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Modeling and Control of PWM Inverter for Photovoltaic Applications

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Abstract*— Grid connected photovoltaic (PV) systems feed electricity directly to the electrical network operating parallel to the conventional source. To make the PV generation system more flexible and expandable, the back stage power circuit is composed of a boost converter and a pulse width modulation (PWM) inverter. Since the conversion efficiency of PV arrays is very low, it requires Maximum Power Point Tracking (MPPT) control techniques to extract the maximum available power from PV arrays. In this paper, Perturb and Observe (P&O) Maximum Power Point Tracking algorithm is used for the control of PV systems. This paper deals with the design and simulation of a grid connected PV system. In the grid connected power supply mode, the goal of power management can be achieved by controlling the amplitude and direction of the output current in the PV inverter. An Adaptive Total Sliding Mode Control (ATSMC) scheme is designed for the PWM inverter with a full bridge frame work. Digital Phase lock loop (PLL) is used to lock grid frequency and phase. Hence the grid connected inverter with the ATSMC scheme has low Total Harmonic Distortion and high power factor to provide an ac output with high power quality. The effectiveness of the proposed inverter with the ATSMC scheme is verified using MATLAB / Simulink power system toolbox.

***Index Terms*—Adaptive control, Distributed Generation (DG), Maximum Power Point Tracking (MPPT), grid connection, digital PLL, Total Sliding Mode Control (TSMC).**

I. INTRODUCTION

In the past century, global surface temperatures have increased at a rate near 0.6^0C/century because of the global warming taking place due to effluent gas emissions and increasing CO_2. Problems with energy supplies and use are related not only to global warming but also to such environmental concerns as air pollution, acid precipitation, ozone depletion, forest destruction, and radioactive emissions. To prevent these effects, some potential solutions have evolved including energy conservation through improved energy efficiency, a reduction in fossil fuel use and an increase in environmentally friendly energy supplies. Recently, energy generated from clean, efficient and environmentally friendly sources has become one of the major challenges for engineers and scientists. Among them, photovoltaic (PV) application has received a great attention in research because it appears to be one of the most efficient and effective solutions to this environmental problem [1]. Dc–dc converters with high voltage gain are required in many industrial applications, such as front-end stages for clean-energy sources, dc back-up energy systems for uninterruptible power supplies (UPS), high-intensity discharge lamps for automobile headlamps, and the telecommunications industry. In this paper, a boost converter topology is introduced to boost and stabilize the output dc voltage of PV modules for the utilization of a dc–ac inverter. Due to the high capital cost of PV array, maximum power point tracking (MPPT) control techniques are essential in order to extract the maximum available power from PV array in order to maximize the utilization efficiency of PV array. Perturb and Observe method (P&O) which is a direct method of MPPT algorithms is discussed in this paper [2]. DG systems commonly need dc–ac converters or inverters as interfaces between their single-phase loads and sources. DG inverters often experience a wide range of input voltage variations due to the fluctuations of energy sources, which impose stringent requirements for inverter topologies and controls [3]. Developments in microelectronics and power devices have caused the widespread application of pulse width modulation (PWM) inverters in industries. The basic mechanism of a PWM inverter is to convert the dc voltage to a sinusoidal ac output through the inverter LC filter blocks. The performance is evaluated by the total harmonic distortion (THD), the transient response, and the efficiency. Thus, much attention has been paid to the closed-loop regulation of PWM inverters to achieve good dynamic response under different types of load, e.g., linear control [5], observer for grid current control [6], Lyapunov - based control and sliding-mode control (SMC) [7]. These topologies are only suitable for stand-alone power supply applications. Synchronization issues are predominant when the PWM inverter is connected to the grid. In other words, the phase angle of the utility voltage should be measured in real time inorder to set the energy transfer between the grid and the PWM inverter. For achieving a higher power factor in the grid connection, digital PLL can be used. SMC is one of the effective nonlinear robust control approaches since it provides system dynamics with an invariance property to uncertainties once the system dynamics are controlled in the sliding mode. The insensitivity of the controlled system to uncertainties exists in the sliding mode, but not during the reaching phase, i.e., the system dynamic in the reaching phase is still influenced by uncertainties. Recently, some researchers have adopted the idea of total SMC (TSMC)to get a sliding motion through the entire state trajectory, i.e., no reaching phase exists in the control process ,so that the

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controlled system through the whole control process is not influenced by uncertainties. This paper attempts to extend the Adaptive TSMC (ATSMC) methods to voltage and current control of a single PWM inverter [4]. This paper is organized into six sections. Following the introduction, the system description of grid connected PV system are described in section II. The PV – Boost system along with MPPT control are explained in section III. In section IV, the dynamic model and the control based on ATSMC methods are developed for the grid-connected power supply mode. In addition, simulation analysis are performed to demonstrate the efficiency and applicability of the developed methodologies in Section V. Finally, some conclusions are drawn in Section VI.

II. SYSTEM DESCRIPTION

The block diagram representation of grid connected inverter with PV generation system is depicted in Fig. 1. The system is mainly composed of a PV system, a boost converter, a P & O MPPT controller, a full-bridge inverter, a system controller, digital PLL, utility grid and an output load. Due to the PV effect, the voltage of a PV plate is not very high. However, the PV array with a higher output voltage is difficult to fabricate and it may fail when any single PV plate is inactive. Besides, the corresponding output voltage is varied easily with respect to the variation of loads. To satisfy the requirement of high voltage demand, a high-efficiency dc–dc converter with high voltage gain is needed as one of the essential mechanisms in the high-performance grid connected PV generation system. In this paper, a step-up converter is implemented to reduce the series-connected numbers of PV plates, to maintain a constant dc bus voltage for the inverter utilization, and to decouple and simplify the control design of a dc–ac inverter. Perturb and Observe (P&O) MPPT algorithm is used to control the switching of DC-DC converter by applying pulse-width modulation (PWM) technique. This is a simple algorithm that does not require previous knowledge of the PV generator characteristics or the measurement of solar intensity and cell temperature and is easy to implement with analogue and digital circuits. The output voltage from PV panel is step up to required DC voltage through DC – DC boost converter. This constant DC voltage from PV boost system fed the PWM inverter. An AC load is connected between the PWM inverter and the utility grid. So that the load is served by both the inverter and the grid. An Adaptive Total Sliding Mode Control scheme is used to control the output current of the propose DG inverter. Digital PLL is used to provide the reference current required in the controller in order to achieve synchronization with the utility grid. A PWM full bridge inverter with four power semiconductors and a low pass filter is regarded as the dc–ac power conversion circuit to meet the requirement of an ac power source. Since the PWM inverter dominates the performance in converting the dc voltage source to an ac voltage source, the quality of the ac output waveform of the PV generation system is highly dependent on the performance of the PWM inverter. Thus, an ATSMC system is introduced by way of switching four power semiconductors in this inverter for possessing the output current with a high power factor.

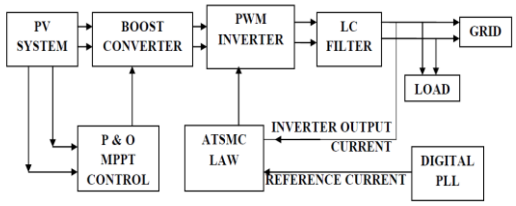

Fig. 1. Block Diagram of Grid Connected PV System

III. PV – BOOST SYSTEM

The PV Boost system provides the constant DC voltage across the proposed DG inverter. A photovoltaic system is a system which uses one or more solar panels to convert solar energy into electricity. It consists of multiple components, including the photovoltaic modules, mechanical and electrical connections and mountings and means of regulating and/or modifying the electrical output. The building block of PV arrays is the solar cell, which is basically a p-n junction that directly converts light energy into electricity: it has a equivalent circuit as shown below in Fig. 2.

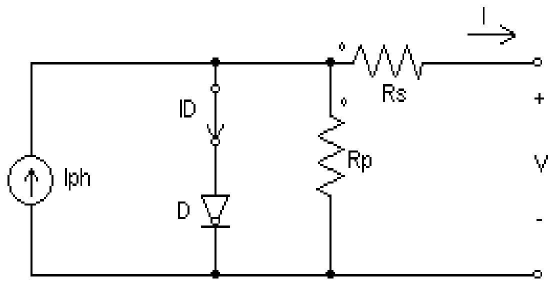

Fig. 2. Equivalent Circuit of a PV cell [8]

The current source I_{ph} represents the cell photo current, R_s and R_p are used to represent the intrinsic series and shunt resistance of the cell respectively. Usually the value of R_p is very large and that of R_s is very small, hence they may be neglected to simplify the analysis. PV cells are grouped in larger units called PV modules which are further interconnected in series-parallel configuration to form PV arrays or PV generators. The PV mathematical model used to simplify the PV array is represented by the equation:

$$I = n_p I_{ph} - n_p I_{rs} \left[\exp\left(\frac{q}{kTA} * \frac{V}{n_s} \right) - 1 \right] \quad (1)$$

where I is the PV array output current; V is the PV array output voltage; n_s is the number of cells in series and n_p is the number of cells in parallel; q is the charge of an electron; k is the Boltzmann's constant; A is the p-n junction ideality factor; T is the cell temperature (k); I_{rs} is the cell reverse saturation current. The factor A determines the cell deviation from the ideal p-n junction characteristics; it ranges between 1-5 but for our case A=2.15[8].

A. *Boost Converter*

DC-DC converters can be used as switching mode regulators to convert an unregulated dc voltage to a regulated dc output voltage. The regulation is normally achieved by PWM at a fixed frequency and the switching device is generally BJT, MOSFET or IGBT. The circuit diagram for boost converter is shown in Fig. 3. When the switch is ON for a time duration DT, the switch conducts the inductor current and the diode becomes reverse biased. This results in a positive voltage $v_L = V_d$ across the inductor. This voltage causes a linear increase in the inductor current i_L. When the switch is turned OFF, because of the inductive energy storage, i_L continues to flow. This current now flows through the diode, and $v_L = V_d - V_o$ for a time duration (1-D)T until the switch is turned on again [8].

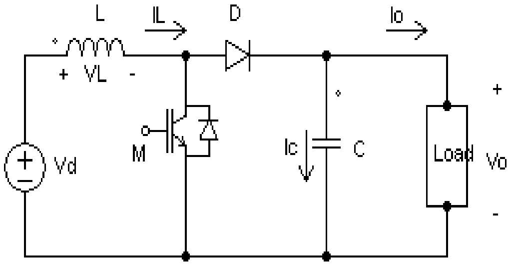

Fig. 3. Circuit diagram of boost converter [8]

The voltage conversion ratio for the boost converter is obtained by equating the integral of the inductor voltage over one time period to zero.

$$\int_0^T V_L dt = \int_0^{t_{on}} V_L dt + \int_{t_{on}}^{t_{off}} V_L dt = 0 \quad (2)$$

$$V_d DT + (V_d - V_o)(1 - D)T = 0 \quad (3)$$

$$\frac{V_o}{V_d} = \frac{1}{1-D} \quad (4)$$

Where D is the duty cycle and T is the time period.

B. *Perturb and Observe (P & O) MPPT Algorithm*

There are many MPPT algorithms have been developed and implemented by researchers. The P & O method is most widely used in MPPT because of its simple structure and it requires only few parameters. Fig. 4 shows the flow chart of P & O method. It perturbs the PV array's terminal voltage periodically and then it compares the PV output power with that of the previous cycle of perturbation. Based on Fig. 4, when PV power and PV voltage increase at the same time and vice versa, a perturbation step size, ΔD will be added to the duty cycle, D to generate the next cycle of perturbation in order to force the operating point moving towards the MPP. When PV power increases and PV voltage decreases and vice versa, the perturbation step will be subtracted for the next cycle of perturbation. This process will be carried on continuously until MPP is reached. However, the system will oscillate around the MPP throughout this process, and this will result in loss of energy. These oscillations can be minimized by reducing the perturbation step size but it slows down the MPP tracking system [2]. This MPPT algorithm is introduced to provide gate pulses to the MOSFET switch used in the boost converter. P & O method determines the duty cycle of MOSFET switch in the PV boost system.

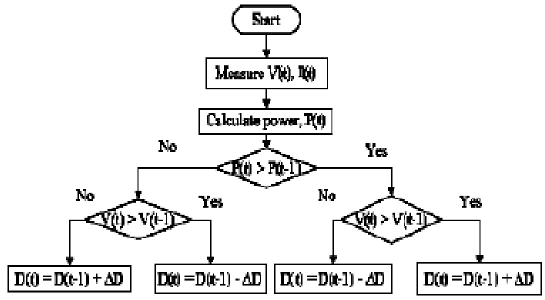

Fig. 4. Flow chart of P & O method [2]

IV. PWM INVERTER CONTROL

A. *Dynamic Model of Grid Connected Power Supply*

Fig. 5 shows the grid-connected power-supply framework, where v_u is the utility voltage, i_0 is the output current of the full-bridge inverter and the voltage source v_{ld} emulates the disturbance incurred by the utility power [10]. Due to the symmetry property of the positive-half and negative-half periods in the unipolar PWM switching, the dynamic equation during the positive-half period can be represented via the state-space average method and the linearization technique as

$$\dot{i}_0 = \frac{1}{L_f}(D_i V_d - v_u - v_{ld}) \quad (5)$$

According to the definitions of $D_i = \frac{v_{con}}{\hat{v}_{tri}}$ and $K_{PWM} = \frac{V_d}{\hat{v}_{tri}}$, then the dynamic equation of the PWM inverter in the grid connected power supply mode can be given by

$$\ddot{i}_0 = \frac{K_{PWM}}{L_f} v_{con} - \frac{1}{L_f} v_u - \frac{1}{L_f} v_{ld} \quad (6)$$

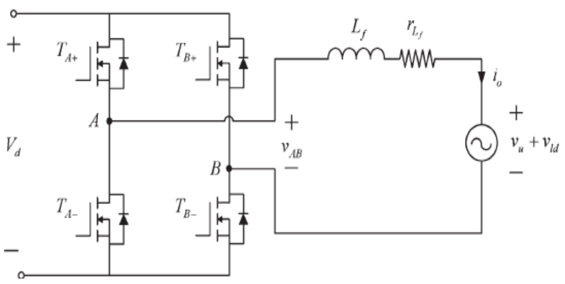

Fig. 5. Grid connected power supply framework [10]

By choosing the ac output current (i_0) as the system state and the control signal (v_{con}) as the control input can be rearranged

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$$\dot{x}_g(t) = d_p u(t) + f_p g(t) + h(t)$$

$$= (d_{pn} + \Delta d_{pn})\, u(t) + (f_{pn} + \Delta f_{pn})\, g(t) + h(t)$$

$$= d_{pn} u(t) + f_{pn} g(t) + p(t) \quad (7)$$

where $x_g(t) = i_0$, $u(t) = v_{con}$, $f_p = -1 / L_f$, $d_p = K_{PWM} / L_f$, $g(t) = v_u$ and $h(t) = -v_{1d} / L_f$: d_{pn} and f_{pn} denote the nominal values of d_p and f_p respectively: Δd_{pn} and Δf_{pn} represent the system parameter variations; p(t) is called the current lumped uncertainty. Here, the bound of the current lumped uncertainty is assumed to given by

$$|p(t)| < \rho_g \quad (8)$$

Where ρ_g is a positive constant [10].

A. ATSMC For Grid Connected Power Supply Mode

The objective of the ATSMC in the grid connected power supply mode is to force the system state ($x_g = i_0$) to track a reference output current ($x_{gd} = i_{cmd}$) under the possible occurrence of system uncertainties. Define a voltage control error (e_i) and a grid connected sliding surface (s_g) as

$$e_i = x_g - x_{gd} = i_0 - i_{cmd} \quad (9)$$

$$s_g(t) = e_i(t) - e_i(0) + \alpha \int_0^t e_i(\tau)\, d\tau \quad (10)$$

$e_i(0)$ is the initial value of $e_i(t)$ and α is a positive constant..

The proposed ATSMC system for the grid connected power supply mode, as shown in Fig. 6, can be divided into three main parts. The first part addresses the performance design. The objective is to specify the desired performance in terms of the nominal model, and it is referred to as the baseline model design (u_{gb}). Following the baseline model design, the second part is the curbing controller design (u_{gc}) to totally eliminate the unpredictable perturbation effect from the parameter variations and external disturbance so that the baseline model design performance can be assured. Finally, the third part is the adaptive observation design to estimate the upper bound of the current lumped uncertainty to alleviate the chattering phenomenon caused by the inappropriate selection of a conservative constant control gain in the curbing controller. The entire control methodology of the ATSMC system is summarized Theorem 1. Theorem 1: If the PWM inverter scheme shown in eqn (7) is controlled by the three part ATSMC system described by eqn (11) – eqn (13) with the adaptive observation design shown in eqn (14), then the stability of the ATSMC system for the current control of the PWM inverter can be guaranteed [9][11].

$$u = u_{gb} + u_{gc} \quad (11)$$

$$u_{gb} = -d_{pn}^{-1}\left(f_{pn} g - \dot{x}_{gd} + \alpha e_i\right) \quad (12)$$

$$u_{gc} = -\hat{\rho}_g(t)\, d_{pn}^{-1}\, \mathrm{sgn}\left(s_g(t)\right) \quad (13)$$

$$\hat{\rho}_g(t) = |s_g(t)| / \lambda_g \quad (14)$$

Where λ_g is a positive constant.

Proof: According to the Lyaponov analyses, the stability of the controlled system can be assured [12][13].

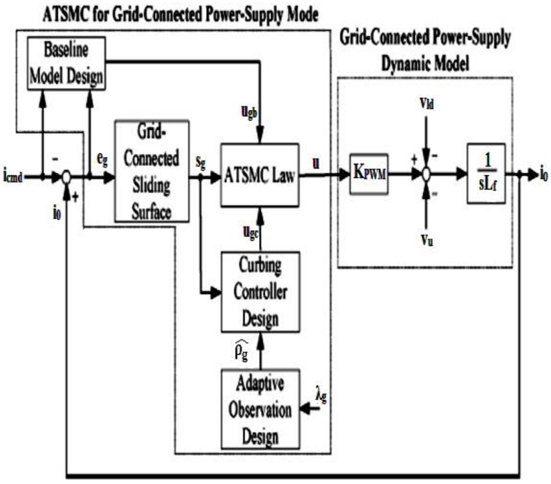

Fig. 6. Block diagram of ATSMC for grid connected power supply mode [4]

A. Digital PLL Control

In order to achieve a unity power factor in the grid-connected power supply mode, a digital PLL control scheme shown in Fig. 7 is introduced into the proposed ATSMC to produce the unit grid-connected current command (i^u_{cmd}). The phase angle (θ) of the reference grid-connected current (i_{cmd}) is assumed to take the following form:

$$\theta = \int_0^t \omega dt + \theta_a = \omega t + \theta_0 + \theta_a \quad (15)$$

Where is the compensation angle generated by a proportional – integral (PI) compensator, ω is the predetermined angular velocity of the utility power and θ_0 is the predetermined initial phase angle .

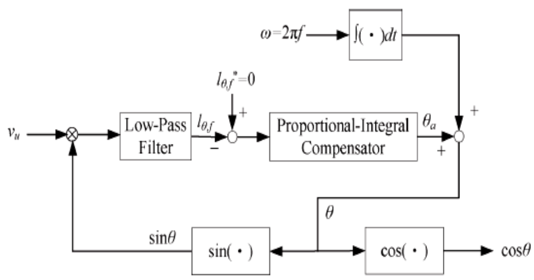

Fig. 7. Digital PLL control scheme [4]

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By passing through a low pass filter, the signal $(l_{\theta,f})$ with only dc components can be expressed by the definitions of the estimated phase angle $\theta_c = \theta_0 + \theta_a$ and the phase angle error $\theta_e = \theta_{u,0} - \theta_c$, where $\theta_{u,0}$ is the phase angle of the utility voltage v_u. The PI compensator produces the compensation phase angle which will gradually force the phase angle error to converge to zero. It means that the phase angle of the utility voltage can be obtained to compute the unit grid connected current command $(i^u_{cmd} = \cos\theta)$. According to Theorem 1, the ATSMC system with the adaptive observation in can guarantee the stable current control of the inverter in the grid connected power supply mode, i.e., the current control error will converge to zero. Since the reference current command (i_{cmd}) with cosine waveform is produced by the digital PLL control, theTHD within the grid connected current can be controlled in the grid connected power supply mode, even when the grid is noticeably distorted [11][4].

V. SIMULATION RESULTS

The performance of the proposed control strategy was evaluated by computer simulation using MATLAB / Simulink power system toolbox. The proposed system was tested under the following conditions:

Switching frequency f_s: 20 kHz;
Output frequency: 50 Hz;
Filter inductor L_f : 85 mH;
Filter capacitor C_f : 50 µF;
DC-link voltage V_d: 360 V;
Output phase voltage V_0 (single phase): 220 V (V_{rms});
Output capacity: 1 KW

A. PV - Boost Model

The PV boost system provides constant DC voltage to the proposed PWM inverter. The output voltage from the PV panel is step up to sufficient DC voltage to meet the requirements of the PWM inverter. Here V_{dc} is set to 360V. Fig. 8 shows the PV curve of a single PV panel. Here two 327 W, 54.7 V, 5.98 A PV panels are connected in series to provide a DC voltage of 100 V. Output voltage of a single PV panel is approximately 50 V. Maximum power output of a single panel is 327 W. This power is maintained using the P & O method.

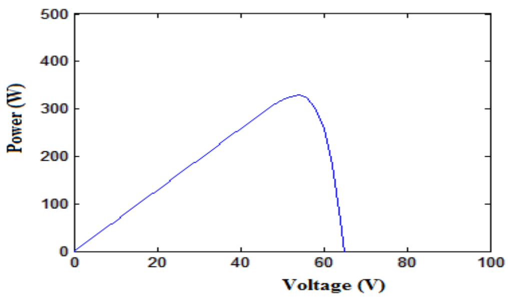

Fig. 8. PV curve of a single PV panel

From the PV curve it is clear that the maximum power is obtained at the open circuit voltage of the PV panel ie; at 64.9 V. The short circuit current of a single PV panel is 6.46 A. The P & O method is used as the MPPT algorithm for extracting maximum power output from the PV panel. The MPPT controller maintains the output power constant at its maximum value. The output power curve in Fig. 9 shows that P & O method extracts a maximum power of 590 W from the two PV panels in series. The DC - DC step up converter rises the voltage from 100 V to 360 V. Fig. 10 shows voltage response of step up dc to dc converter with the MPPT controller. Boost converter is modeled to provide required DC voltage across the PWM inverter. P & O method gives the triggering pulses to converter switch. Duty cycle of the converter switch is obtained by the mathematical modeling of P & O algorithm.

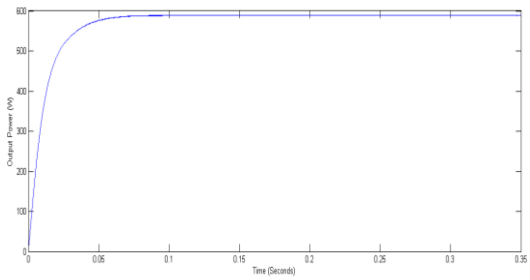

Fig. 9. Output power curve of MPPT controller

Analysis of boost converter is performed in continuous mode of operation with duty cycle D = 0.72, Switching frequency and fs = 20 KHz. The components included in the simulink model of boost converter are inductance, L = 2.267e-4 H, capacitance, C = 2.032e-5 F and resistance, R = 250 . The output voltage and current of boost converter are 360 V and 1.816 A respectively. Two series connected PV panels along with the MPPT controlled boost converter fed up the PWM inverter. The output voltage of PV boost system with the MPPT is always confined to 360 V DC in order to meet the requirement of proposed DG inverter.

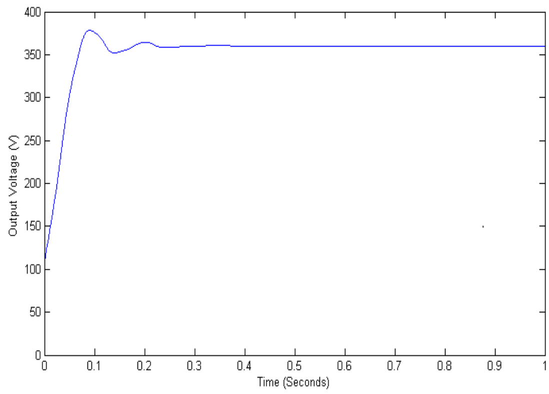

Fig. 10. PV boost system response

A. Grid Connected Power Supply Mode

The parameters for the ATSMC system in the grid connected power supply mode are chosen to achieve the best control performance by considering the requirement of stability as follows:

$\alpha = 13$, $\lambda_g = 0.5$

Referring to the sliding surface in eqn (10), the parameter α is decided by the convergent time of the current control error at the nominal system. The positive constant λ_g in eqn (14) can

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be determined according to the adaptation speed. Fig. 11 shows the experimental response of the digital PLL control scheme, where i_{cmd} denotes the grid connected current command. As can be seen from Fig. 11, one can obtain that the grid connected current command can be quickly controlled in phase with the utility voltage (v_u) inside 50 ms. This performance is helpful to achieve the objective of unity power factor in the grid connected power supply mode.

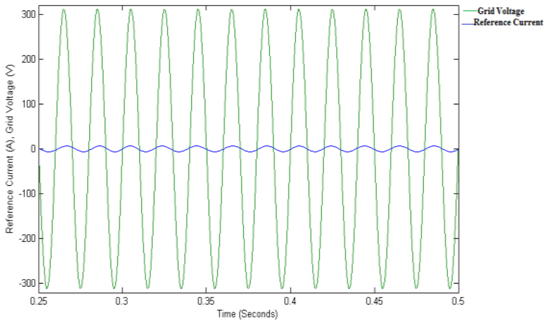

Fig. 11. Response of digital PLL control

The experimental voltage and current responses of the grid connected power supply mode with the proposed ATSMC are shown in Fig. 12. In grid connected power supply mode, the current injected by the PWM inverter should be in phase with the grid voltage. So, the controller compares the inverter current and the grid connected current command inorder to synchronize with the grid voltage. As the inverter current is synchronized with the utility voltage, the grid-connected power factor is measured to be 99%. By observing Fig. 12, the grid connected current can be stably controlled to be in phase with the utility voltage. The THD within the grid connected current is less than 3%.

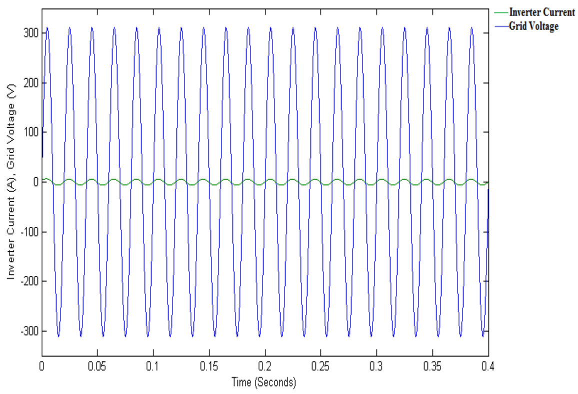

Fig. 12. Synchronization of inverter current with grid voltage

The load voltage response in grid connected power supply mode is shown in Fig. 13. In grid connected power supply mode, the load is served by both the utility grid and the PWM inverter. The PWM inverter is designed for 1 KW. So, for a 5 KW resistive load, 1 KW is supplied by the inverter and the remaining 4 KW is provided by the utility grid. The active power sharing of the inverter and the utility grid along with the load active power are shown in Fig. 14. The load draws active power from both the inverter and the grid to satisfy its demand.

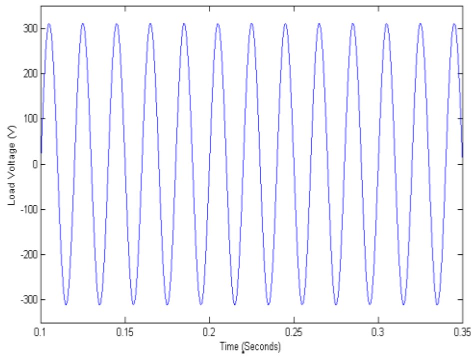

Fig. 13. Load voltage response in grid connected mode

From Figures 12, 13 and 14, one can conclude that the inverter with the proposed ATSMC in the grid connected power supply mode possesses excellent properties, including robust control performance, high power factor and high grid connected power supply quality.

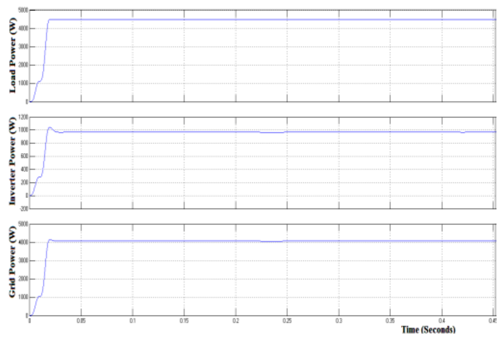

Fig. 14. Active power sharing of inverter and the grid

VI. CONCLUSION

Renewable energy sources like solar, wind, and micro-hydro power can be interfaced through the distributed power generation modules with the micro grid system, which can operate in islanded mode (off grid) and grid connected mode. This paper has successfully developed a grid-connected PV generation system. For simplicity and effectiveness reasons, P&O MPPT algorithm which can find the real Maximum Power Point of a PV system was also reviewed. The effectiveness of the boost converter and the PWM inverter control for a grid connected PV generation system was verified by simulation analysis. An Adaptive Total Sliding Mode Controller can be used for current control of the PWM inverter in order to address the issues of utility grid connection. Moreover, the output current of the PWM inverter can almost be maintained in phase with the utility voltage. The corresponding PF is 0.99, satisfying the PF standards in industrial applications. Besides, robust control performance, high power conversion efficiency and high grid connected power supply quality can be obtained from the grid connected inverter with the ATSMC scheme.

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REFERENCES

[1] S. Al-Hallaj, "More than Enviro-friendly: Renewable Energy is also Good for the Bottom Line", IEEE Power Energy Magazine, Vol. 2, No. 3, May/June 2004.

[2] Mei Shan Ngan and Chee Wei Tan, "A Study of Maximum Power Point Tracking Algorithms for Stand-alone Photovoltaic Systems", IEEE Applied Power Electronics Colloquium, August 2011.

[3] Y. Xue, L. Chang, S. B. Kjaer, J. Bordonau, and T. Shimizu, "Topologies of Single-Phase Inverters for Small Distributed Power Generators: An Overview", IEEE Transactions Power Electron, Vol. 19, No. 5, September 2004.

[4] Rong-Jong Wai, Chih-Ying Lin, Yu-Chih Huang and Yung-Ruei Chang, "Design of High-Performance Stand-Alone and Grid-Connected Inverter for Distributed Generation Applications", IEEE Transactions on Industrial Electronics, Vol. 60, No. 4, April 2013.

[5] D. C. Lee and G. M. Lee, "Linear control of inverter output voltage in over modulation", IEEE Transactions on Industrial Electronics, Vol. 44, No. 4, August 1997.

[6] I. S. Kim and M. J. Youn, "Variable-structure observer for solar-array current estimation in a photovoltaic power-generation system", Proceedings, Electrical Power Applications, Vol. 152, No. 4, July 2005.

[7] K. David Young, Vadim I. Utkin and Umit Ozgner, "A Control Engineers Guide to Sliding Mode Control", IEEE Transactions on Control Systems Technology, Vol. 7, No. 3, May 1999.

[8] Debashis Das and Shishir Kumar Pradhan, "Modeling and Simulation of PV Array with Boost Converter: An Open Loop Study", Thesis Report, 2011.

[9] F. Plestan, Y. Shtessel, V. Bregeault and A. Poznyak, "New Methodologies for Adaptive Sliding Mode Control", International Journal of Control, February 2010.

[10] Rong Jong Wai and Wen Hung Wang, "Grid Connected Photovoltaic Generation System", IEEE Transactions on Circuits and Systems, Vol. 55, No. 3, April 2008.

[11] Rong Jong Wai and Wen Hung Wang, "Design of Grid Connected Photovoltaic Generation System With High Step Converter and Sliding Mode Inverter Control", IEEE International Conference on Control Applications, Vol. 50, No. 4, October 2007.

[12] Rong Jong Wai and Kuo Min Lin, "Robust Decoupled Control of Direct Field Oriented Induction Motor Drive", IEEE Transactions on Industrial Electronics, Vol.52 No.3, June 2005.

[13] R. J. Wai, "Adaptive Sliding Mode Control for Induction Servomotor Drive", IEE Proceedings Electrical Power Applications, Vol. 147 No. 6, November 2000.

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