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Design of Grid-Connected Photovoltaic Systems and Technical Requirements in case of Grid Failure

Md. Sazzadur Rahman, Md. Walid Islam, Imtiaz Mahmud and Md. Mehedi Islam

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Abstract

Growing energy demand and environmental consciousness have re-evoked human interest in grid-connected photovoltaic (PV) systems. This work is focused on the modelling and simulation studies of the dynamic behaviour of a grid connected photovoltaic system. The model is implemented using MATLAB/Simulink with the SimPowerSystems Block Set. This work also presents the results of a comparative study referred to the characteristics of two types of inverters like half bridge and full bridge inverter. Finally, normal and faulty conditions of the photovoltaic generation, especially in the case of grid failure, were simulated and commented. The simulation of the system is developed for testing control algorithm before a real-time implementation.

Keywords: *Grid connected photovoltaic system, MATLAB/Simulink, inverter, grid failure.*

I. INTRODUCTION

Proper use of freely available renewable energy sources has become a global need today. There are two major global challenges ahead; one is to reduce the carbon emission to mitigate the reduction in global warming and another is to allow easy access to the basic need for power to all human beings. The solar energy is abundant in the world and it is helpful for solving the energy shortage and environmental pollution. Photovoltaic generation is an efficient approach for using solar energy. Although Solar Home Systems (SHS) are now gradually becoming popular and have obtained good dimension, Grid-connected Photovoltaic (PV) systems can be good power sources in cities and in remote areas where power generation in the existing grid is needed to be increased. Moreover, to remove dependencies from the fossil fuel based energy sources, it has very important influence on all the sectors of gird current.

Grid-connected PV systems, although small compared with other power generation sources are becoming very popular all over the world. Countries like Germany, Japan, USA and others have been doing a lot of research to improve the efficiency of solar cell and their grid connection capabilities [1]. South Korea has emerged a project to establish world's first national smart grid within 2030 [2]. Grid-Connected PV Systems, also called utility interactive PV systems, always have a connection to the public electricity grid via a suitable inverter, because a PV module delivers only a dc power which needs to be converted to ac to connect it to the grid system. Inverters do this by converting dc signals to ac sinusoidal wave [3]. Normally

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AUTHORS INFO

Md. Sazzadur Rahman
e-mail: sazzad_043@yahoo.com
Address: Dept. of Telecommunication and Electronic Engineering, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, Bangladesh.

Md. Walid Islam
e-mail: walid_tee@yahoo.com
Address: Dept. of Telecommunication and Electronic Engineering, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, Bangladesh.

Imtiaz Mahmud
e-mail: imtiaz.tee@gmail.com
Address: Dept. of Telecommunication and Electronic Engineering, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, Bangladesh.*Corresponding author

*Md. Mehedi Islam**
e-mail: mehedi_eap@yahoo.com
Address: Dept. of Telecommunication and Electronic Engineering, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, Bangladesh.

*Md. Mehedi Islam
e-mail: mehedi_eap@yahoo.com
Tel: 00 880 17 16239606

there is almost no effect of the PV system on the grid affecting power quality, load on lines, and transformers etc. However, for a larger share of PV in low-voltage grids, as in solar installations, these aspects need to be taken into account [4]. From a technical point of view, there will be no difficulty in integrating as much PV into low voltage grids as the peak load of the respective segment.

In this work, grid connected PV model was implemented using MATLAB/Simulink software with the SimPowerSystem Block Set [5][6] based on computer simulation. Computer simulation plays an important role in the design, analysis, and evaluation of power electronic converter and their controller. MATLAB is an effective tool to analyse a PWM inverter [7].

Simulation of modern electrical systems using power electronics has always been a challenge because of the non-linear behaviour of power switches, their connection to continuous sub-systems and the design of discrete-time control [8]. Nowadays, more and more complex systems are studied for designing efficient control strategies, such as renewable energy conversion systems, whole traction systems and so on [9]. In these cases efficient simulations before practical control implantation are required.

II. RELATED WORKS AND METHODS

A. *Design of Grid Connected Photovoltaic System*

The block diagram below in Fig. 1 presents the design for the grid connected P-V inverter system. It is consisted of: 1. P-V array that simulates the P-V module voltage and current output, depending on the temperature and solar irradiance, 2. the stabilizer which regulates the P-V array voltage at an acceptable rate in order the inverter to be fed and actualize the MPPT, 3. an inverter which converts the generated DC power into AC, 4. the Filter which is an LC low pass filter reducing the harmonic distortion by cutting off the high frequency harmonics, 5. the control unit in which a Phase Lock Loop (PLL) synchronizes the output phase of the inverter with the phase of the grid and the PWM synchronizes the IGBTs [10].

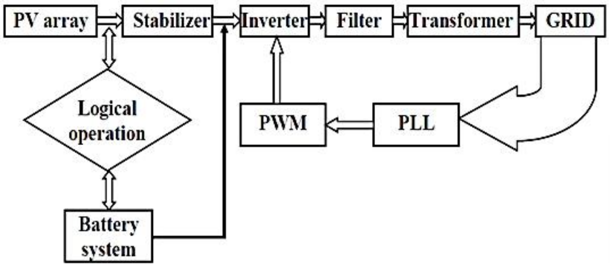

Fig. 1. Block diagram of grid connected topology.

B. *Inverter modelling*

An inverter is a circuit for converting direct current (DC) to alternating current (AC). The Grid Connected Inverter (GCI) system primarily controls three major parameters; current magnitude, phase and frequency. Several types of inverter topology and controller strategy have been used for three phase and single phase systems in the past. Synchronization of the systems with the utility supply is a challenging issue [11].

Suitable inverter topologies include half bridge inverter and full bridge inverter. Half bridge inverters require two equal capacitors in series connection across the DC input with an equal voltage drop across each capacitor. The peak voltage and current ratings of the switches are same as DC voltage and output AC peak current. This topology is not suitable for high current applications. Full bridge inverters consist of two legs with twice number of switches than the half bridge inverter. It gives an output voltage twice than of the half bridge inverter for same DC voltage input. Thus it is preferred for high power ratings [12].

i. *Half-bridge inverter:*

Half–bridge inverter as shown in Fig. 2. The number of switches is reduced to two by dividing the dc source voltage into two parts with the capacitors denoted as S1 and S2. Each capacitor will have the same value and will have voltage $\frac{V_{dc}}{2}$ across it. When S1 is closed, the load voltage is $+\frac{V_{dc}}{2}$. When S2 is closed, the load voltage is $-\frac{V_{dc}}{2}$. Thus, a square-wave output or a bipolar PWM output can be produced [13]. The output waveform is shown in Fig. 2.

When S1 is on and S2 is off, $V_o = +\frac{V_{dc}}{2}$

When S2 is on and S1 is off, $V_o = -\frac{V_{dc}}{2}$

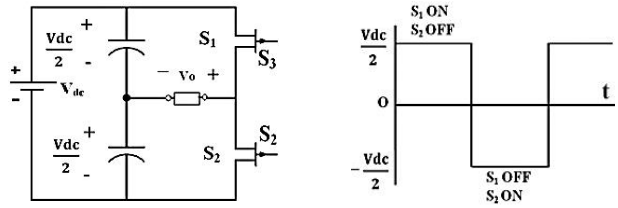

Fig. 2. A half-bridge inverter and its output waveform.

ii. Full-bridge inverter:

Full-bridge inverter is built from two half-bridge leg. The Fig. 3 shows the full-bridge inverter. The simplest switching scheme will produce a square-wave output voltage. The four switches denoted as S1, S2, S3 and S4 connect the load to + Vdc when S1 and S2 are closed or to – Vdc when S3 and S4 are closed [13]. The switching scheme is shown in the Table 1 below. The periodic switching of the load voltage between +Vdc and -Vdc produces a square wave voltage across the load. The output waveform is shown in Fig. 3.

TABLE I. Switching scheme of full bridge inverter

Switch	S1	S2	S3	S4
+ Vdc	on	on	off	off
-Vdc	off	off	on	on

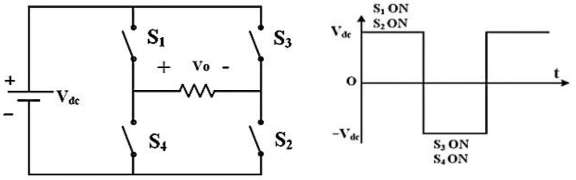

Fig. 3. A full-bridge inverter and its output waveform.

iii. Simulation of PV inverter:

Half-bridge inverter and the full-bridge inverter were virtually implemented which are shown in Fig. 4 & Fig. 5 in this work. In the half bridge inverter, we used two insulated-gate bipolar transistors (IGBT) and on the other hand, in the full bridge inverter we used four IGBTs. We generated control pulses to drive the IGBTs. The pulse generator gave a digital signal to the IGBTs. This consisted of the basic operation in order to convert the DC to AC, with the technique of the Pulse Width Modulation (PWM) [14]. The modulation factor was used as a parameter for the dynamic control of the system. When modulation factor was changing, we could control the voltage output and correct the voltage fluctuations. The half-bridge inverter used the DC voltage (Vdc = 400V), carrier frequency (1080 Hz) and modulation index (m = 0.8) and the full-bridge inverter used the DC voltage (Vdc = 250V), carrier frequency (1080 Hz) and modulation index (m = 0.8)

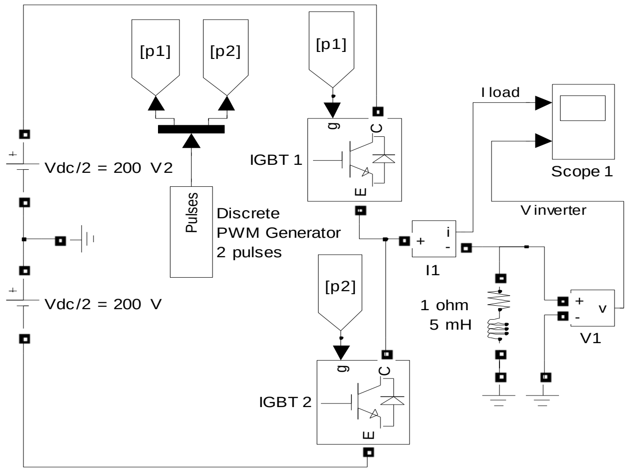

Fig. 4. Simulation of half bridge inverter and the pulse generator.

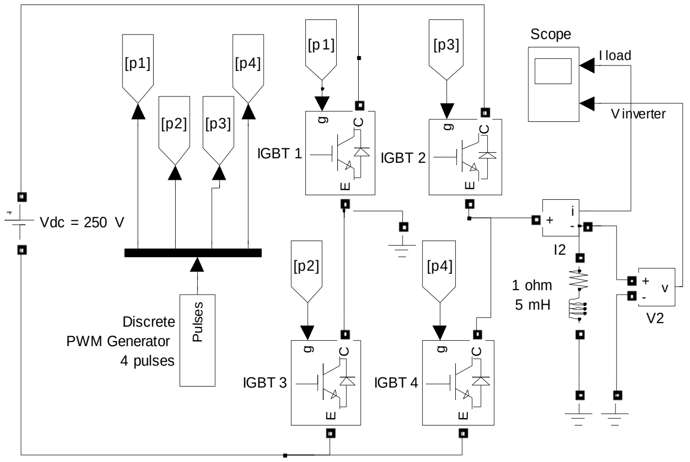

Fig. 5. Simulation of the full bridge inverter and the pulse generator.

The main speciation of the grid connected inverter is that current must be drawn from the PV plant and delivered to the utility grid at unity power factor. We considered the grid connected inverter of Fig. 6 where inverter voltage (Vinv) was the fundamental component of inverter output, VL was the voltage drop across the link inductor and Vac was the utility grid waveform.

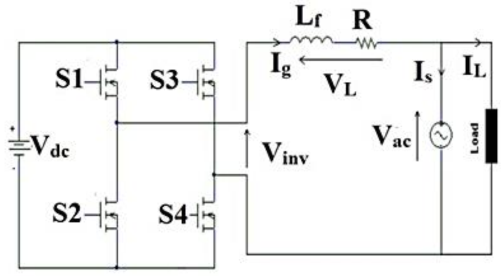

Fig. 6. Full bridge grid connection.

Equivalent block diagram of the grid connected topology is given in the Fig. 7.

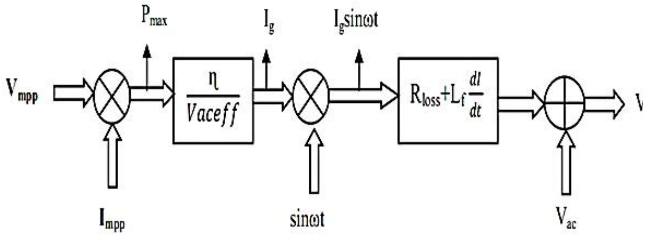

Fig. 7. Block diagram of the control system.

The implementation of the above block diagram (Fig. 7) in MATLAB is shown in Fig. 8.

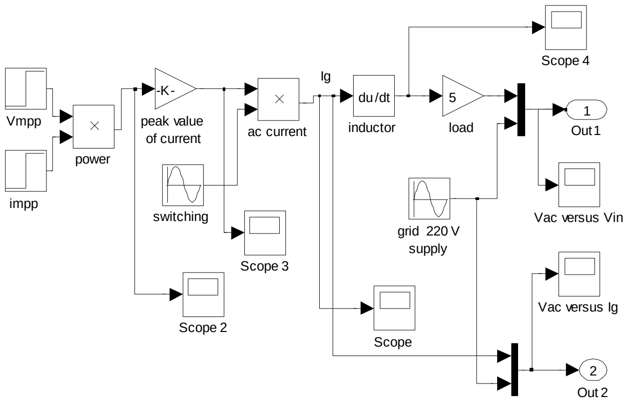

Fig. 8. Block diagram of the control system using MATLAB.

We considered Fig. 6 and assumed that the losses are negligible. It was observed that:

Vinv = Vac + Ig … … … … … … … … … (1)

Where all variables were vectors of the form:

V = Vejφ

Then, Vinv = Vac + j . Lf . ω . Ig … … … (2)

To achieve the unity power factor condition, the current waveform was kept in phase with the utility voltage waveform.

The key to control this operation was the inverter voltage variable, Vinv . From equation (2), it can be written as:

$$Ig = \frac{V_{inv} - V_{ac}}{j.Lf.\omega} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \quad (3)$$

The phasor, this looks like:

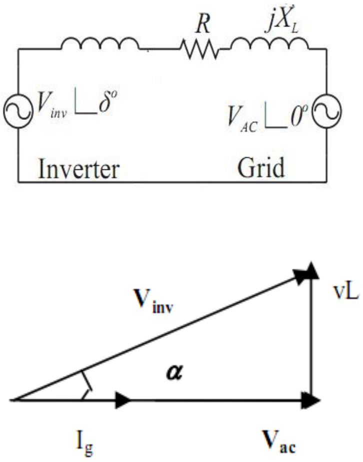

Fig. 9. Phasor diagram of grid-connected PV system.

The above phasor in Fig. 9 shows that the magnitude and direction of current flow (and therefore power flow) which was controlled by the phase shift α and magnitude of the inverter output waveform.

III. RESULTS AND DISCUSSIONS

A. *Inverter Simulation:*

By playing the simulation which is shown in Fig. 4 & Fig. 5, we observed the two waveforms which are shown in Fig. 12 & Fig. 13 on the two Scope blocks: Current into the load (trace 1) and Voltage generated by the PWM inverter (trace 2).

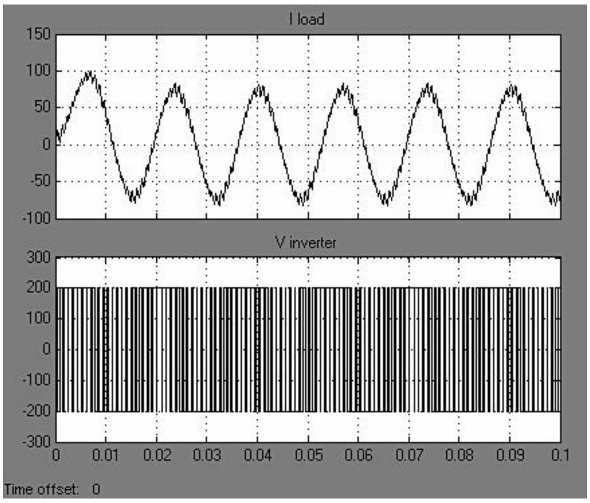

Fig. 10. The half-bridge inverter output waveform.

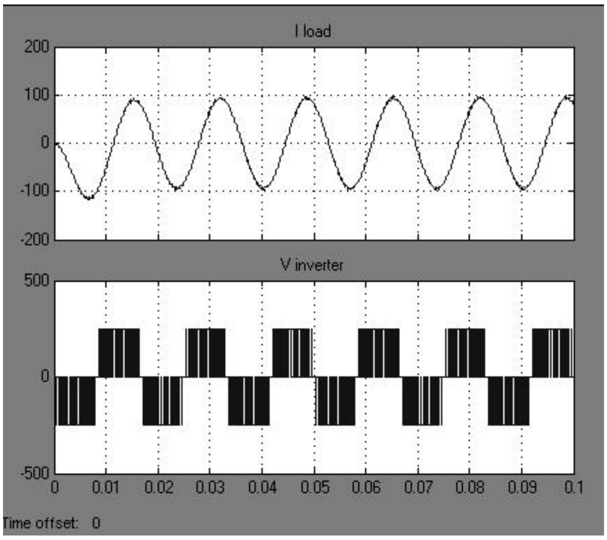

Fig. 11. The full-bridge inverter output waveform.

The half-bridge inverter generated a bipolar voltage (-200V or +200V). Harmonics occurred around the carrier frequency (1080 Hz ± k*60 Hz), with a maximum of 103% at 1080 Hz. The full-bridge inverter generated a monopolar voltage varying between 0 and +250V for one half cycle and then between 0 and -250V for the next half cycle. For the same DC voltage and modulation index, the fundamental components magnitude was twice the value obtained with the half-bridge. Harmonics generated by the full-bridge were lower and they appeared at double of the carrier frequency (maximum of 40% at 2*1080 ± 60 Hz). As a result, the current obtained with the full-bridge was smoother.

B. Simulation results of inverter & grid voltage:

The simulation result of the scope in Fig. 8 is shown in the Fig. 12 below.

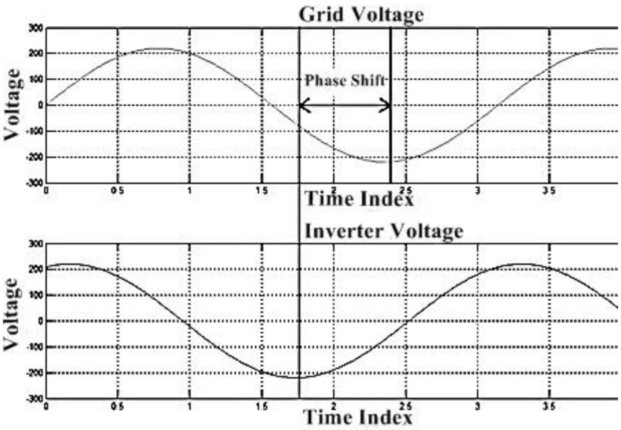

Fig. 12. Grid voltage vs inverter voltage.

The above Fig. 12 shows the phase difference between the grid voltage and the inverter output waveform. The phase difference between the grid voltage and the inverter had occurred due to filter impedance between inverter and grid which was highly inductive.

C. Simulation results in case of grid failure:

In this case, we witnessed the transient analysis. When a switch is on or off, then if we want to know the instantaneous current or voltage, it is defined as transient analysis.

We assumed that the instantaneous current just before the grid failure was I(o-) = 12*sin(ωt+450). Then the grid connected PV system which is shown in Fig. 6 reduced to following equivalent circuit (Fig. 13) in terms of grid failure.

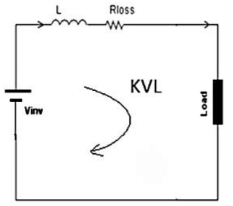

Fig. 13. Equivalent circuit when grid failure occurs.

Then KVL was applied in the above loop and instantaneous current in terms of grid failure was found as:

$$i(t) = 12 * \sin(\omega t + 45^{\circ})\ e\ -800t + 9[1- e\ -800t]$$

So finally the instantaneous current was determined with the help of transient analysis when grid failure occurs. Plotting of the signal using MATLAB is shown in the following Fig. 14.

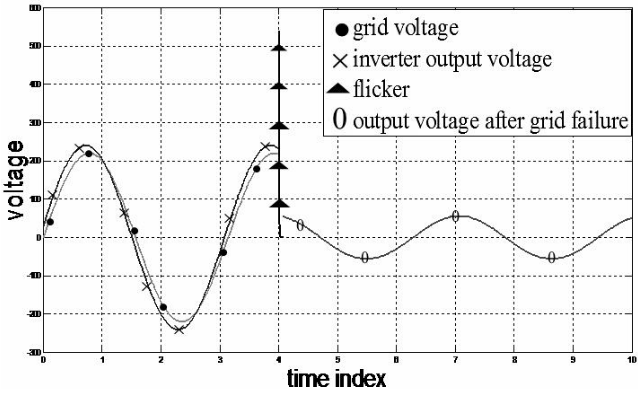

Fig. 14. Inverter output voltage Vinv vs grid voltage Vac in case of grid failure.

The simulated result had shown that the inverter output voltage was sensitive to sudden changes in the reference current and the ac main voltage failure. From the figure we noted the apparition of a flicker with a high voltage at the moment of grid failure, which could cause damages to the connected loads.

IV. CONCLUSIONS

This work was focused on the simulation of the grid connected photovoltaic system before its real-time implementation. First a particular case for simulation of single-phase PV inverter in Simulink was observed focusing on the control design and some important characteristics were perceived. In this work we presented a simulation study of PV grid connected inverter based on the interactive model. The simulation results have shown that the inverter output voltage showed a good sensitivity to sudden changes in the reference current or the ac main voltage failure. It has been also observed that, grid disconnection is needed for all grid-tied inverters if the ac line voltage or frequency goes above or below limits as prescribed in the standard. Furthermore, the inverter must also shut down the PV current supply to the grid if it detects an island i.e. the grid is no longer present. In either case, the inverter should not interconnect and export power until the inverter records the proper utility voltage and frequency in the grid. These protections eliminate the chances of injection of voltage or current into disconnected utility wires or switchgear or other loads and thus prevents any threats to utility personnel making the whole system secure.

REFERENCES

[1] Makoto Konagai, “Present Status and Future Prospects of Silicon Thin-Film Solar Cells”, Japanese Journal of Applied Physics 50 (2011) 030001.

[2] Fact Sheet: South Korea climate change policies, Available at: http://www.climate-connect.co.uk/Home/sites/default/files/Fact%20Sheet%20South%20Korea%20Climate%20Policy.pdf; Accessed on: 21 October 2013.

[3] Soeren Baekhoej Kjaer, John K. Pedersen and Frede Blaabjerg, “Review of Single-Phase Grid-Connected Inverters for Photovoltaic Modules”, IEEE Transactions on industry applications, vol. 41, no. 5, September/October 2005.

[4] Mohamed A. Eltawil and Zhengming Zhaoa, “Grid-connected photovoltaic power systems: Technical and potential problems-A review”, Renewable and Sustainable Energy Reviews 14 (2010), pp 112–129.

[5] H. Mohd Hanafi, Z. Idris, M. K. Hamzah and Azilah Saparon, “Modelling & Simulation of Single-phase Matrix Converter as a Frequency Changer with Sinusoidal Pulse Width Modulation Using MATLAB/Simulink”, First International Power and Energy Conference PECon 2006, November 28-29, 2006, Putrajaya, Malaysia.

[6] Huan-Liang Tsai, Ci-Siang Tu, and Yi-Jie Su, “Development of Generalized Photovoltaic Model Using MATLAB/SIMULINK”, Proceedings of the World Congress on Engineering and Computer Science 2008, WCECS 2008, October 22 - 24, 2008, San Francisco, USA

[7] AB Alias, “Modeling and simulation of single phase inverter with pwm using matlab/Simulink”, B. Sc. thesis, Faculty of Electrical & Electronic Engineering, 2007, University Malaysia Pahang.

[8] MP Kazmierkowski, R Krishnan, F Blaabjerg, “Control in power electronics”, Academic Press, 2002, Elesevier Science.

[9] JT Bialasiewicz and E Muljadi, “Analysis of Renewable-Energy Systems Using RPM SIM Simulator,” IEEE Trans. on Power Electronics, vol. 53, no. 4, 2006.

[10] C Alafodimos, P Fetfatzis, P Kofinas, M Kallousis, X Kikidakis, “Design simulation for a 3-phase grid connected PV inverter in Simulink”, Proceedings 3d Intrernational Scientific Conference (ERA-3), 2008, Aegina, Greece.

[11] Y Xue, L Chang, S B Kjaer, J Bordonau, T Shimizu, “Topologies of single-phase inverters for small distributed power generators: An overview”, IEEE Transactions on Power Electronics,Volume: 19, Issue: 5, 2004. Publisher: IEEE, Pages: 1305-1314.

[12] N. Mohan, T. M. Undeland, W. P. Robbins, Power Electronics Converters, Applications and Design. John Wiley & Sons, 2003.

[13] M H Rashid, Power Electronics: circuits, devices and application, 3rd edition, 2004, pp 531-640.

[14] M Ciobotaru, T Kerekes, R Teodorescu, “PV inverter simulation using MATLAB/Simulink graphical environment and PLECS blockset”, 32nd Annual Conference , IEEE Industrial Electronics, IECON, 2006.