RIGA TECHNICAL UNIVERSITY

Faculty of Power and Electrical Engineering

Institute of Industrial Electronics and Electrical Engineering

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RESEARCH AND DEVELOPMENT OF CONTROL MEANS FOR INTELLIGENT HOUSEHOLD ELECTRICAL GRIDS

Summary of doctoral thesis

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RTU Press
Riga 2013

UDK 621.311(043.2)
Su 980 r

Suzdalenko A. Research and development of control means for intelligent household electrical grids. Summary of doctoral thesis.–R.: RTU Press, 2013. - 27 pp.

Printed according to the decision of IEE institute on 19 June 2013. Protocol Nr.71.

This work has been supported by the European Social Fund within the project «Support for the implementation of doctoral studies at Riga Technical University».

EIROPAS SOCIĀLAIS FONDS

EIROPAS SAVIENĪBA

ISBN 978-9934-507-41-0

DOCTORAL THESIS
PRESENTED TO OBTAIN THE DOCTOR'S DEGREE IN ENGINEERING SCIENCES

Doctorate work for the doctor's degree in the engineering sciences was publicly presented on the 28 November 2013 at 14:00 o’clock in Riga Technical University, Kronvalda boulevard 1 – 117.

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CONFIRMATION

Hereby I confirm that I have worked out the present doctorate work, which is submitted for consideration to the Riga's Technical University for the degree of Doctor of engineering sciences. Doctorate work has not been submitted in any other university for obtaining the Doctor’s degree.

Alexander Suzdalenko ....

Date ....

The thesis is written in English language on 114 pages, and consists of an introduction, 4 chapters and conclusions, and 8 appendices. 88 figures, 124 formulas, 11 tables, and 91 references are included in the thesis.

PROJECT MOTIVATIONS

Electrical energy consumed in residential sector accounts for about a fourth part of global electricity market in worldwide scale. European households consume 28.6% of totally generated electricity [1]. The demand curve of this sector is highly uneven due to people absence from home during working hours and inactivity during night period. Two basic load peaks during morning and evening hours overlap with demand curves of industrial and commercial sectors, the result of which compiles the peak load of the day [2]. This problem leads to under-utilization of generation capacities, for instance, 20% of USA generation plants operate during 5% of the total time [3], which leads to rise of operation cost.

Demand-side management [4]-[5] is one of the solutions that helps to form residential demand curve. It is based either on electricity tariffs, agreements, real-time electricity price information delivery to the end-user, or in some cases – on government policies that mitigate peak demand. Features of intelligent distribution grid (IDG) allow implementation of even more flexible demand management, as IDG behaves as controllable load by using internal energy resources, shedding loads, or generating energy to the utility grid.

Considering Denmark experience on popularity of PV panel installation at the end-user side it can be assumed that other countries could take over Danish practice on integration of RES application in residential sector into the power grid, thus increasing the installed RES capacity in worldwide scale. On the other hand, high penetration of renewable energy sources raised discussions about grid stability issues, advising to implement virtual inertia for grid-tied inverters and small energy storages for smoothing energy generation [6].

The prevalence of small renewable energy sources and energy storages in households has opened discussions on DC subgrid installation [7][8][9] as most of the loads, renewable energy sources, and storages are in fact DC elements that accordingly to [10] allow saving up to 15% by reduction the number of unnecessary energy conversions.

Moreover, energy efficiency issues can be promoted by providing detailed energy consumption data to the end-user. Pilot projects described in[11][12], and [13]show that energy reduction by 5-15% is achievable due to provided so-called “real time plus” information about user’s consumption pattern, with energy data divided according to consumption by separate electrical appliances. As a result, the various changes in energy saving behaviour could develop: 1) changes in habits and daily routines; 2) low-cost stackholding (inefficient lamps replacement); 3) money investment in more efficient electrical devices, materials, etc.

Proposed ideas raise the necessity for energy management system capable of controlling local electrical appliances and located in each household. Thus, the demand-side management is realized by changing the consumption pattern upon the request from utility grid operator or when operated in islanded mode, where the power balance between sources and loads should be kept. The detailed feedback on consumed energy would promote energy efficiency.

MAIN HYPOTHESIS AND OBJECTIVES

Hypothesis

1. Non-intrusive load monitoring function can be implemented by means of proposed interconnection switch.
2. Use of load surface, which represents load categorization based on time-triggering, price triggering, and price-responsive load scheduling, enables predictive control of long-term energy management.
3. Single-phase half-bridge based bidirectional AC/DC converter driven by special current control algorithms allows eliminating instantaneous measurement of inductor current.

Objectives

1. To develop a multifunctional interconnection switch with integrated non-intrusive load monitoring functionality, which enables RES generated energy disaggregation.
2. To develop a communication node capable to control electrical appliances of the intelligent distribution grid.
3. To analyse the existing instantaneous, short-term, and long-term power balancing algorithms and to improve them, enabling superior operation of intelligent distribution grid.
4. To define the current control algorithms for bidirectional AC/DC converter that would allow its operation in rectification, grid-tied, and stand-alone inverter modes.

MEANS AND METHODS OF RESEARCH

In order to speedup mathematical calculations and visualise obtained functions the *Mathcad* software was used. The simulations of power electronic schemes were carried out in *PSIM* software, where verification of obtained analytical control laws for proposed bidirectional converter were made. The *LabVIEW* software was used to check electric price estimation algorithm, as well as to control Lambda DC laboratory power supply block in order to implement automated tests. The *Quartus Web Edition* and *Code Composer Studio* were used to write application firmware for FPGA and DSP based control boards correspondingly, as well as appropriate built-in debugging tools were used during optimization process. The PCB design was made in *OrCAD* software pack.

The theory of electrical circuits were utilized in order to obtain mathematical model of power electronic converter. Bisection method was used as numerical approach for root estimation of transcendental equation.

SCIENTIFIC NOVELTIES

1. Algorithm for electrical energy price estimation in intelligent grid applications based on load categorization, which provides the result in two steps, is developed.
2. The constant switching current control technique is defined for active rectifier based on half-bridge topology for rectification, grid-tied, and stand-alone inverter modes operating in discontinuous and continuous input of inductor current modes.
3. The current limits for adaptive hysteresis current control are defined in order to provide nearly constant switching frequency operating in rectification and grid-tied inverter modes.

PRACTICAL NOVELTIES

1. The multifunctional interconnection switch with non-intrusive load monitoring functionality is developed for intelligent grid applications.
2. Transformerless bidirectional AC/DC converter based on double half-bridge topology with common neutral point is proposed as a common point interface converter.
3. The FPGA control board is developed that is pin-to-pin compatible with Piccolo LaunchPad development board from TI, which can be used in advanced course of Digital Electronics for electrical engineers.

PRACTICAL APPLICATION OF THE WORK

Proposed bidirectional interface converter together with multifunctional interconnection switch can be redesigned for market-ready solutions targeted for unsaturated niche of energy management means. Small-scale intelligent grids such as contemporary households with installed renewable energy sources can be considered as a typical application for the mentioned devices.

DISSEMINATION OF RESULTS

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11. [accepted for publication] Suzdalenko, A., Galkin, I. Current Sensorless Control of Front-end Bidirectional AC/DC Converter Based on Half-bridge Topology. *Electrical, Control and Communication Engineering*. Vol.4, 2013, pp.1–7.

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CONTENTS OF DOCTORAL THESIS

INTRODUCTION

Energy is a key resource that allows humanity evolving successfully during centuries that provides force or is transformed to another form of energy used in everyday life activities. On the other hand, present energy delivering system also causes global changes – mining activities changes the landscapes, refining of crude oil produces pollutants released into the atmosphere, water and land, as well as combustion of fossil fuel impact on Earth's climate due to CO_2 emissions.

The world's electrical energy demand is growing at a rate of 2.4% annually, while developing countries has 4% increase of demand [14] due to increasing population [15] and standards of living, forcing countries to install new generation facilities at a regular base. While the consumption of fossil resources remain reasonable, countries also invest finances into development of renewable energy sector. The total amount is estimated as 257 billions of USA dollars in 2011 [16] that results in growing number of installed Solar and wind energy capacities per annum (see Fig.1.1) promoting significant reduction of technology cost having 0.138-0.163 €/kWh for PVs plants in Germany [17]. Hydropower plants are also introduced yearly especially in Africa and Asia, where a lot of undeveloped resources are still available [18].

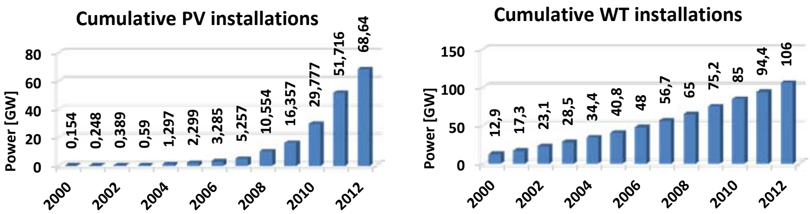


Fig. 1.1. European cumulative PV and WT installations [19][20]

In order to promote RES utilization in residential sector countries might also adopt their legislation concerning connection of small energy sources to the utility grid, so that owners of the RES would become prosumers (producer and consumer). Spectacular example of that is Denmark, where 36 MW of PV panels are connected to the grid monthly in residential sector, after declaration of allowance to "store" energy in the public grid surplus consumption, helping to reach the 2020 governmental goal of 200 MW PV capacity at the end of 2012 [21].

1 DEVELOPMENT OF CONTROL MEANS

Intelligent distribution grid (IDG) consists of various home appliances connected to the electricity grid, which are controlled by means of communication hardware, enabling remote control or data transfer to the Energy Management System (EMS). This configuration enables superior functionality of household grid by interacting with network operator as controllable load.

IDG supply scheme

These grids can be divided into three types depending on supply scheme topology: AC-based, DC-based or hybrid IDG.

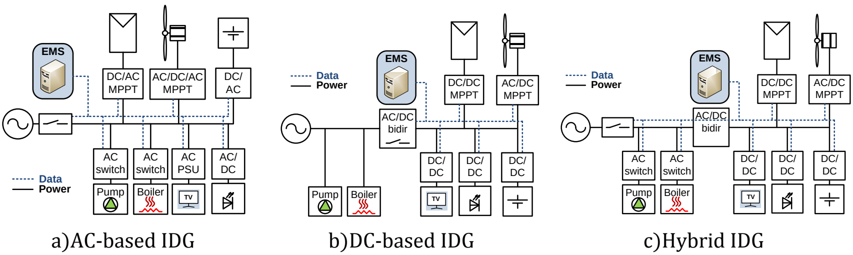
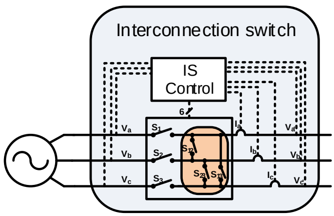


Fig. 1.1. IDG supply topologies

Multifunctional Interconnection Switch

Special IS is proposed capable to solve one or two phase problems by interconnecting unpowered local phases to healthy phases, providing power supply for critical loads. It also allows implementing single-phase inverters interaction to supply the load, which is greater than single RES maximal output power.



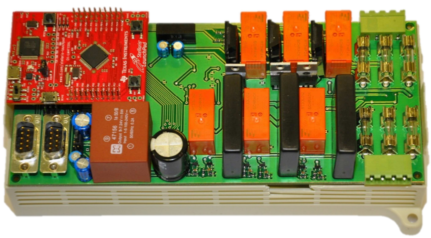


Fig. 1.2. Proposed IS – configuration (left) and photo (right).

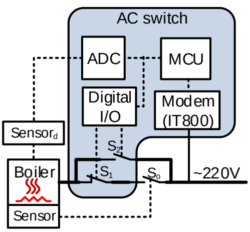
Functionality of proposed IS is listed below:

- measurement of outer and local grid voltages and frequencies, providing these data to local power sources that control the resynchronization procedure.
- Phase commutation according to voltage, phase, and frequency deviation limits.
- Phase interconnection in a local grid, which is used for solving one or two phase problems in the outer grid, as well as combination of local single-phase inverters connected to different phases in order to supply higher load.

The hardware utilised in proposed multifunctional IS allows also realizing additional functionality, such as non-intrusive load monitoring, firstly mentioned by Gearge W. Hart in 1983 [22], who defined cluster identification method [23]. The load disaggregation algorithms have been developed since then implementing more detailed current and voltage sampling realizing harmonic analysis [24], current transients analysis [25]. Modern programming approaches also were utilized for data analysis such as fuzzy logic [26], integer programming [27], dynamic programming [28] and genetic algorithms [29]. Considering the modern trends, many households are getting equipped with RES that makes difficult proper identification of consumed amount of energy as loads and sources make action and counter action. For this reason author proposes to solve it with one of three methods: 1) using meteorological sensors; 2) using additional current sensors and 3) using detailed current spectrum analysis.

Module for connection of non-intelligent load

Module is dedicated for connection of non-intelligent load (controllable AC switch), which allows communicating with and controlling the non-intelligent appliance, enabling such functions for EMS as load shedding and scheduling.



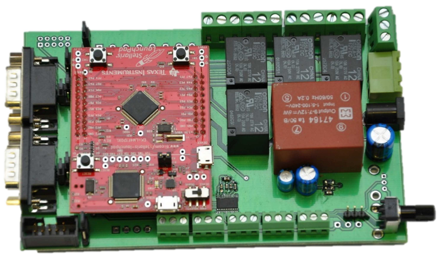


Fig. 1.3. Proposed AC switch: possible configuration (left) and photo (right)

2 POWER BALANCING IN IDG

Currently a major effort is focused on solutions that keep an energy balance in small-scale networks, like nanogrids[30][31] and microgrids[32].

Energy management approaches are divided into groups, which differ by the period of management: instantaneous (real-time) energy management, where balance is kept in a period of milliseconds or seconds, short-term energy management, with periods of seconds or minutes, and long-term energy management, which defines energy management strategy to fulfil objectives for longer periods such as hours, weeks, or months (see Table 2.1).

Table 2.1

Overview of power balancing techniques

Period of power balancing [time range]	Power balancing approach		Functionality
	Communication unavailable	Communication available	
Instantaneous [ms ... s]	Droop-control	-	Instantaneous [ms ... s]
Short-term [s ... min]	Bus signalling	Request-respond commands	Short-term [s ... min]
Long-term [min ... h]	-	Variable references; Dynamic pricing	Long-term [min ... h]

The droop control approach is mostly applied both in AC and in DC power distribution grids, where it defines the method of power sharing between various energy sources by means of definition of different droops accordingly to their nominal power [33]. Control challenges of AC and DC grids are compared in the table below.

Table 2.2

Comparison of instantaneous power balancing control challenges in AC and DC grids

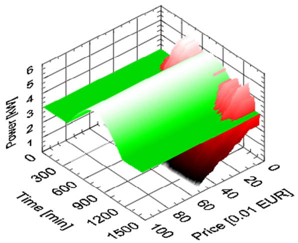
Problem	AC grid	DC grid
P – active power balance	●	●
Q – reactive power balance	●	
F – frequency control; synchronization;	●	
Harmonics, 3-phase unbalance	●	
R=∞ – no load condition	●	
Imax - Inrush currents	●	●

Proposed long-term power balancing technique

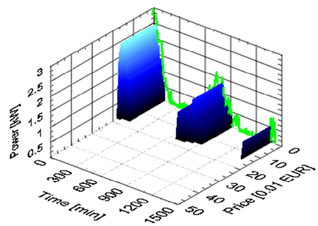
The author proposes to define categories of household appliances, which switch and operate at different conditions:

1. Time-triggered load – pumps, general lighting, etc. – the load basically switches at a nearly defined time;
2. Price-triggered load – energy storage elements, washing machines, etc. – the load turns on when the price lays within an acceptable level;
3. Hybrid-triggered load – heaters, boilers, refrigerators, etc.– the load operates according to a daily schedule (depending on consumption), but it can also switch on a little earlier when the price per electricity is economically profitable;
4. Price-responsive load - controllable lighting – the load changes the consumed power depending on the price of electricity.

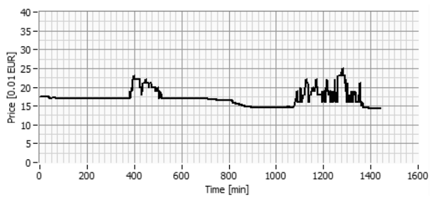
Then the long-term power balancing is realized by pricing approach estimating price per electrical energy in two steps: time-triggered and hybrid-triggered loads operation schedule is aggregated and compared with operation schedule of energy sources. During second step, the energy excess is used to schedule price-triggered loads.



a) 3D representation of first price estimation



b) 3D representation of second price estimation



c) Estimated price function

Fig. 2.1. Long-term power balancing with proposed pricing approach

Thus, proposed algorithm, based on load categorization allows load scheduling, shedding by regulating the price function, and fruitful for utility grid operator due to enabled demand-side management.

3 DEVELOPMENT OF BIDIRECTIONAL AC/DC INTERFACE CONVERTER

The key element of connecting AC grid to the local DC grid is a bidirectional AC/DC converter, responsible for efficient conversion of electrical energy in both directions, capable of supporting both sides by implementing energy balancing algorithms both in a grid-tied and in a stand-alone mode.

The author proposes to use common neutral point dual half-bridge topology, which has less switching devices and eliminates the use of transformer, as the neutral wire is not commutating during the operation of the proposed converter.

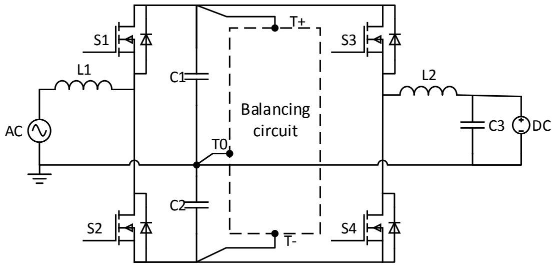


Fig. 3.1. Proposed bidirectional AC/DC converter with common neutral point

Multiple current control techniques are known from the literature [37], [38]. The constant switching current sensorless control technique is selected, as accordingly to [38], it reduces switching losses in comparison with variable frequency hysteresis control, as well as reduces high-frequency components, more over elimination of instantaneous inductor's current measurement potentially allows reducing control system cost and size [39].

3.1 Analysis of operation modes

The interrelation of capacitor voltages are described by two equations below:

$$v_{C1}(t) - v_{C2}(t) = \frac{I_m}{C \cdot \omega} \cdot (1 - cos(\omega t)) + C_d, \tag{3.1}$$

$$\frac{{v_{C1}}^2(t)}{2} + \frac{{v_{C2}}^2(t)}{2} = \frac{I_m \cdot V_m}{4 \cdot C \cdot \omega} \cdot (2\omega t - sin(2\omega t)) + C_0. \tag{3.2}$$

The capacitor's C_2 voltage function can be defined then as:

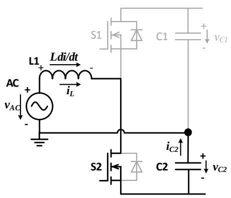
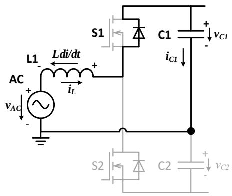
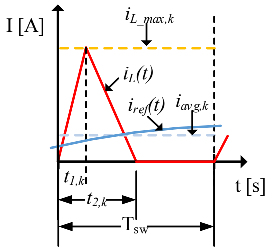
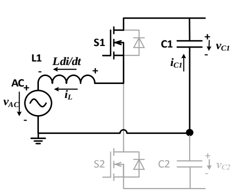
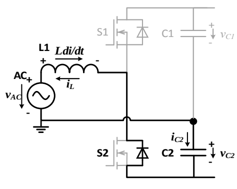
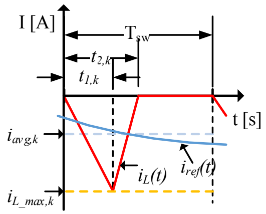
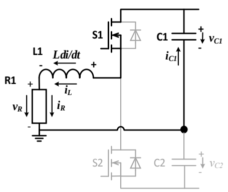
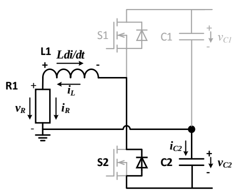
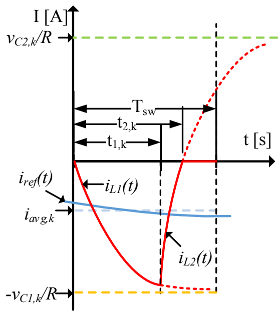
$$v_{C2}{}^2(t) + v_{C2}(t)\cdot\left(\frac{I_m}{C\cdot\omega}\cdot(1-cos(\omega t)) + C_d\right) + \frac{\left(\frac{I_m}{C\cdot\omega}\cdot(1-cos(\omega t)) + C_d\right)^2}{2} = \frac{I_m\cdot V_m}{4\cdot C\cdot\omega}\cdot(2\omega t - sin(2\omega t)) + C_0, \tag{3.3}$$

which can be solved as simple square equation ($ay^2 + by + c = 0$).

The table below represents commutated current paths during single switching period at different operation modes. The positive half-period of input voltage is considered.

Table 3.1

Commutated current paths and waveforms

Mode	Switch is conducting	Reverse blocking diode is conducting	Current shape
Rectification			
Grid-tied inverter			
Stand-alone inverter			

The following table summarizes current sensorless control laws for different operation modes for proposed converter.

Table 3.2

Control laws for different operation modes

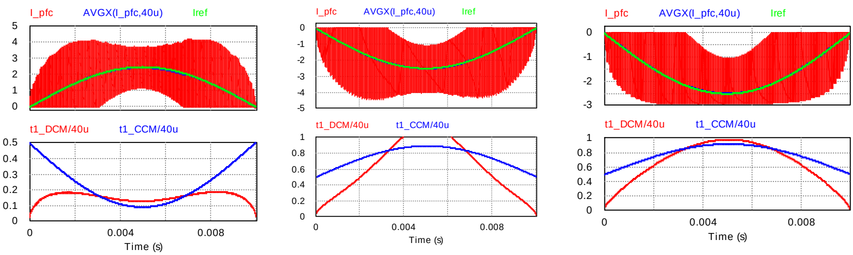
Mode	Discontinuous current mode	Continuous current mode
Rectif.	$t_{1,k} = \sqrt{\frac{\lvert i_{avg,k}\rvert \cdot 2 \cdot L \cdot T_{sw} \cdot (v_{C1,k} - v_{in\_avg,k})}{(v_{in\_avg,k} + v_{C2,k}) \cdot (v_{C1,k} + v_{C2,k})}}$. (3.4)	$t_{1\_ccm,k} = \frac{\Delta i_{ref,k} \cdot L + (v_{C1,k} - v_{in\_avg,k}) \cdot T_{sw}}{v_{C2,k} + v_{C1,k}}$. (3.5)
Grid-tied invert.	$t_{1,k} = \sqrt{\frac{\lvert i_{avg,k}\rvert \cdot 2 \cdot L \cdot T_{sw} \cdot (v_{C2,k} + v_{in\_avg,k})}{(v_{C1,k} - v_{in\_avg,k}) \cdot (v_{C1,k} + v_{C2,k})}}$. (3.6)	$t_{1\_ccm,k} = \frac{-\Delta i_{ref,k} \cdot L + (v_{C2,k} + v_{in\_avg,k}) \cdot T_{sw}}{v_{C2,k} + v_{C1,k}}$. (3.7)
Stand-alone invert.	$\frac{v_{c2,k}}{v_{c1,k}} e^{-\frac{R}{L} t_{1,k}} = \left(1 + \frac{v_{c2,k}}{v_{c1,k}}\right) e^{-\frac{R}{L} t_{2,k}} - e^{-\frac{R}{L}(t_{1,k} + t_{2,k})}$. (3.8)	$t_{1\_ccm,k} = \frac{-\Delta i_{ref,k} \cdot L + (v_{C2,k} - R \cdot i_{avg,k}) \cdot T_{sw}}{v_{C1,k} + v_{C2,k}}$ (3.9)

The DCM control law for stand-alone inverter mode makes sense of transcendental function. Simplified answer for (3.8) has been found as:

$$t_{1,k} = \left(\frac{R^2 \cdot i_{avg,k} \cdot T_{sw}}{L \cdot v_{c2,k}} - ln\frac{1}{2}\right) \cdot \frac{v_{c2,k} \cdot L}{v_{c1,k} \cdot R}. \qquad (3.10)$$

In order to obtain precise control law the bisection method [40] of numerical approach for root estimation was used for solving (3.8).

The simulation results for different operation modes are presented below (see Fig. 3.2) showing identical forms with analytical graphs.



a) active rectifier b) grid-tied inverter c) stand-alone inverter

Fig. 3.2. Simulated current and timing waveforms

Hysteresis control for CCM

Adaptive hysteresis control, which provides nearly constant switching frequency is defined by two functions – the upper and the lower levels of inductor's current that are obtained from graphical representation of inductor's current (rectification mode is analysed):

$$i_{ccm\_min,k} = i_{avg,k} + \frac{v_{in\_avg,k} + v_{C2,k}}{2L} \cdot \frac{t_{1\_ccm,k}^2}{T_{sw}} - \frac{v_{C1,k} - v_{in\_avg,k}}{2L} \cdot \frac{\left(T_{sw} - t_{1\_ccm,k}\right)^2}{T_{sw}} - \frac{v_{in\_avg,k} + v_{C2,k}}{L} \cdot t_{1\_ccm,k}. \tag{3.11}$$

$$i_{ccm\_max,k} = i_{avg,k} + \frac{v_{in\_avg,k} + v_{C2,k}}{2L} \cdot \frac{t_{1\_ccm,k}^2}{T_{sw}} - \frac{v_{C1,k} - v_{in\_avg,k}}{2L} \cdot \frac{\left(T_{sw} - t_{1\_ccm,k}\right)^2}{T_{sw}}. \tag{3.12}$$

Similar current limits of adaptive hysteresis control can be defined as deviation from reference value described by two equations presented below:

$$i_{ccm\_min,k} = i_{ref}(t_k) - \left(\frac{v_{in\_avg,k} + v_{C2,k}}{L} - \frac{\Delta i_{ref,k}}{T_{sw}}\right) \cdot \frac{t_{1\_ccm,k}}{2}, \tag{3.13}$$

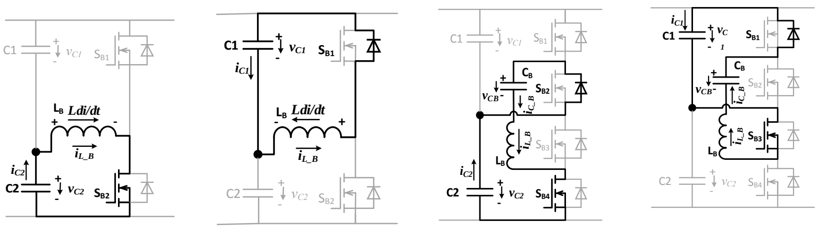
$$i_{ccm\_max,k} = i_{ref}(t_k) + \left(\frac{v_{in\_avg,k} + v_{C2,k}}{L} + \frac{\Delta i_{ref,k}}{T_{sw}}\right) \cdot \frac{t_{1\_ccm,k}}{2}. \tag{3.14}$$

The differences between the two calculation approaches are neglectable, thus, the second approach is preferable for a digital control system due to its lower computational requirements.

3.2 Capacitors' voltage balancing

The proposed converter needs a balancing circuit, since the output half-bridge mostly charges and discharges the capacitor *C1*. Thus, the balancing circuit should provide half of the power required by the output half-bridge. Two solutions are considered: hard-switched and soft-switched.

Hard switched | Soft switched



S_{B2} is conducting | Diode of S_{B1} is cond. | S_{B4} is and diode of S_{B2} are conducting | S_{B3} and diode of S_{B1} are conducting

Fig. 3.3. Commutated current paths during direct power flow of converter discharging capacitor *C2* and charging capacitor *C1*

Controller for balancing circuit

During the operation of front-end half-bridge converter the capacitors' voltages change in accordance with (3.1). Thus, the compensation of these changes should be taken into account in balancing circuit controller (see Fig. 3.4).

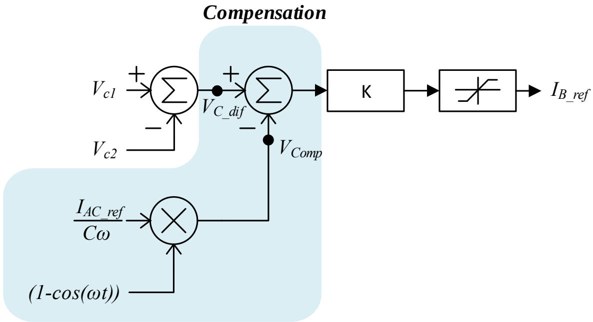


Fig. 3.4. Schematic of controller for balancing circuit

3.3 LCL filter calculation

The following table contains performance analysis obtained by simulation in PSIM for calculated LCL filter (converter side inductance L_{FC}=2.2 mH, C_F=1.6 μF, grid side inductance L_{FG}=0.2 mH).

Table 3.3

Performance of LCL filter

	I_M [A]	7.5	5	2.5	1	0.5
Rrectification mode	THD(I_{L_C}) [%]	13.6	19.5	34.9	67.3	101.2
	THD(I_{L_G})[%]	1.8	2.7	4.5	8.2	11.5
Inverter mode	THD(I_{L_C}) [%]	12.1	17.7	32.4	63.8	96.1
	THD(I_{L_G})[%]	1.7	2.5	4.4	8.2	11.5

The selected values of LCL filter provide admissible THD values, also regulated by IEC61727 [41], which limits THD value for grid-tied inverters to be less than 5% at 75% of rated power.

Special consideration should given in order to use the previously obtained control laws for converter's operation with LCL filter. During DCM mode only converter-side inductor should be taken into account, while during CCM the total inductance of the LCL filter should be considered in equations by which the transistor's conduction time is calculated. The stand-alone inverter's mode with LCL filter should be treated as grid-tied inverter mode, as the current waveforms are similar to grid-tied inverter mode due to filter capacitor.

4 EXPERIMENTAL EVALUATION

Experiments with proposed IS

Proposed solutions for NILM improvement have different advantages and disadvantages summarized in the table below (see Table 4.1).

Table 4.1

Comparison of proposed solutions

Solution	Accuracy	Computational load	Additional hardware
Meteorological sensor	92%	Low	Yes
Current sensor	3%	Low	Yes
Spectral analysis	84%	High	No/Yes

The second is attractive due to the highest accuracy that requires separation of generation and consumption current measurements. Nevertheless, the last approach requires no additional hardware for installation, however it requires the highest computational performance, which may cause to change the NILM device.

Experiments with bidirectional AC/DC interface converter

The prototype of proposed converter was built on two side PCB (70 µm of copper) with air cooling system

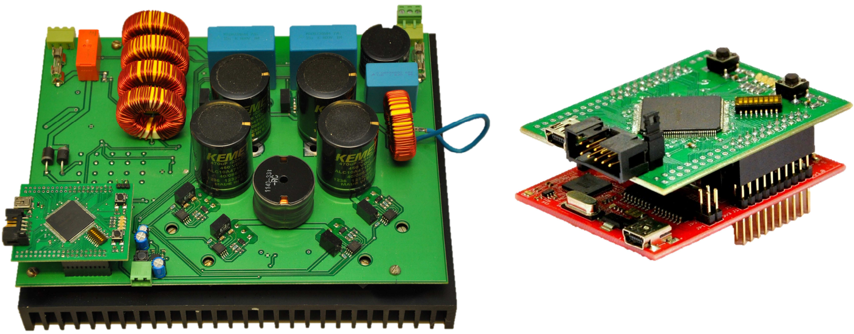


Fig. 4.1. Photo of proposed bidirectional AC/DC converter (left) and FPGA control board (right)

Testing step response

The step response of proposed converter is presented below. The nominal DC load 124 Ω in one case (see Fig. 4.2. left side) or 900 W DC source (see Fig. 4.2. right side) was connected at time 0.01, resulting in DC bus voltage changes by 4% in relation to reference value. The PI regulators of AC half-bridge, balancing circuit and output half-bridge circuits performed the action to stabilize the reference parameters, that are 800 V of internal DC link, 0 V capacitors' unbalance and 300 V of output DC bus correspondingly. By the time 0.15 s all measured values were stabilized. Then the disconnection of load or source occurred at time 0.166 s, after which the control system performed action to stabilize all variables to its reference values in 0.15 s.

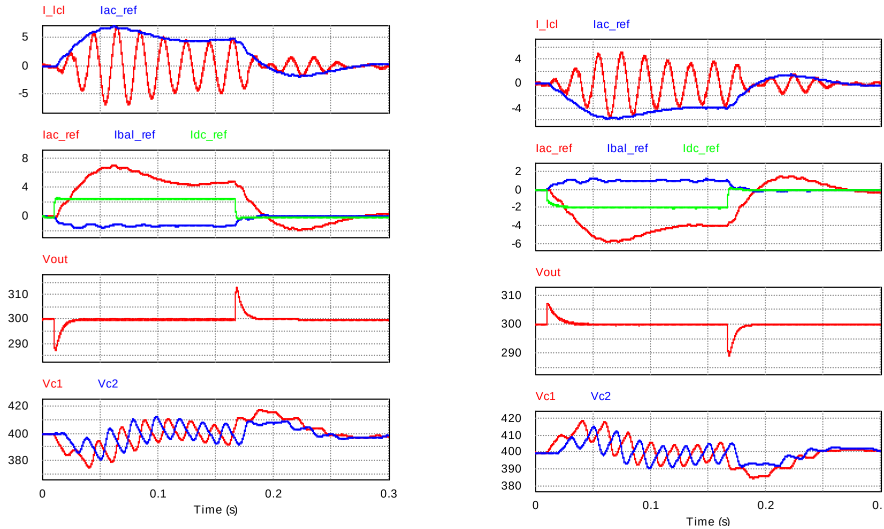


Fig. 4.2. Simulation result of step response for proposed converter (left – connection of 124 Ω load; right – connection of 900 W source)

CONCLUSIONS

Analysis of an intelligent distribution grid (IDG) based on contemporary households that use renewable energy sources (RES) is made in the present thesis. The focus is made on improvement of control means that are used in the IDG for energy management. Finally, it can be concluded that defined hypothesis are confirmed, and objectives are achieved.

The multifunctional interconnection switch (IS) is being proposed for use. It combines functionality of multiple devices: an interconnection switch, a phase selector, and a non-intrusive load monitoring (NILM) device. The proposed product allows implementing the same functions with less electronic and mechanical switches, as well as less number of voltage and current sensors. In particular, the NILM function has been improved in order to enable disaggregation of energy generated by RES, having the best performance with 3% inaccuracy, if an additional current sensor is used for measurement of RES generated current.

New long-term energy management algorithm for IDG has been discussed. It was proposed to categorise electrical appliances into four groups: time-triggered, price-triggered, hybrid-triggered, and price-responsive loads. Based on that, scheduling of generators and energy storage components are obtained and load shifting and shedding is performed by defining the electricity price function, when IDG operates autonomously. In case if IDG is connected to a utility grid and the price function is defined by the network operator, the proposed algorithm enables demand-side management – desirable function for network operator to mitigate peak demand issues.

Current sensorless control algorithm has been defined for half-bridge front-end bidirectional rectifier capable to operate at a constant switching frequency in different modes: rectification, grid-tied inverter and stand-alone inverter modes. It has also been adopted for operation with LCL input filter. The proposed approach eliminates the need for input inductor's instantaneous current sensing that reduces the cost and size of the control system. Par excellence, the current form is resistant to input voltage harmonic distortion, improving THD of utility grid's current. The performance of the proposed current control algorithm with calculated LCL filter provided current THD value admissible for IEC61727 standard.

The future work will comprise the following activities: adaptation of the proposed switching technique used in AC/DC converter supplying non-linear load; improvement of converter controller functionality with islanding detection and parallel inverter operation.

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ALEXANDER SUZDALENKO

RESEARCH AND DEVELOPMENT OF CONTROL MEANS FOR INTELLIGENT HOUSEHOLD ELECTRICAL GRIDS

Summary of doctoral thesis

Registered for printing on 22.10.2013. Registration Certificate No. 2-0282. Format 60x84/16. *Offset* paper. 1,75 printing sheets, 1,22 author's sheets. Calculation 50 copies. Order Nr. 88.
Printed and bound at the RTU Press, 1 Kalku Street, Riga LV- 1658, Latvia.