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dsPIC33 Based Control for PV-Grid System with a Buck-Boost MPPT

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Abstract

The use of solar energy is very important due to the fossil based energy crisis. Rapid progress in PV technologies has contributed to its applications. There are many PV based power plants built around the world. Maximum Power Point Trackers (MPPT) take significant role in operating PV modules to produce their maximum power. They are implemented by using choppers to match the load resistance and the PV resistance. Recently, integration between PV modules and grids is more popular due to their advantages. The PV-Grid system can be single stages, two stages or any other types and all of them use PWM (pulse width modulation) converters as their cores. In this paper, a PV-Grid System using buck-boost chopper as MPPT is analyzed. Power generated by PV modules is transferred to the grid by using an inverter that operated as a controlled current source so the complexity can be reduced. Finally, the dsPIC33 based control scheme for such a PV-Grid System was made as a laboratory scaled-prototype to verify the analysis and simulations.

Keywords: *buck-boost chopper, PV-Grid, inverter, dsPIC*

1. Introduction

Solar energy has become an alternative solution since the fossil based energy crisis hit the world. By using solar panels (PV), solar energy can be converted into electrical energy and an MPPT is required to maximize the output power. An MPPT in principle is a DC-DC converter (chopper) that is capable to force a PV module operating point near its maximum power point (MPP) [1-3]. There are three types of chopper: buck, boost and buck-boost types. A buck chopper based MPPT can be applied for the output resistance less than the PV resistance at its MPP [4] while for the output resistance greater than the PV resistance, a boost chopper based MPPT has to be used. MPPTs have been developed by many researchers especially in control methods.

Recently, integration between PV modules and grid systems become popular due to their advantages, it is named as PV-Grid Systems. There are some methods to make PV-Grid, they can use single stage, two stage or any other types [5-7]. An inverter is a core in a PV-Grid System for the output of PV modules are DC voltage/current while the grid voltage is AC and it is also required synchronization in parallel connection. PWM technique is very important to operate inverters with controlled output voltage/current [8]. A PWM based voltage source inverter (VSI) will be capable to be synchronized to the grid voltage [9-11]. Some inverters are operated as controlled voltage sources in a PV-Grid System and complexities are faced due to the synchronization requirements. Operating inverters as controlled current sources are simpler in PV-Grid Systems for the inverter output voltage is automatically locked to the grid voltage.

In this paper, a PV-Grid System using buck-boost MPPT is described. This MPPT has flexibility in magnitude of DC output voltage. To provide a constant DC-link voltage as an input of the inverter, such an MPPT shows its advantages. The proposed inverter operated as a controlled current source is capable to transfer all power generated by PV modules. Finally, simulations and laboratory experiments were done to verify the analysis. The prototype uses control circuits that based on dsPIC33.

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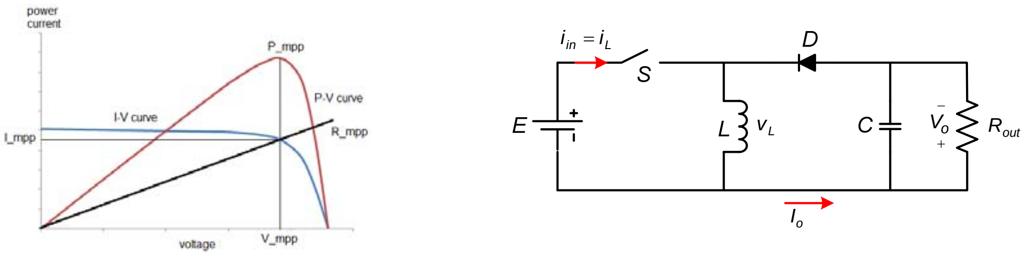
2. Research Method

2.1. Buck Boost Chopper as a Maximum Power Point Tracker (MPPT)

A photovoltaic cell can convert solar energy into electric energy. Based on its characteristic curve (Figure 1(a)), direct connecting a resistive load to this cell will produce less electric power. Some cells can be arranged as serial and/or parallel connection to be a PV module. To maximize the power generated by a PV module, an MPPT is needed. By using a buck-boost chopper, the output voltage of an MPPT can be greater or less than the input voltage. For a PV-Grid Connected System, an inverter is required with specified DC-link voltage level so such a chopper is better to be implemented. In the other hand, the number of PV modules can be more flexible. Figure 1(b) represents a buck-boost chopper as an MPPT. The relationship between input voltage E, output voltage V_O and duty cycle d can be stated as:

$$V_o = \frac{d}{1-d} E \tag{1}$$



(a) (b)

Figure 1. (a) Characteristic curve of photovoltaic, (b) A buck-boost chopper as an MPPT

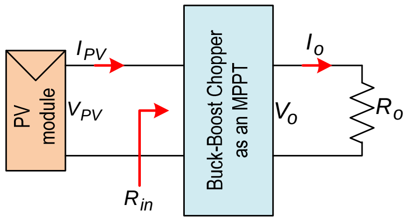


Figure 2. Connecting an MPPT to a PV Module

Connecting such a chopper as an MPPT to a PV module is aimed to get maximum power. By controlling the duty cycle, the operating point of a PV modules can be around the MPP. This can be achieved if the resistance of load seen from the PV module equals to R_{MPP}. Referring to the law of energy conservation, under an ideal system, the input power will equal to the output power of the chopper, then we have (where $E = V_{PV}$ and $R_{in} = R_{MPPL}$):

$$E.I_{in} = V_o.I_o \Leftrightarrow E\frac{E}{R_{in}} = V_o\frac{V_o}{R_{out}} \Leftrightarrow \frac{E^2}{R_{in}} = \frac{V_o^2}{R_{out}} = \left(\frac{d}{1-d}\right)^2 \frac{E^2}{R_{out}}$$

$$R_{in} = \left(\frac{1-d}{d}\right)^2 R_{out} \tag{2}$$

Equation (2) shows that the load resistance connected to a PV module can be greater or less than R_{MPP}.

2.2. Full-Bridge Inverter as an Interface in PV-Grid Connected System

The output voltage of an MPPT is DC voltage. To transfer electric energy generated by PV modules, it is required an inverter to convert DC into AC voltage. Connecting an inverter to a grid, the synchronization requirements must be regarded so the complex problems will be faced. If an inverter is operated as a controlled current source, it is simple to construct the control circuit. Figure 3 depicts a PV-Grid Connected System consists of PV modules, a buck-boost chopper based MPPT and a controlled current source implemented by a Voltage Source Inverter (VSI). Two digital signal controllers implemented by dsPIC33 are used to control the MPPT and the inverter separately. The first dsPIC33 needs two input signals (voltage and current of the PV modules) to force the MPPT operate at its MPP. The second dsPIC33 has four input signals (reference voltage, capacitor voltage, template and the inverter output current) to operate the inverter transferring all power generated by the PV modules to the grid. Under ideal condition the MPPT runs optimally and the electric power generated by the PV modules can be stated as:

$$P_{PV} = V_{MPP}.I_{MPP} \tag{3}$$

Assuming an ideal buck-boost chopper, the output power of the MPPT.

$$P_{MPPT} = V_o.I_o = V_o.\left(\frac{1-d}{d}\right)I_{MPP} \tag{4}$$

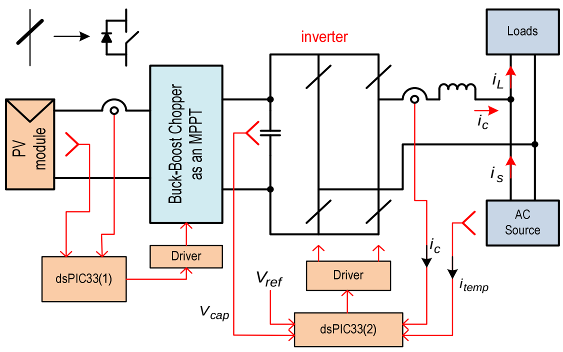


Figure 3. PV-Grid Connected System Consists of PV Modules, Buck-boost MPPT and a Controlled Current Source Implemented by an Voltage Source Inverter

The voltage V_o is the output voltage of the MPPT, it equals to the DC-link voltage (input side of the inverter). For this inverter is parallel connected to the grid, so its voltage must be the same as the grid voltage v_s. Operating an inverter as a controlled current source with template current i_{temp} taken from the grid voltage results in sinusoidal current flowing at the output side of the inverter. The reference current is obtained by $k.i_{temp}$ (where k is multiplying factor) then the output current of the inverter i_c will fluctuate around the reference current. Under ideal condition, the output power of the inverter can be expressed as:

$$P_c = V_s.I_c \approx V_s.I_{ref} \tag{5}$$

Where $I_{ref} = k.i_{temp}$.

For all the power generated by the PV module must be transferred into the grid, then:

$$P_c = P_{PV} = P_{MPP}$$

$$V_s I_{ref} \approx V_{MPP}.I_{MPP} \quad \text{then} \quad I_{ref} \approx \frac{V_{MPP}.I_{MPP}}{V_s} \tag{6}$$

Power equilibrium in the inverter can be detected by sensing the capacitor voltage. If the input power of the inverter is greater than the output power, the capacitor voltage will increase, this means that the inverter absorbs the part of power transferred. If the input power of the inverter is less than the output power, the capacitor voltage will decrease; it means that the inverter sends the part of power to the grid.

2.3. dsPIC33 Based Control Method

dsPIC33 is a family of 16-bit digital signal controller that provides high speed ADCs. In this paper, dsPIC33FJ16GS502 is used as the core of control. To force the PV modules operate near their MPP, the dsPIC33 requires two analog inputs through a current transducer for PV current and a voltage divider for the PV modules voltage (Figure 4(a)). The flow diagram used by the first dsPIC33 is shown in Figure 5(a).

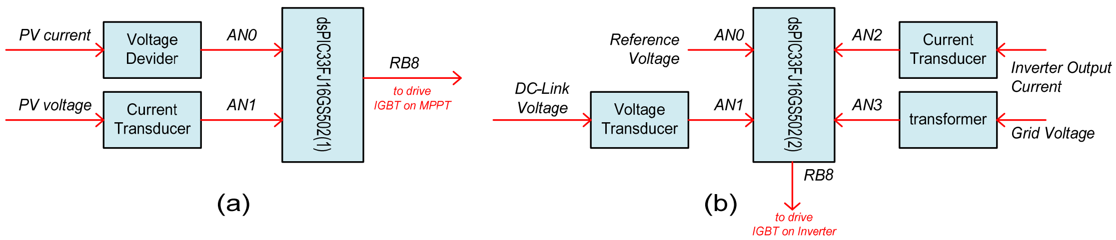


Figure 4. (a) Control scheme of the proposed MPPT using dsPIC33, (b) Control scheme of the proposed inverter using dsPIC33

The control scheme of the inverter operated as a controlled current source is depicted in Figure 4(b). It requires four analog input signals. The reference voltage and the DC-Link voltage signals are needed to keep power equilibrium of the inverter. The two other signals, the inverter output current and the grid voltage as current template are used to make sinusoidal grid current. The flow diagram used by the first dsPIC33 is shown in Figure 5(b).

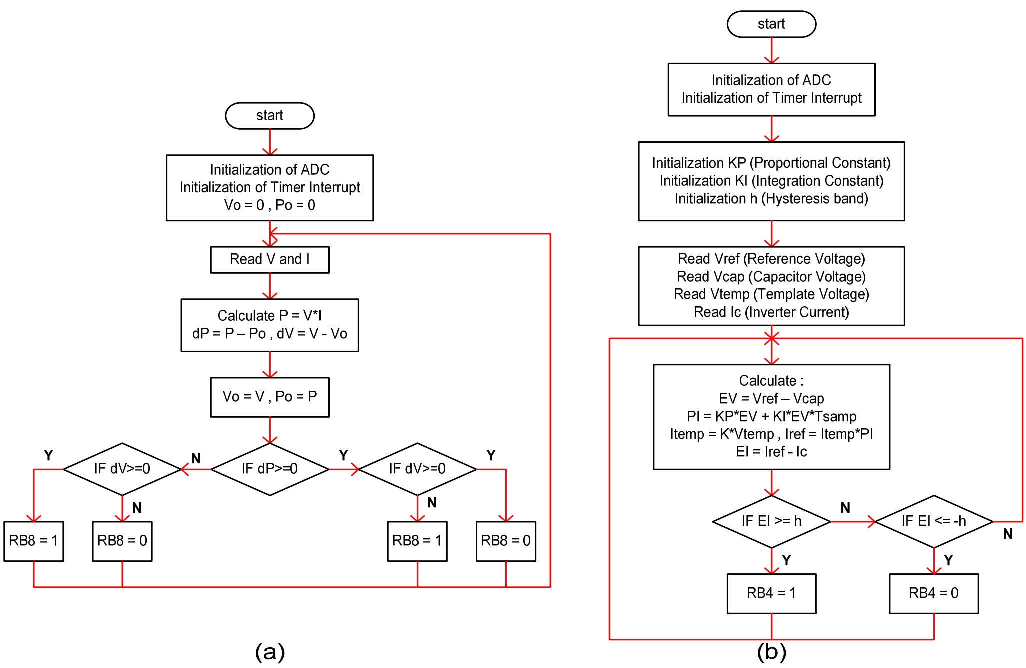


Figure 5. (a) Flow diagram of the proposed MPPT control, (b) Flow diagram of the proposed inverter control

3. Results and Analysis

To verify the analysis, simulations and laboartory experiments were done based on the circuit depicted in Figure 3. The simulations were done by using the PSIM software and the laboartory experiments were tested by using the prototype designed.The simulations for the PV-Grid System were done with the MPPT operated as a boost chopper and a buck chopper under two power condition, when the the load power (P_L) is greater or less than the power generated by the PV modules (P_{PV}). Figure 6 and Figure 7 show the simulation results when the MPPT is operated as a boost chopper. The output voltage of the MPPT is greater than the voltage of the PV modules (Figure 6(a) and 6(b)). The inverter is also capable to transfer all the power generated by the PV modules to the grid because the average power of the inverter output equals to P_{PV} (Figure 6c and 6d). When P_L is greater than P_{PV} , the load current equals to the sum of the grid current and the inverter output current while if P_L is less than P_{PV} , the part of the power generated by the PV modules will enter into the grid side. This means that the grid current has the opposite polarity with respect to the grid voltage or inverter output current (Figure 7). Operating the MPPT of the PV-Grid System as a buck chopper results in the MPPT output voltage less than the PV modules voltage (Figure 8). The currents under two power condition are depicted in Figure 9.

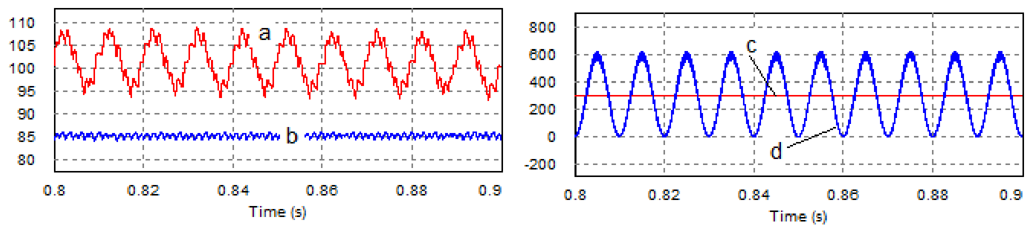


Figure 6. Simulation Results of the PV-Grid Connected System with MPPT Operated as a Boost-chopper (a) MPPT voltage (b) PV voltage (c) power generated by PV modules (d) power transferred by the inverter to the grid

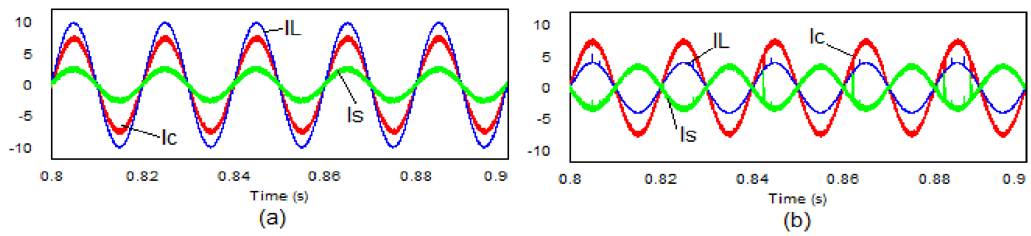


Figure 7. Simulation Results of the PV-Grid Connected System with MPPT Operated as a Boost-chopper (load current I_L, grid current I_s, inverter output current I_c) (a) when the load power is greater than the power generated by PV (b) when the load power is less than the power generated by PV

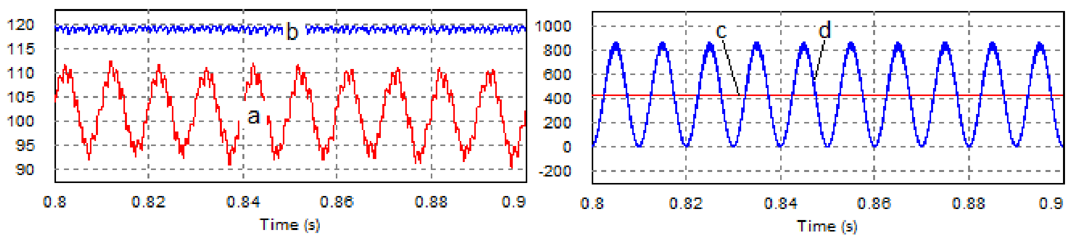


Figure 8. Simulation Results of the PV-Grid Connected System with MPPT Operated as a Buck-chopper (a) MPPT voltage (b) PV voltage (c) power generated by PV (d) power transferred by the inverter to the grid

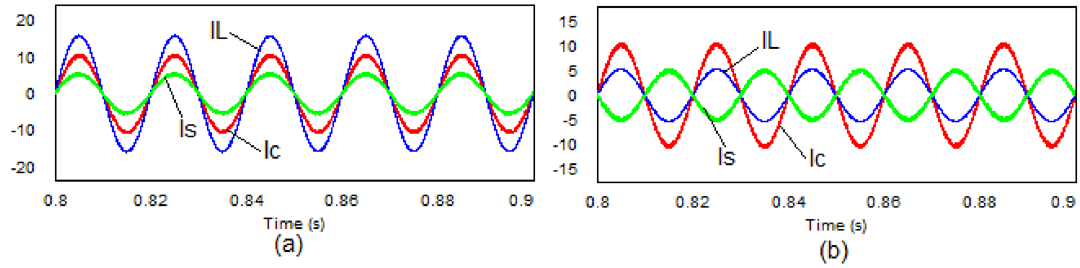


Figure 9. Simulation Results of the PV-Grid Connected System with MPPT Operated as a Buck-chopper (load current I_L, grid current I_s, inverter output current I_c) (a) when the load power is greater than the power generated by PV (b) when the load power is less than the power generated by PV

To do the laboratory experiments, the PV-Grid System was designed by using dsPIC33 based control scheme as presented in Figure 10. The gird voltage applies 32 Volt RMS and the resistive loads of 3.3 Ohm and 9 Ohm. The load current, the grid current and the inverter output current are depicted in Figure 11 and Figure 12. Based on the results, it is proved that the proposed system is capable to transfer all the power generated by the PV modules into the grid without synchronization requirements. Taking a template from the grid voltage as the current reference will force the inverter transmit the real power. The output voltage of the inverter that operated as a controlled current source is automatically locked to the grid voltage. The use of dsPICs as cores of the control scheme makes the system simple, they also provide high speed ADC. For the DC-link voltage of the inverter must be set on common value, the use of a buck-boost MPPT is more attractive.

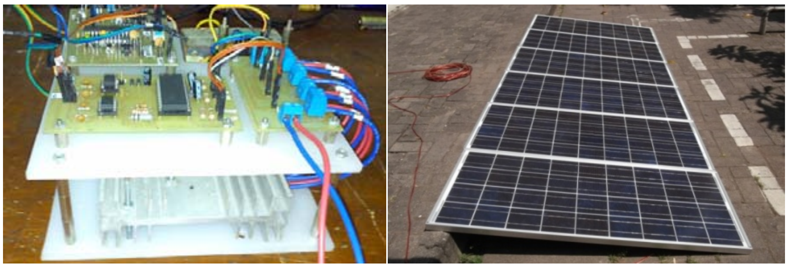


Figure 10. The Prototype used for Laboratory Experiments

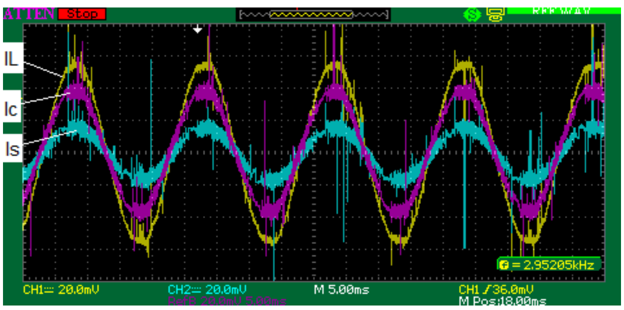


Figure 11. Experimental Results of the PV-Grid Connected System for Load Current I_L, Grid Current I_s and Inverter Current I_c when the Load Power is Greater than the Power Generated by PV Modules [scale : 5A/div – 5ms/div]

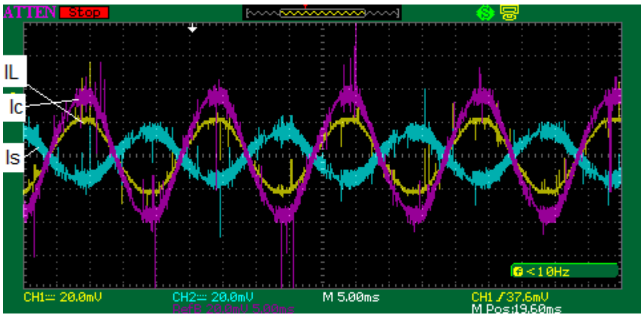


Figure 12. Experimental Results of the PV-Grid Connected System for Load Current I_L, Grid Current I_s and Inverter Current I_c when the Load Power is Less than the Power Generated by PV Modules [scale : 5A/div – 5ms/div]

4. Conclusion

A PV-Grid Connected System with a buck-boost MPPT has been presented. By using a dsPIC33 based control, such a PV-Grid System is capable to transmit all the maximum power generated by the PV modules into the grid. The dsPIC33 is suitable for the core of the control circuit because it has high speed ADCs. Detection of the DC-link voltage can be used to identify the behavior of the power transferred. By keeping its voltage nearly constant, the power equilibrium is achieved. This concept is then used as the basic to control the magnitude of the inverter output current. In the other hand, the template current taken from the grid voltage results in the inverter output current in phase with respect to the grid voltage.

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