current value of the Li-ion battery. The current control is also a simple on/off switching nonlinear hysteresis controller [6].

- **Intermediate voltage controller**

It senses the intermediate voltage, and observes the difference between the measured and the setpoint value. The controller changes the fundamental harmonic amplitude of the injected current using a simple P controller based on the difference. Upper harmonic components have no effect on the intermediate voltage so they are not used by the upper harmonic controller. The controller adjusts the effective power injection to the grid in each 20 ms cycle.

- **Upper harmonic controller**

The main controller of the complex multi-functional unit is the upper harmonic controller. Its' inputs are the computed 3rd, 5th, 7th, 9th and 11th upper harmonic component amplitudes of the measured voltage, the outputs are the output current base, and its 3rd, 5th, 7th, 9th and 11th upper harmonic components' amplitudes and phases. These currents are used for compensating the nonlinear distortion using an advanced controller (see details in [9, 11]).

- **Current waveform generator**

This block will calculate the necessary exact time function of the output current setpoint, which is the setpoint of the bridge current controller.

- **Bridge controller**

It calculates the difference between the measured output current and the output current setpoint, and switches the IGBT bridge two half's control signal (S1-S4, S2-S3) on and off in alternate way using a simple Schmitt trigger comparator, that realizes a simple on/off switching hysteresis controller [6].

The above blocks influence each other directly, and also through some measurable voltages and currents of the inverter (see *Fig. 4*).

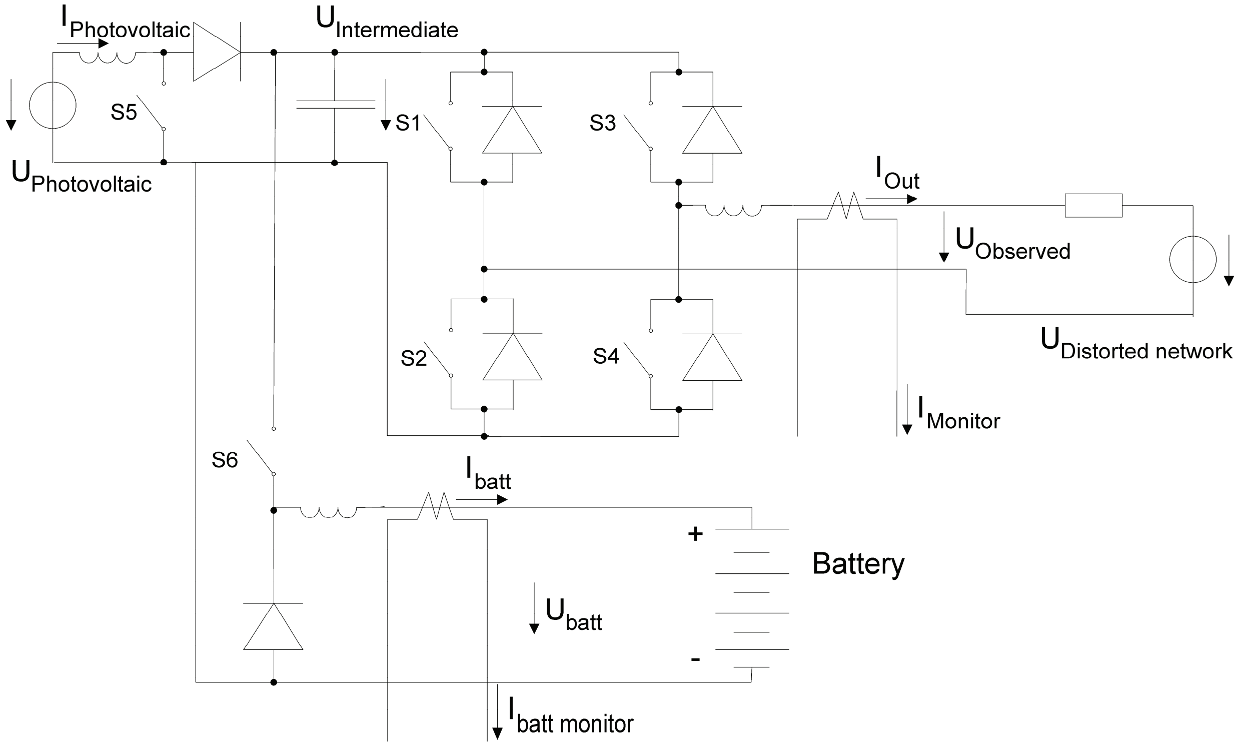

Figure 1: Grid Tie Inverter model

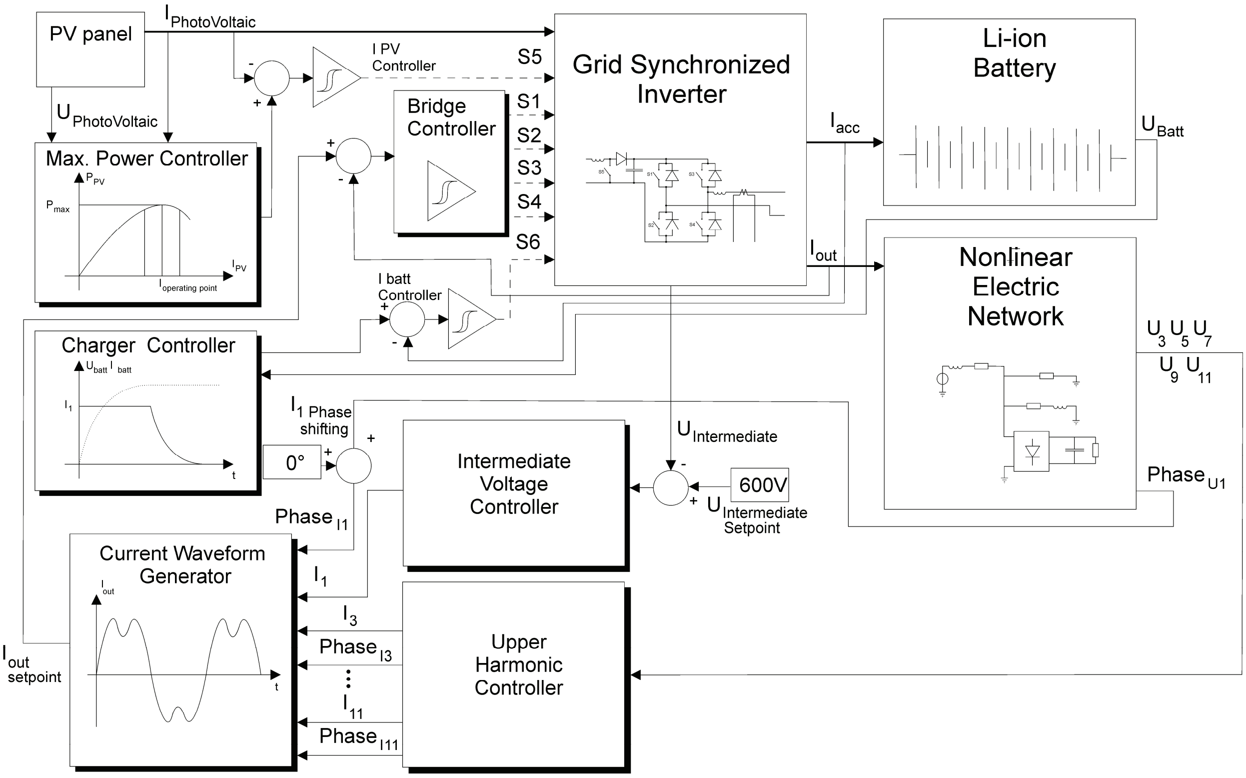

Figure 2: Control Flow Chart diagram

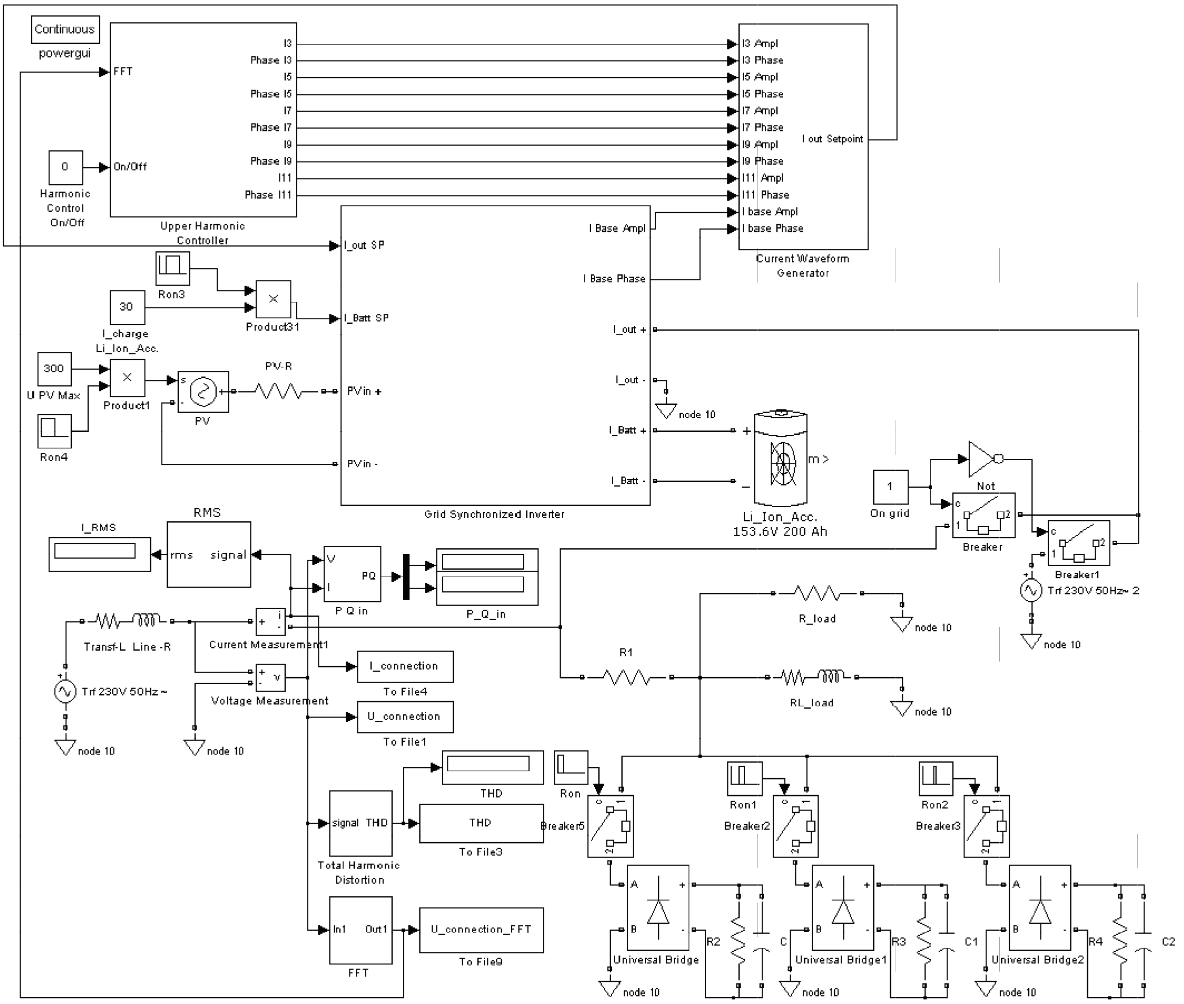

Figure 3: System Matlab Simulink model

Modeling and simulation

The mathematical model of the nonlinear distorted network has been implemented in Matlab Simulink using the Power Electronics Toolbox [7]. The control flow chart of the complete model can be seen in Fig. 3.

Modeling the nonlinear network and the battery

Three type of loads have been modeled: (i) an ohmic one, that represents, for example, heating devices, traditional bulbs, (ii) an ohmic with serial inductance representing motors and rotating household appliances (washing machine, lawnmower etc.) and (iii) a capacitive input stage load for representing the simple nonlinear switching mode power supplies.

Table 1: Load parameter values

Load	NL1	NL2	NL3
Resistance	25 Ω	50 Ω	35 Ω
Capacitance	10 mF	5 mF	7 mF

The battery has been modeled by the Battery block of Matlab Simulink Power Electronics Toolbox using the following parameters: Nominal Voltage 153.6 V, Rated Capacity 200 Ah.

Simulation experiments

As a first step of model verification, the basic elements of the system, the load part, the maximum power controller, and the intermediate voltage controller have been tested. These results served as reference values for comparison. Fig. 4 shows these simulated voltage and current values as functions of time.

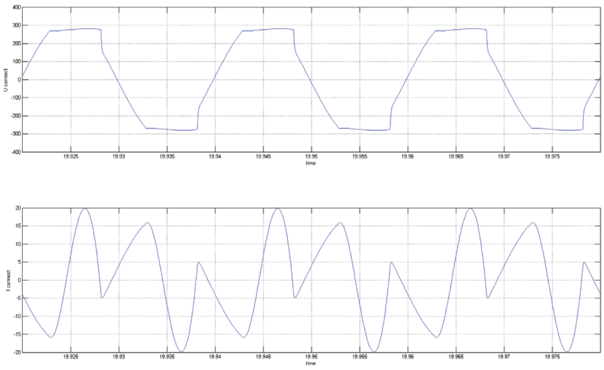

Figure 4: Voltage and Current with Inverter ON

Robustness analysis against the energy flow

The robustness of the intermediate voltage controller against the changing of the energy flow from the sources to the different loads has been examined using the following four cases:

- **Normal inverter mode** The energy flows from the renewable source to the grid only *(Fig. 5)*.
- **Normal inverter and Battery Charger mode** The energy flows from the renewable source to the Li-ion battery and to the grid too *(Fig. 6* and *7)*.
- **Battery Charger mode** The energy flows from the grid to the Li-ion battery only *(Fig. 8)*.
- **Distortion reduction mode** The energy flows from the grid into the intermediate capacitance and from the intermediate capacitance into the grid. The energy balance is zero for a whole period, the active power is zero *(Fig. 9)* [9, 11].

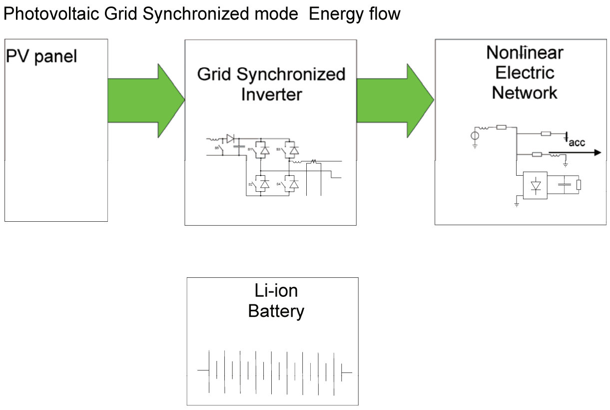

Figure 5: Energy flow: Normal inverter mode

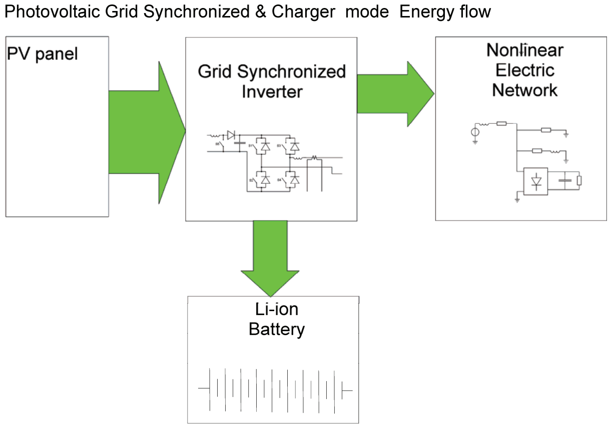

Figure 6: Energy flow: Normal inverter and Battery Charger mode

The robustness analysis has been performed by changing the energy flow modes in subsequent time intervals as seen in *Table 2* implemented by changing the source (U_{0PV}) and load ($I_{BattCharge}$) parameters. The simulation results can be seen in *Fig. 13*, where $U_{Intermediate}$ (the intermediate voltage value of the puffer capacitor) and $I_{BaseAmpl}$ (the amplitude of the base harmonic current component injected to the grid) are plotted as a function of time.

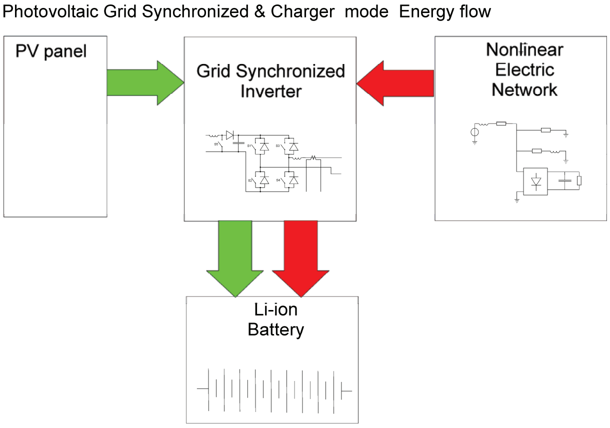

Figure 7: Energy flow: Normal inverter and Battery Charger mode

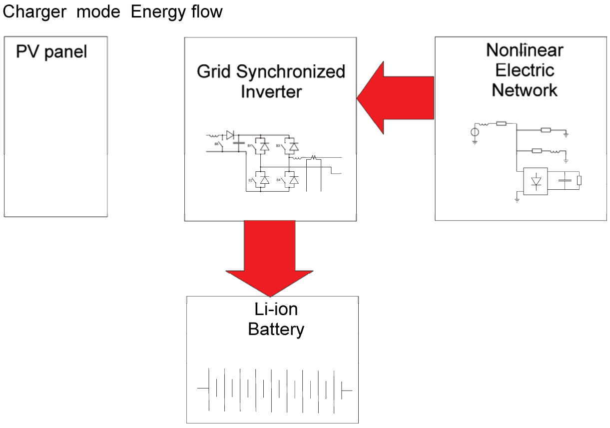

Figure 8: Energy flow: Battery Charger mode

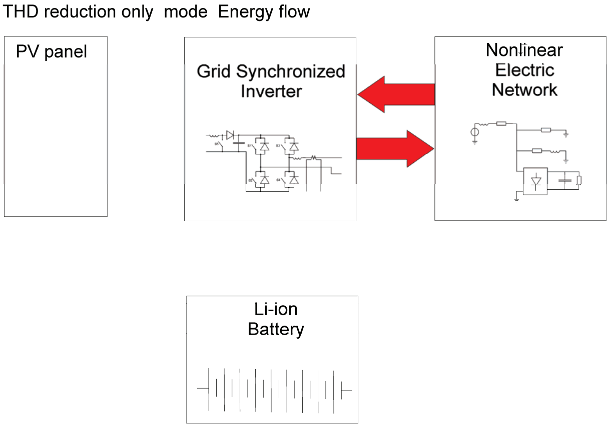

Figure 9: Energy flow: Distortion reduction mode

The controller has been found very robust and tolerant against changing the energy flow mode; the operating mode change transients are monotonous without overshoot. The castor time is less than 0.1 second. A preliminary distortion reduction performance has also been computed in normal inverter mode, the results are seen in *Fig. 10* and *Table 3*.

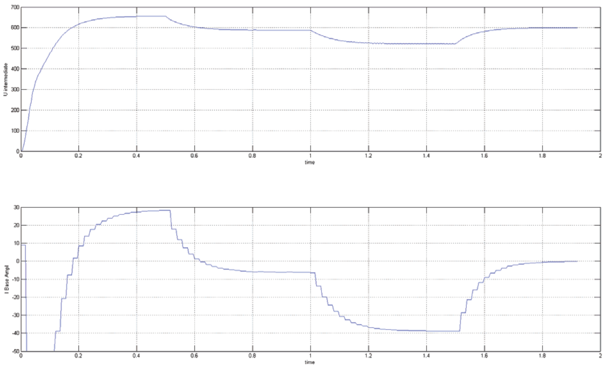

Figure 10: Robustness analysis of the controller

Table 2: Parameters of the robustness analysis

Time	0–0.5 sec	0.5–1 sec	1–1.5 sec	1.5–2 sec
U_{0PV}	300 V	300 V	0 V	0 V
$I_{BattCharge}$	0 A	30 A	30 A	0 A

Table 3: Preliminary performance analysis results in normal inverter mode

Mode	IRMS	Error	THD
Inverter OFF	NI	39.63	14.26%
Upper h.contr ON	5.74 A	3.87	5.23%

Conclusion

A novel control structure for small domestic power plants integrated with electric car battery charger using renewable energy is described in this paper. It is capable of optimizing the working point of the plant and maintaining the convenient energy balance.

The proposed controller has been investigated by using Matlab simulation, and a stable and robust operation has been achieved. Preliminary analysis showed that the extended controller was able to reduce voltage THD almost as much as our previous inverter controller [11].

Future work will be directed towards investigating the effect of the Upper Harmonic Compensation in this combined application using the different source-load modes on the THD and effective current values. Furthermore, a new connection type will be defined to allow the injection of the electric power into the grid from the stored reserve in battery in case of highly fluctuating needs [12].

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