Low Voltage Grid Optimization with Power Injection of Renewable Sources and EV batteries

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The increase of renewable power sources in today's energy production systems results in high non-deterministic fluctuations in energy distribution network. At the same time, the use of nonlinear switching power supplies is more and more widespread nowadays, that creates serious nonlinear distortion in the line. In addition, the insufficient energy storage capacity commonly available in public energy distribution networks makes it very difficult to operate it an efficient and balanced way.

Therefore, a novel control method for combining small domestic power plants using renewable energy and electric vehicle battery chargers where the battery can be used as temporal energy storage is proposed in this paper. The method is not only capable of optimizing the working point of the plant, but also implements active power factor (PF) correction and lowers the extant harmonic distortion in the line. In addition, the proposed control method allows one to create systems that can absorb the peaks of power production, or can feed power back into the grid in fluctuating energy production. The novel element is the voltage level controller which independently optimizes the effective value of the voltage at the connection point. This controls the energy flow direction between the grid, the renewable power source and the EV batteries. The system is able to communicate with an external controller through a Smart Grid Interface to be an element of a larger grid control scheme as an executer part. The proposed controller has been verified by simulation in Matlab environment, and as a result, substantial improvement of the output voltage and current effective value and waveform could be achieved. Robustness of the method against nonlinear loads has also been tested.

1. Introduction

Nowadays the small domestic power plants are coming into general use in the European Union too (in the range of 1kVA-5kVA). 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 vehicle (EV) development turns to be general in vehicle industry. These two elements can be well combined, since the working point of the renewable power source (solar or wind generator) and the charging current of the EV battery can 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 nowadays widespread use of low consumption equipments with simple switching power supplies (mobile phone chargers, notebooks, networking products, small variable frequency motor drives, telecommunication consumer electronics) induses a capacitive load with high nonlinearities, that creates significant 3th and 5th upper harmonic current components and serious distortion in the current and voltage shape (Görbe et al., 2009). The upper harmonic components have many undesirable effects on power grid (Görbe et al., 2010a), that may cause faulty operation of the network.

Grid tie inverter systems can be used to inject spare power to the local low voltage mains, and they would be suitable for improving the power quality, too. This additional functionality doesn't need expensive change of the constructions, because one should only modify the control methods and regulators to develop the ability of line conditioning. Several papers deal with power injection to the grid, see e.g. Carrasco et al. (2006), including the possibility of power factor correction and nonlinear distortion reduction in conjunction with it (Lo et al., 2008), (García-Canseco et al., 2007), (Cerdeira et al., 2004), (Limongi et al., 2009) and (Limongi et al., 2008). On the other hand it has been indicated that the connected electric car batteries can absorb peaks of power production or can feed the power into the grid (Binding C. et al., 2010).

The general 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 (Görbe et al., 2009), (Görbe et al., 2010a), this aim can be achieved in addition to control the maximum power operating point from the renewable source 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.

2. 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 combined plants can be extended with new elements to form a complex multifunctional control 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 a novel element, 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 novel function would be the *compensation of the nonlinear distortion* that is intended to achieved by injecting upper harmonic (mainly 3th 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. The fourth new element *controls the exact energy flow* to *absorb the high peaks* of overall energy production (renewable and non-renewable power plants and domestic power plants) and *feed the grid* from the batteries in insufficient power production conditions.

Our aim has been to implement the missing element, the charger controller, and its relationships the simplest possible way. The main goals are to approach unity power factor for the overall system for the range of the possible loads and working modes, to reduce THD and keep the grid in energy balanced state to a high degree renewable energy production condititons. 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, zero THD and exact energy balance, but unfortunately, this optimum is not achievable in practice, just approachable.

3. Structure of the multifunctional complex controller

A simple model of the grid tie inverter (Lo et al., 2008) is used for the controller structure design, that is shown in Figure 1. It contains a simple booster stage with an IGBT bridge, connected to the grid through serial inductance with a two way current controllable battery charger and discharger. The control system is divided to six main functional parts as shown in Figure 2 in shadowed boxes. The details of the blocks *Maximum power controller, Intermediate voltage controller, Upper harmonic controller, Current waveform generator* and *Bridge controller* can are described in (Görbe et al., 2010a).

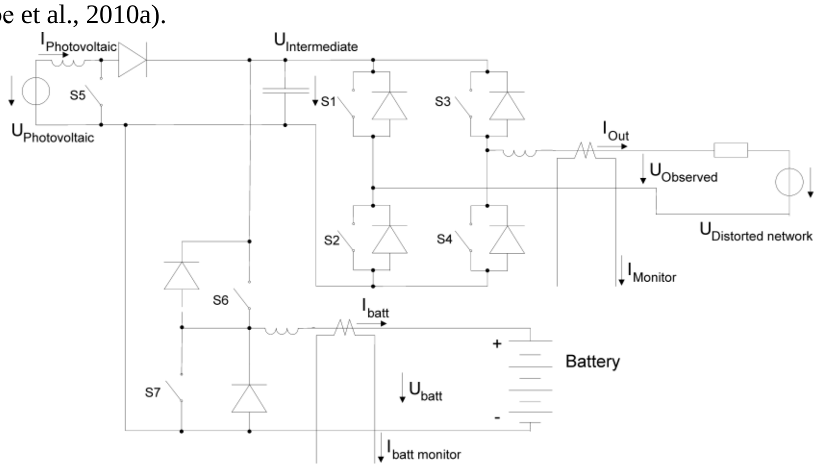

Figure 1: Grid Tie Inverter model

The new element is the *Charger controller*. It is responsible for controlling the Bulk converter's switching element S6 and the Boost converter’s switching element S7 (see in Figure 3) in order to adjust the optimal charging or discharging current value of the Li-ion battery. The current control is also a simple on/off switching nonlinear hysteresis controller (Limongi et al., 2009).

The other new element is the *RMS Voltage Controller* which is responsible for controlling the effective voltage value at the connection point, because the insufficient power generation and overloading causes a voltage drop in the low voltage line, and when energy is overproduced the voltage rises over in the line. It is a PI controller, and can be switched to manual mode for outer control through the Smart Grid Interface. The manipulated value is the charger or discharger current value of the EV Li-Ion Battery.

4. Modeling and simulation

The dynamical model of the nonlinear distorted network has been implemented in Matlab Simulink using the Power Electronics Toolbox. The control flow chart of the complete model can be seen in Figure 2. We modelled the nonlinear network, the battery and the grid synchronised inverter with the controller sructures. The battery was modeled by the Battery block of Matlab Simulink Power Electronics Toolbox using the nominal voltage 153.6V, and rated capacity 200Ah. The plots of the simulated time functions and the THD time functions are available in (Görbe et al., 2010a). The most important numarical values are in Table 1.

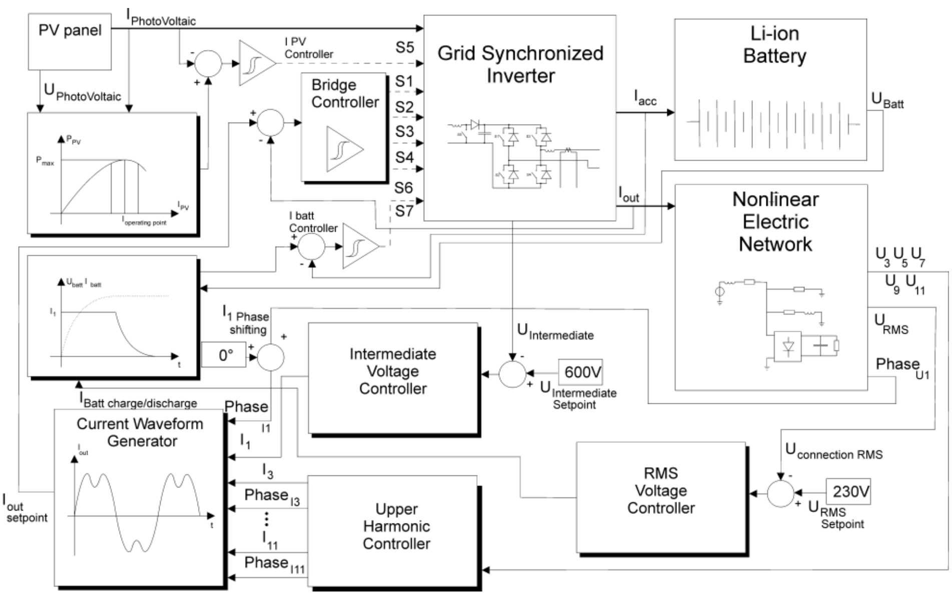

Figure 2: Control Flow Chart diagram

Table 1: Preliminary performance analysis results in normal inverter mode

Mode	I RMS	Error	THD
Inverter OFF	NI	39.63	14.26%
Upper h.contr OFF	11.58A	47.03	14.75%
Upper h.contr ON	5.74A	3.87	5.23%

In our earlier work it was possible to reduce voltage THD almost as much as current THD in (Limongi et al., 2009) and (Görbe et al., 2010b), with performing voltage measurement instead of current measurement at the connection point. In addition, it has been shown that the proposed upper harmonic controller is capable of reducing the effective current value and the power loss of the line dramatically. The robustness analysis of the intermediate voltage controller was performed by changing the energy flow modes in subsequent time intervals, see (Görbe et al., 2010b).

The robustness of the RMS Voltage controller was investigated by simulation using the changing conditions in Table 2. The battery current values and the measured effective voltage at the connection point can be seen in Figure 3 as time functions.

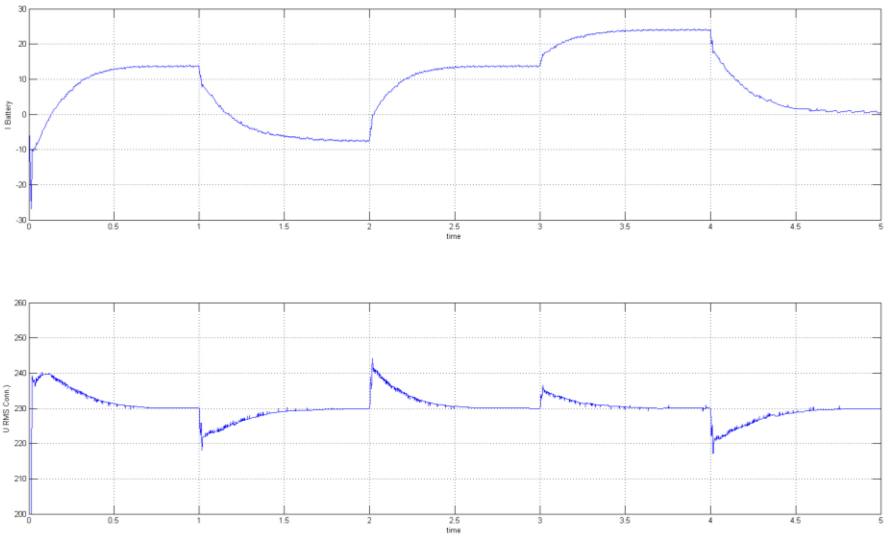

Figure 3: Robustness analysis of the RMS Voltage Controller

Table 2: Parameters of the robustness analysis

Time	0-1 sec	1-2 sec	2-3 sec	3-4 sec	4-5sec
I Outer Load Peak	0A	50A	0A	-20A	30A

5. 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 (Görbe et al., 2010a).

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References

Binding C., Sundström O, Gantenbeim D., Jansen B., (2010), Integration of an Electrical Vehicle Fleet into the Power Grid, European Research Consortium for Informatics and Mathematics News, 82, 57-58

Carrasco A J.M., Franquelo L.G., Bialasiewicz J.T., Galván E., Guisado R.C.P., Prats Ma.Á.M., León J.I. and Moreno-Alfonso N., (2006), Power-Electronic Systems for the Grid Integration of Renewable Energy Sources: A Survey, IEEE Transactions on Industrial Electronics, 53, 1002-1016

Lo Y.K., Lee T.P., and Wu K.H., (2008), Grid-Connected Photovoltaic System with Power Factor Correction, IEEE Transactions on Industrial Electronics 55, 2224-2227

García-Canseco E., Grino R., Ortega R., Salichs M. and Stankovic A., (2007), Power-Factor Compensation of Electrical Circuits, A framework for analysis and design in the nonlinear nonsinusoidal case, IEEE Control Systems Magazine, 46-59

Cerdeira A., Alemán M.A., Estrada M., Flandre D., (2004), Integral function method for determination of nonlinear harmonic distortion, Solid-State Electronics 48, 2225-2234

Limongi L.R., Bojoi R., Griva G., Tenconi A., (2009), Comparing the Performance of Digital Signal Processor-Based Current Controllers for Three-Phase Active Power Filters, IEEE Industrial Electronics 3, 20-31

Limongi L.R, Bojoi. R., Tenconi A., Clotea L., (2008), Single-phase inverter with power quality features for distributed generation systems, Optimization of Electrical and Electronic Equipment, OPTIM 2008. 11th International Conference 313-318

Görbe P, Magyar A., Hangos K.M., (2009), Line Conditioning with Grid Synchronized Inverter's Power Injection of Renewable Sources in Nonlinear Distorted Mains, 10th International PhD Workshop on Systems and Control, ISBN: 978-80-903834-3-2.

Görbe P, Magyar A., Hangos K.M., (2010a), THD Reduction with Grid Synchronized Inverter’s Power Injection of Renewable Sources, 20th International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM) ISBN:978-1-4244-7919-1, 1381-1386

Görbe P., Magyar A., Hangos K.M., (2010b), Power Conditioning with Electric Car Battery Charging from Renewable Sources, Hungarian Journal of Industrial Chemistry, 38(1) , HU ISSN: 0133-0276, 27-33