DSP Based Control of Grid Interactive Inverter for Small Scale DG Applications

Noufal. P, Sujith. S

***Abstract*— This paper describes a single phase grid interactive inverter system especially for small scale DG renewable sources. The hardware part of the system consists of a single phase full bridge inverter. The control strategy consists of a hysteresis controller operating in coordination with a single phase PLL. The simulation model of the overall system is developed in MATLAB/Simulink environment. The viability of the scheme has been ensured by performing experimental studies on a laboratory prototype. The control strategy is digitally implemented in TMS320F2812, 32 bit processor. MATLAB-DSP Interfacing method is used for programming the DSP processor.**

Index Terms*— DSP Processor, Distributed Generation (DG), Hysteresis Controller, H-Bridge Inerter, Phase Locked Loop(PLL).

I. Introduction

Power production from renewable energy sources is gaining impetus all over the world. If the energy produced from renewable energy sources can be converted into ac form and if it could be integrated to electrical grid, it will be of great interest. There are very popular systems where power produced from the renewable sources are exported to electrical grid as a generator.

Grid-connected systems are installed in areas where the grid is present and robust, and able to accept energy feeding from the renewable energy sources like photovoltaic systems. Operating a renewable system in parallel with an electric grid requires special inverters. The inverter is the heart of the total system and is the focus of all utility-interconnection. This inverter is used to synchronize the output of inverter and the utility. Since the grid variables cannot be considered as constant, when a power converter is connected to the grid, it should be continuously monitored in order to ensure that the grid state is suitable for the correct operation of the power converter.

Every grid interactive inverter control scheme consists of a current control/power control and synchronization technique. There are a lot of linear as well as non-linear current control strategies suitable for single phase grid interactive inverters. Classical PI control with grid voltage feed-forward is commonly used for current-controlled inverters. In this control, the error between actual and reference current is fed to a PI controller. The current error is then amplified through this controller and emerges as a control voltage [1]. This control voltage is then compared with a ramp signal to generate the ON and OFF times. But this solution exhibits two well-known drawbacks: the inability of the PI controller to track a sinusoidal reference without steady state error and a poor disturbance rejection capability. This is due to the poor performance of the integral action when the disturbance is a periodic signal.

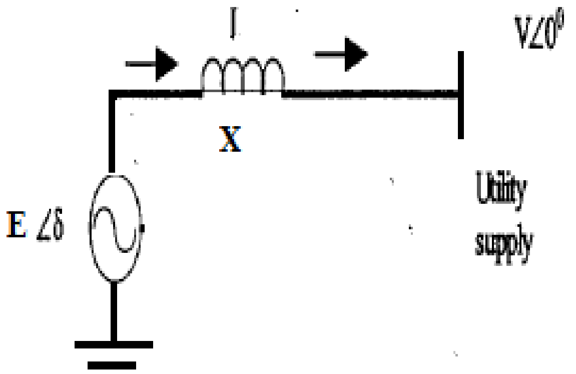
Instantaneous current control is not exercised in the PWM based control explained above. In between two consecutive switching, the current can exceed the maximum limit. If the PWM controller is sampled and held once a switching cycle, then current is controlled on an average but not on an instantaneous basis [7]. Hysteresis controller overcomes such a drawback by converting a voltage source into a fast acting current source. The current is controller within a narrow band of excursions from its desired value in the hysteresis controller. The hysteresis window determines the allowable or preset deviation of current Δi.

II. Principle of Operation

Operation of single phase grid interactive inverter can be explained well with the single line diagram shown in Figure.1.

Figure.1. Single Line Diagram of Grid Interactive Inverter

Where E is the fundamental inverter output voltage, X is the



filter reactance and V is the utility voltage (after synchronized). While synchronizing frequency, magnitude and phase of the terminal voltage are made in synchronism with the utility voltage V. Then the fundamental inverter output voltage should lead the terminal voltage, for the flow of power to grid. This angle of lead is called power angle δ. The power flow equation is given below [16]. P,Q are active, reactive power respectively.

Manuscript received August 20, 2014.

Noufal. P, M-Tech Scholar, Department of Electrical and Electronics Engineering, NSS College of Engineering, Palakkad.

Sujith. S, Associate Professor, Department of Electrical and Electronics Engineering, NSS College of Engineering, Palakkad.

$$S = P + jQ$$

$$S = \frac{\mathbf{E}\ V}{X}\sin\delta + j\left[\frac{\mathbf{E}\ V}{X}\cos\delta - \frac{V^2}{X}\right]$$

From the above equation, it is clear that the export of more active power is achieved by increasing the power angle δ even by maintaining the magnitude of 'E' as a constant. But increase of δ also causes the change in reactive power. If ECosδ = V then reactive power transfer will be zero hence upf operation.

III. System Description

The schematic diagram of the overall system is shown in Figure.2.

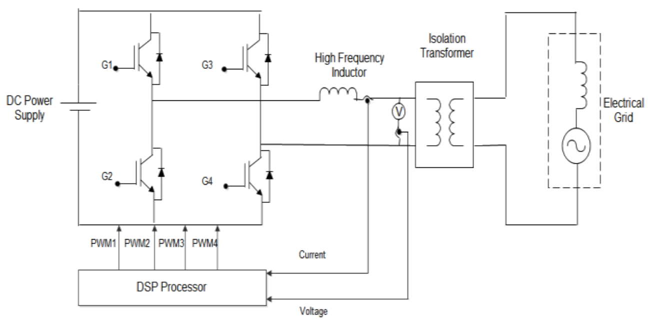


Figure.2. Schematic Diagram of Total System

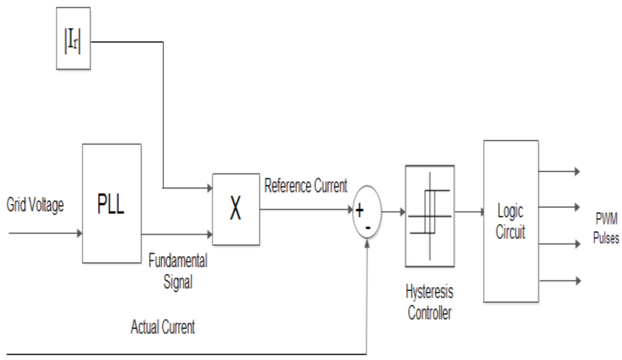
The constant DC input voltage source is given to single phase H bridge inverter. The output of the inverter is connected to the electrical grid through a filter inductor and an isolation transformer. Grid voltage and injected current are feedback to the processor. The control scheme implemented in the DSP processor will generate pulses necessary to run the inverter.

IV. Control Scheme

Requirements of the control scheme mentioned in section II are possible by the implementation of hysteresis current control in conjugation with a PLL. The proposed scheme is given in Figure.3.Grid voltage is fed to a single phase PLL. From PLL the position of grid voltage is obtained, using which "sinωt" function is generated. Then required magnitude of injected current is set. Now "I_r sinωt" will be the reference current for the hysteresis controller. Incorporation of PLL to generate reference current will ensure the condition that injected current should be in phase with the grid voltage (unity power factor operation). Moreover, delays introduced by the controller and sensors can be compensated by just advancing the phase-angle detected by the PLL.

The error between the reference current hence generated and actual current is found out. That error is given to the hysteresis controller. Controller will generate pulses necessary to run the H bridge inverter. The inerter produces modulated output voltage for satisfying the entire requirements.

Figure.3. Operation of Hysteresis Controller with PLL



In the above mentioned control scheme, grid voltage magnitude is not at all taken into account. Because the control scheme produces sufficient voltage at the inverter output so as to inject the set current. Hence sufficient DC link voltage should be provided. If the grid voltage is V, then dc input voltage should be at least 1.5 times V. If this condition is violated, then current injection won't takes place.

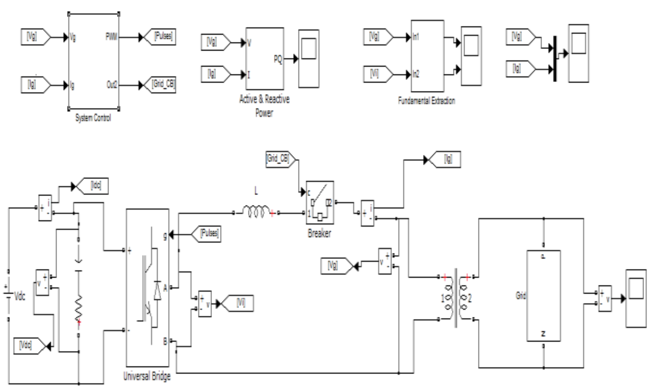
V. Simulation of the Total System

In this simulation study, the DC input voltage of the inverter is taken as a constant magnitude under the assumption that with the help of suitable DC-DC converter and the battery storage, DC input voltage will be maintained as constant.

The hardware part of the simulation model is shown in Figure.4.The constant DC input voltage is given to single phase H-bridge inverter using IGBT/diode. The output of the inverter is connected to a series inductor and then to a step-up isolation transformer. The secondary of the step-up transformer is connected to the single phase electrical grid. The electrical grid is realized using programmable source block in series with varying inductance. The programmable source block can create major grid disturbances like changes in amplitude, frequency and phase jump/lag.

Figure.4.Hardware Part of the Simulation

The control part of the simulation is shown in Figure.5.



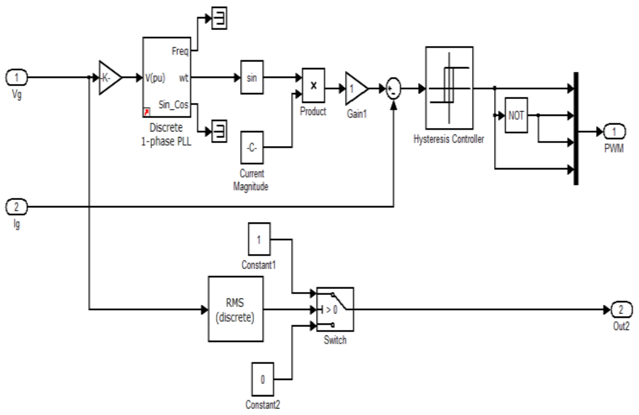


Figure.5.Simulation Block of the Control System

The first part of the control scheme is the realization of hysteresis control running by extracting the fundamental grid voltage. Using Discrete 1-phase PLL, position of fundamental (50Hz) grid voltage is extracted, and using which sinusoidal function is realized. The injected current magnitude is set to the desired value, and then reference current signal will be generated. The error between the reference current and actual injected current is calculated, which is then fed to the hysteresis controller. The bandwidth of the hysteresis current controller, Äi = 0.05A.

The second part of the control system is the control of circuit breaker (CB) connecting the inverter system to the grid. The Grid CB is controlled while islanding condition is detected. For a reference current magnitude of 2 A (ie. 2sinωt), the grid voltage and injected current waveforms in the primary side of isolation transformer are shown in Figure.6, which are in phase hence unity power factor operation could be achieved.

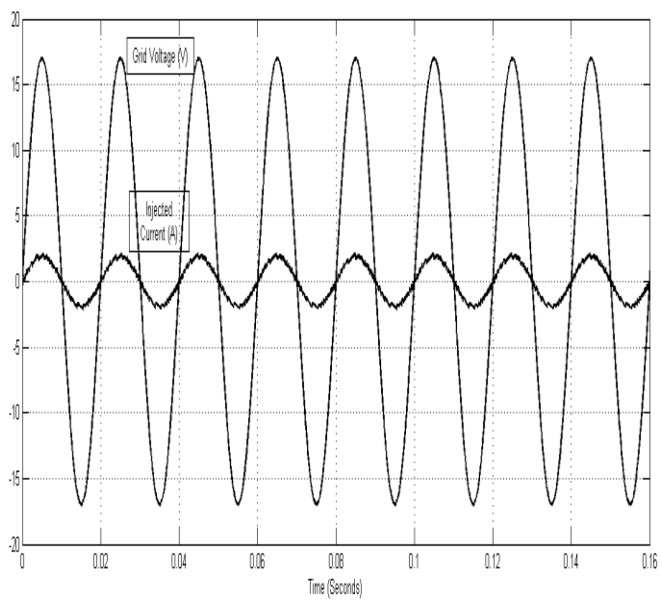


Figure.6. Grid Voltage and Injected Current Waveforms

IV. Hardware Setup

A. Control Design in Matlab/Simulink

Creation of Simulink model by utilizing blocks in Embedded Coder Toolbox is the first step in this programming method. The first Simulink block to insert in the model is the "Custom Board" (found in the Embedded IDE Link library). This block configures the Simulink model for the DSP that is used (F2812 in the case of this project). Then according to the requirement, processor architecture blocks such as PWM and ADC can be utilized. The control design implemented in Simulink for the proposed control strategy is shown in Figure.7.

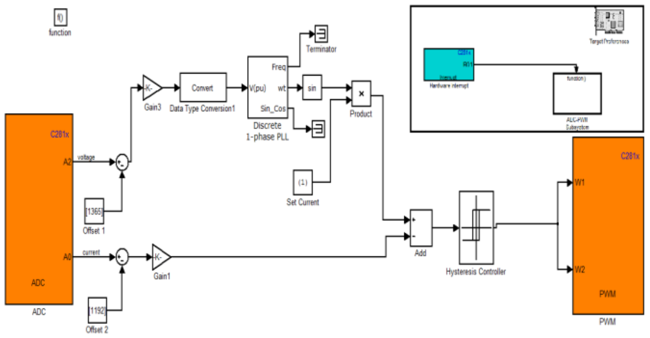


Figure.7.Simulink Model of the Control System for DSP Programming

B. Hardware Results

Hardware setup of the total system is shown in Figure.8.

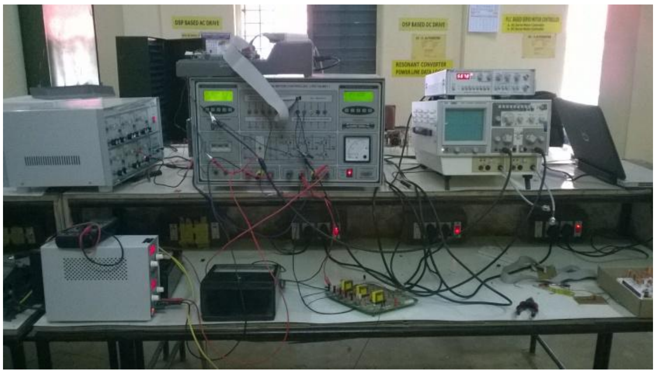


Figure.8.Total Hardware Setup

DC power supply is given to the input of inverter module. The output of the inverter is connected to electrical grid through inductive filter. Using Hall Effect transducer module grid voltage and injected current are fed to the processor. DSP-PC communication is enabled through JTAG emulator. The hardware parameters are shown in Table.2.

The control algorithm is so developed to export 1A current. Grid voltage and current is shown in Figure.9. It is clear from the figure that, upf operation is achieved. THD of the current waveform is found to be within the IEEE recommended standard, i.e. 5%.

Table.2. Hardware Parameters

	Parameters	Details
1	Input DC Power Supply	25V, 1A
2	IGBT Intelligent Power Module	Mitsubishi -PM25RSB120
3	High Frequency Inductor	Ferrite Core, 10mH, 0.5A
4	Isolation Transformer	230/12 V, 1A
5	Voltage Sensor	Hall Effect Transducer LV25-P
6	Current Sensor	Hall Effect Transducer LTS 25-NP
7	PC-DSP Communication	JTAG Emulator XDS100

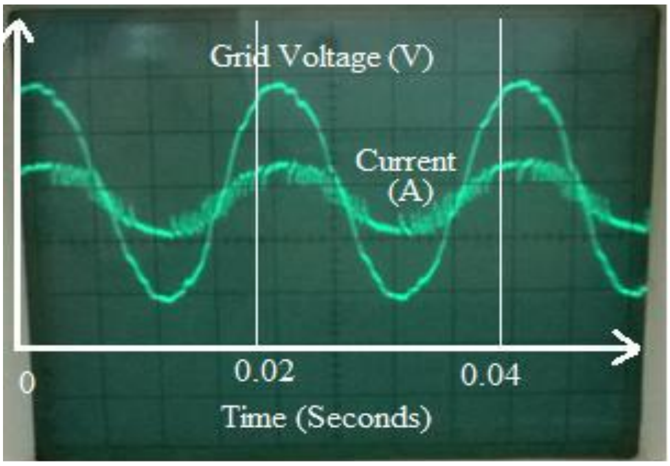


Figure.9.Grid Voltage and Injected Current Waveforms

V. Conclusion

A simple and effective control for single phase grid interactive inverter has been presented. The importance of this control scheme has been checked by performing experimental studies on a laboratory prototype. The steady state performance of the system is analyzed and unity power factor operation has been achieved.

The control strategy is implemented in Texas Instrument DSP processor TMS320F2812. The algorithm implementation is achieved by utilizing MATLAB-DSP interfacing method.

References

[1]. R. Teodorescu, M. Liserre, and P. Rodr´ýguez., Grid Converters For Photovoltaic and Wind Power System. West Sussex, U K: John Wiley & Sons, Inc.,2011.

[2]. B. I. Rani, G. S. Ilango and C. Nagamani, "Control Strategy for Power Flow Management in a PV System Supplying DC Loads," IEEE Trans. Ind. Electron., vol. 60, no. 8, Aug 2013.

[3]. F. D. Freijedo, J. D. Gandoy, and O. López,, "Tuning of Phase-Locked Loops for Power Converters Under Distorted Utility Conditions," IEEE Trans. Ind. Appli., vol. 45, no. 6, Nov-Dec. 2009.

[4]. M. Chithra and S. G. B. Dasan, "Analysis of cascaded H bridge multilevel inverters with photovoltaic arrays," in Proc. Int. Conf. Emerging Trends Elect. Comput. Technol., pp. 442–447, Mar. 2011.

[5]. M. Chithra and S. G. B. Dasan, "Analysis of cascaded H bridge multilevel inverters with photovoltaic arrays," in Proc. Int. Conf. Emerging Trends Elect. Comput. Technol., pp. 442–447, Mar. 2011.

[6]. O. Lopez, F. D. Freijedo, A. G. Yepes, P. Fernandez-Comesaa, J. Malvar, R. Teodorescu, and J. Doval-Gandoy, "Eliminating ground current in a transformerless photovoltaic application," IEEE Trans. Energy Convers., vol. 25, no. 1, pp. 140–147, Mar. 2010.

[7]. K.A. Corzine, "A Hysteresis Current–Regulated Control for Multi-Level Drives", IEEE Transactions on Energy Conversion, Vol. 15, No.2, pp. 169-175, June 2000.

[8]. T. Basso and N.R. Friedman, "IEEE 1547 National Standard for Interconnecting Distributed Generation," Colorado: National Renewable Energy Laboratory.,2003.

[9]. R. Burkart and J. W. Kolar, "Overview and Comparison of Grid Harmonics and Conducted EMI Standards for LV Converters Connected to the MV Distribution System," in Proc.Power Electron. PCIM 2012, Brazil, Sept, 2012.

[10]. Frede Blaabjerg, Zhe Chen, and Soeren Baekhoej Kjaer, "Power Electronics as Efficient Interface in Dispersed Power Generation Systems", IEEE Trans. Power Electron., vol. 19, no. 5, pp. 1184–1194, Sept. 2004.

[11]. Zhilei Yao and Lan Xiao, "Control of Single-Phase Grid-Connected Inverters with Nonlinear Loads", IEEE Trans. Ind. Appli., vol. 60, no. 4, Nov-Dec. 2013.

[12]. Ahmed Abdalrahman, Abdalhalim Zekry and Ahmed Alshazly, " Simulation and Implementation of Grid-connected Inverters", J. Comput. Appl., pp. 0975 – 8887, vol. 60, no. 4,Dec. 2012.

[13]. J. M. Chang, W. N. Chang and S. J. Chiang, "Single-Phase Grid-Connected PV System using Three-Arm Rectifier-Inverter", IEEE Trans. Aero. Electron., vol. 42, no. 1, Jan. 2006.

[14]. Francisco D. Freijedo, Alejandro G. Yepes, Óscar López, Pablo Fernández-Comesaña and Jesús Doval-Gandoy", IEEE Trans. Instr. Meas., vol. 60, no. 9, Sept. 2011.

[15]. H.P. Garg., Solar Energy-Fundamentals.New Delhi: Tata McGraw-Hill,2008

[16]. M. H. Rashid.,Power Electronics Handbook. Florida: Academic Press Ltd., 2011.

[17]. N. Mohan, T.M. Undeland and W.P.Robbins, Power Electronics-Converters, Applications, and Design.New York: John Wiley & sons, Inc,1989