International Journal of Electrical and Electronic Engineering & Telecommunications

ISSN 2319 – 2518 www.ijeetc.com
Vol. 3, No. 1, January 2014


*Research Paper*

# THE IMPLEMENTATION OF BOOST CASCADED BUCK CONVERTER BASED PV INVERTER WITH HIGH EFFICIENCY

Solomon Thilakar J[1]*, Pawan Kumar R[1], Madhusudhanan S[1] and Kavaskar S[2]

*Corresponding Author: Solomon Thilakar J, ✉ solomonthilakarj@gmail.com

This paper deals with the simulation and implementation of a single-phase grid-connected transformer-less photovoltaic inverter. The simulations were carried out using MATLAB/SIMULINK software package and hardware implemented. Results show that the proposed topology boosts or bucks the output voltage level depending upon the value of the reference (grid) signal. The inverter is derived from a boost cascaded with a buck converter along with a line frequency unfolding circuit. Due to its novel operating modes, high efficiency can be achieved because there is only one switch operating at high frequency at a time and the converter allows the use of power MOSFET and ultra-fast reverse recovery diode. The interleaved multiple phase structure is proposed to have small equivalent inductance; meanwhile, the ripple can be decreased, and the inductor size can be reduced as well. A two-phase interleaved inverter is then designed accordingly. Finally, the simulation and experiment results are shown to verify the concept and the tested efficiency under 3-kW power condition.

Keywords: Photovoltaic inverter, Topology, Power MOSFET, Interleaved inverter

## INTRODUCTION

As the power demand is going on increasing day-by-day, one of the best alternatives is choosing non-conventional sources like solar energy as the primary sources for power generation in power stations. The power from these sources is several times greater than the one, which we are using at the present. The power from the sun intercepted by the earth is approximately $1.8*10^{11}$ MW, which is thousands of times larger than the present consumption rate on the earth of all commercial energy sources. Thus if we convert this to other forms of energy, it may be one of the most promising of the non-conventional energy resources. The solar

[1] Electrical and Electronics Engineering Department, Panimalar Engineering College, Nasarathpettai Poonamallee, Chennai 600123, India.

[2] Faculty of Electrical and Electronics Engineering Department, Panimalar Engineering College, Nasarathpettai Poonamallee, Chennai 600123, India.

inverter is a critical component in a solar energy system. It performs the conversion of the variable DC output of the Photovoltaic (PV) module(s) into a clean sinusoidal 50 or 60 Hz AC current that is then applied directly to the commercial electrical grid or to a local, off-grid electrical network. Typically, communications capability is included so users can monitor the inverter and report on power and operating conditions, provide firmware updates and control the inverter grid connection. Depending on the grid infrastructure wired (RS-485, CAN, Power Line Communication, Ethernet) or wireless (Bluetooth, ZigBee/ IEEE802.15.4, 6loWPAN) networking options can be used. At the heart of the inverter is a real-time microcontroller. The controller executes the very precise algorithms required to invert the DC voltage generated by the solar module into AC. This controller is programmed to perform the control loops necessary for all the power management functions necessary including DC/DC and DC/AC. The controller also maximizes the power output from the PV through complex algorithms called Maximum Power Point Tracking (MPPT). A DC-to-DC converter is a device that accepts a DC input voltage and produces a DC output voltage. Typically the output produced is at a different voltage level than the input. In addition, DC-to-DC converters are used to provide noise isolation, power bus regulation, etc. The following is a summary of some of the popular DC-to-DC converter topologies. The theoretical advantage of InterCell transformers over separate inductors is demonstrated in an interleaved power converter. Different practical ways to build InterCell transformers are described. A theoretical approach dedicated to interleaved converters and Inter Cell Transformers analysis was presented by Laboure *et al.* (2008). Parallel converter architecture using intercell transformers is one of the most adapted architecture for low-voltage, high-current and fast transient power conversion applications. The main advantage with an interleaved buck converter to intercell transformer is the current ripple reduction in each converter arms which is not the case with non-coupled inductor architectures as per the findings of Le Bolloch *et al.* (2009). Here in this paper, the concept of interleaved boost cascaded buck converter described by Zhao *et al.* (2012) is used for the purpose of improving the efficiency of the PV inverter.

## BUCK BOOST CONVERTER BASED PV INVERTER WITHOUT INTERLEAVED INDUCTOR

With continuous conduction for the Buck-Boost converter, input voltage $V_x = V_{in}$ when the transistor is ON and output voltage $V_x = V_o$ when the transistor is OFF. For zero net current change over a period the average voltage across the inductor can be derived from the Figure 1.

The Waveforms for buck-boost converter are represented in Figure 2. From the waveform shown in Figure 2.

$$V_{in}t_{ON} + V_O t_{OFF} = 0$$

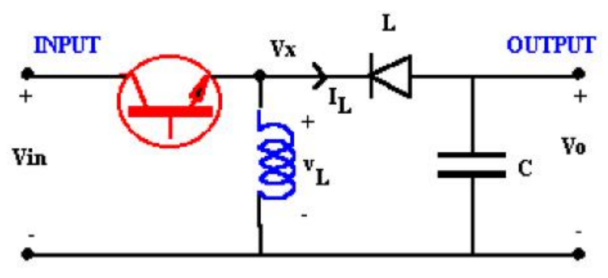
which gives the voltage ratio

$$\frac{V_O}{V_{in}} = -\frac{D}{(1-D)}$$

and the corresponding current ratio is

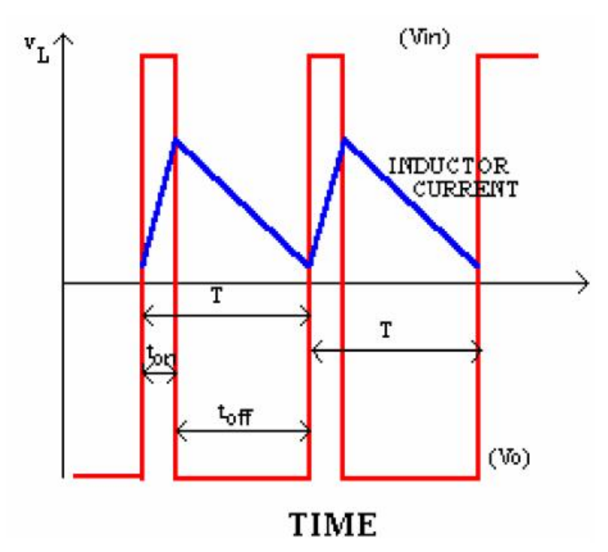
$$\frac{I_O}{I_{in}} = -\frac{(1-D)}{D}$$

Figure 1: Schematic for Buck-Boost Converter




**Note:** $V_{in}$ - Input Voltage; $V_x$ - Voltage at x; $V_L$ - Inductor Voltage; $I_L$ - Inductor Current; $V_O$ - Output Voltage; L - Diode; C - Capacitor.

Figure 2: Waveforms for Buck-Boost Converter




**Note:** $V_L$ - Inductor Voltage; $V_{in}$ - Input Voltage; $V_O$ - Output Voltage; T - Time; $t_{on}$ - On Time; $t_{off}$ - Off Time.

Since the duty ratio "*D*" is between 0 and 1 the output voltage can vary between, being lower or higher than the input voltage in magnitude. The negative sign indicates a reversal of sense of the output voltage.

### Drawbacks

1. High switching loss
2. High inductor size
3. High input filter value

## BUCK BOOST CONVERTER BASED PV INVERTER WITH INTERLEAVED INDUCTOR

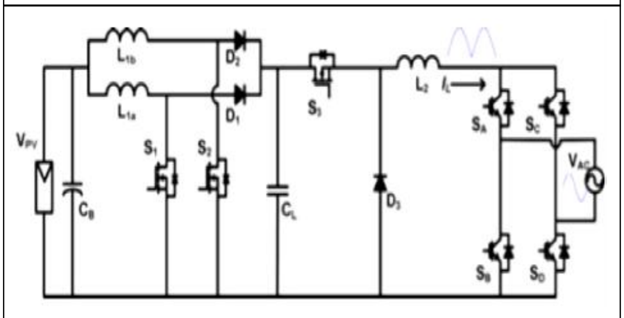
Interleaving technique was proposed a long time ago. In the last years, some applications made use of this technique to improve the performance of the dc-dc conversion. Dynamic response of VRMs (Variable Reluctance Machines) is improved with it; also, automotive systems use it to reduce the size of input and output capacitors; and other applications take advantage of this technique to improve a particular characteristic.

Most of the published papers regarding multiphase converters include a current loop in each phase to achieve two objectives:

1. Improve dynamic response: by using a current mode control, a higher bandwidth can be achieved.
2. Balance the phase currents: dc currents differences are restored by the control.

The application of interleaved converters in PV inverters to improve their efficiency is the summary of this paper as shown in Figure 3.

Figure 3: Schematic Diagram of an Interleaved Buck-Boost Converter Based PV Inverter



**Note:** $V_{PV}$ - PV Panel Voltage; $L_{1a}$ and $L_{1b}$ - Interleaved Inductor Pair; $S_1$, $S_2$, $S_3$, $S_A$, $S_B$, $S_C$ and $S_D$ - MOSFET Switches; $D_1$, $D_2$ and $D_3$ - Diodes; $L_2$ - Inductor; $C_B$, $C_L$ - Capacitors; $I_L$ - Load Current; $V_{AC}$ - Terminal Voltage.

### Advantages

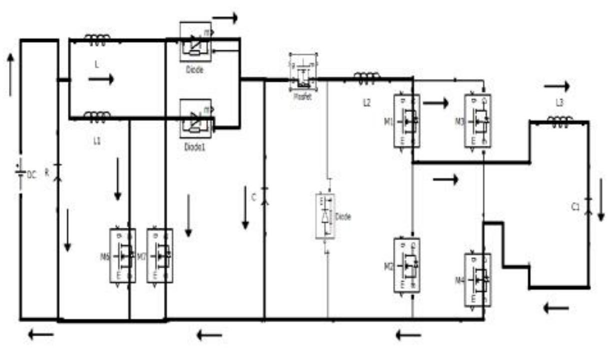
1. Reduced inductor size and switching loss
2. High efficiency

### Modes of Operation

#### Mode 1

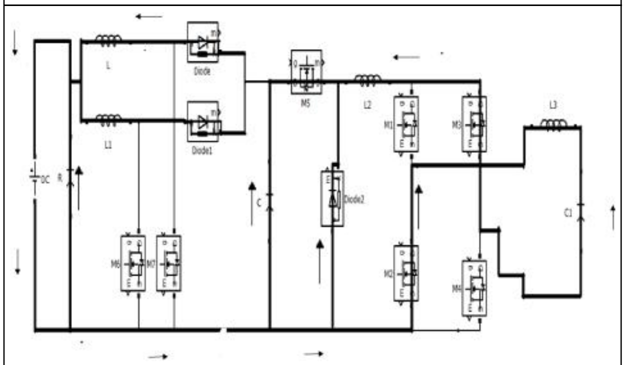
1. In mode 1 shown in Figure 4, the switches M6, M7 are ON, the energy will be stored in the inductance L, L1 and the Switches M1, M4 are ON.
2. The current path is in positive direction.

Figure 4: Schematic Diagram of an Interleaved Buck-Boost Converter Based PV Inverter (Mode 1 of Operation-Boost Mode)



**Note:** L, $L_1$, $L_2$ and $L_3$ - Inductors; $M_1$, $M_2$, $M_3$, $M_4$, $M_5$, $M_6$, $M_7$ - MOSFET Switches; R - Resistor; C, $C_1$ - Capacitors.

Figure 5: Schematic Diagram of an Interleaved Buck-Boost Converter Based PV Inverter (Mode 2 of Operation-Buck Mode)



**Note:** L, $L_1$, $L_2$ and $L_3$ - Inductors; $M_1$, $M_2$, $M_3$, $M_4$, $M_5$, $M_6$, $M_7$ - MOSFET Switches; R - Resistor; C, $C_1$ - Capacitors.

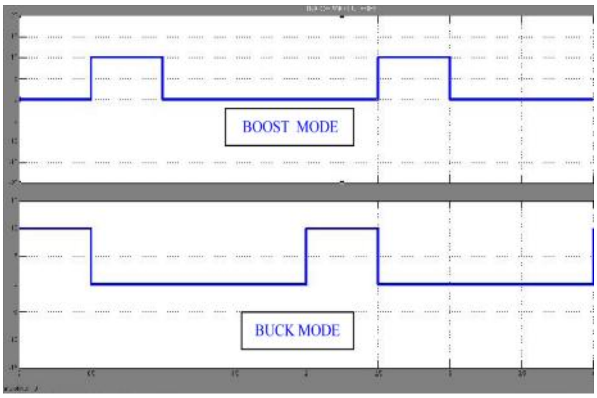
#### Mode 2

1. In mode 2 shown in Figure 5, the switches M2, M3 are ON, the energy will be stored in the inductance L, L1, L2 and the Diode 2 act as a forward bias.
2. The current path is in negative direction.

### The Role of Simulation in Design

Electrical power systems are combinations of electrical circuits and electromechanical devices like motors and generators. Engineers working in this discipline are constantly improving the performance of the systems. Requirements for drastically increased efficiency have forced power system designers to use power electronic devices and sophisticated control system concepts that tax traditional analysis tools and techniques. Further complicating the analyst's role is the fact, that the system is often so nonlinear that the only way to understand it is through simulation and for this we need software. The simulations were carried out using MATLAB Simulink software package and results show that the proposed topology boosts or bucks the output voltage level depending upon the value of the reference

Figure 6: Triggering Pulse for Boost and Buck Modes



(grid) signal as shown in Figures 6, 7, 8, 9 and 10.

As we can see from the graph shown in Figure 6, for the triggering pulse for boost and buck modes, a delay is introduced in order to differentiate the two pulses. This is done in accordance with the duty cycle of the prototype.

Figure 7: Schematic Diagram for Buck Mode of PV Inverter

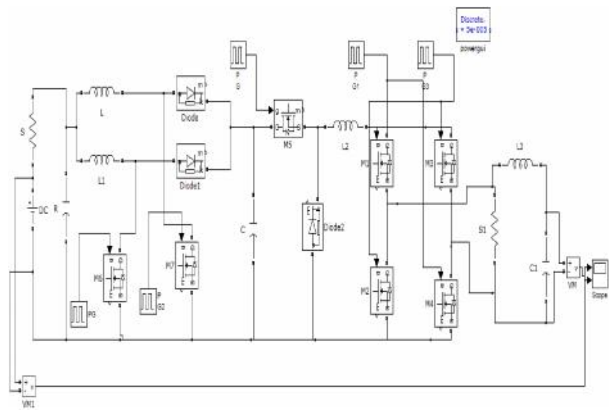
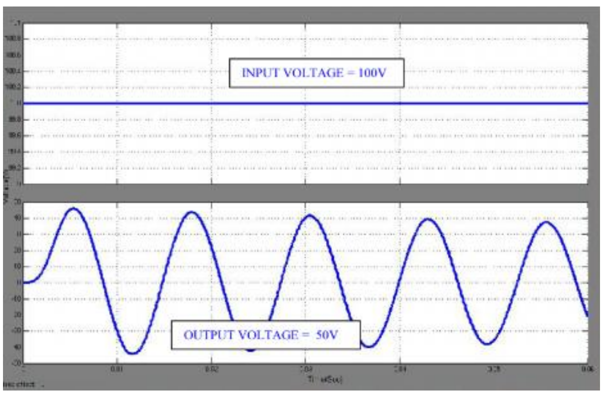


Figure 8: Input and Output Voltage of Buck Mode




The above Figure 7 is the schematic diagram is for the buck mode during which MOSFETS M2 and M3 are ON.

The above Figure 8 shows the simulation results for the input and output voltages for the buck mode. The input voltage undergoes a 50% reduction.

Figure 9: Schematic Diagram for Boost Mode of PV Inverter

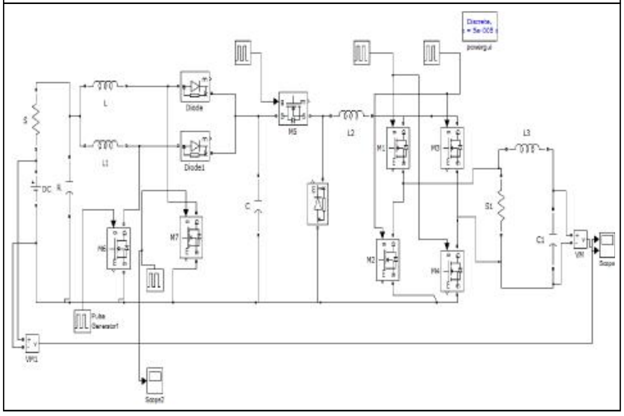
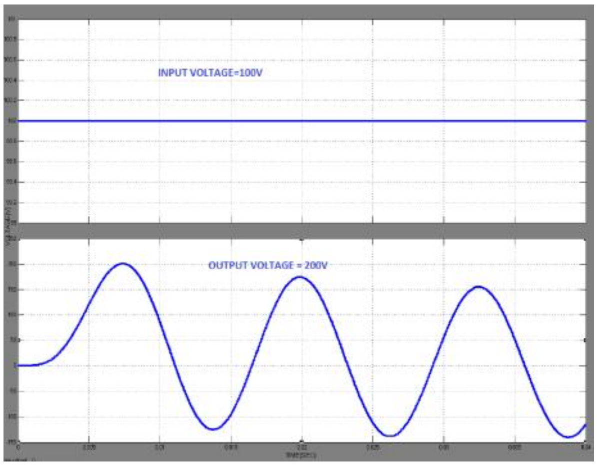


Figure 10: Input and Output Voltage of Boost Mode



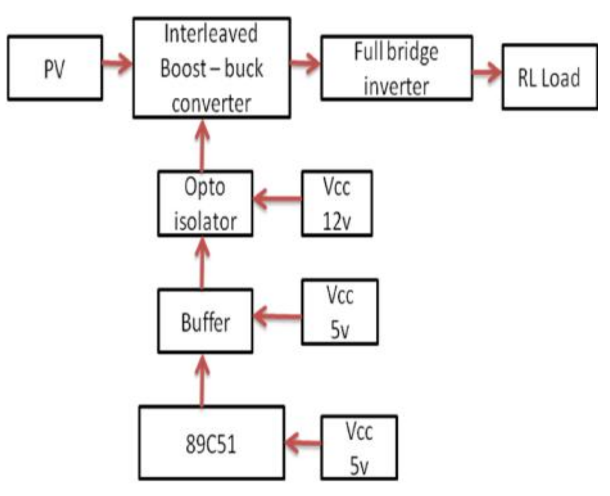

The above Figure 9 is the schematic diagram is for the boost mode during which MOSFETS M1 and M4 are ON.

The above Figure 10 shows the simulation results for the input and output voltages for the boost mode. The input voltage becomes double.

## HARDWARE IMPLEMENTATION

The PV panel acts like a dc source feeding the converter and the boost-buck converter gives a rectified sinusoidal dc output. The dc voltage is fed as the input to the full bridge inverter in unfolded nature to get a line frequency ac output voltage. The output voltage is then supplied to the load as shown in Figure 11.

Figure 11: Block Diagram of PV Inverter




The above block diagram shows the different components involved in the hardware of the boost cascaded buck converter based PV Inverter.

## HARDWARE COMPONENTS

**Full Bridge Inverter:** It consists of four switches. They will conduct in a diagonal shape.

**MC89C51:** It has Automatic address recognition. It is a 40 pin IC

**Buffer:** It is used to amplify the microcontroller signals.

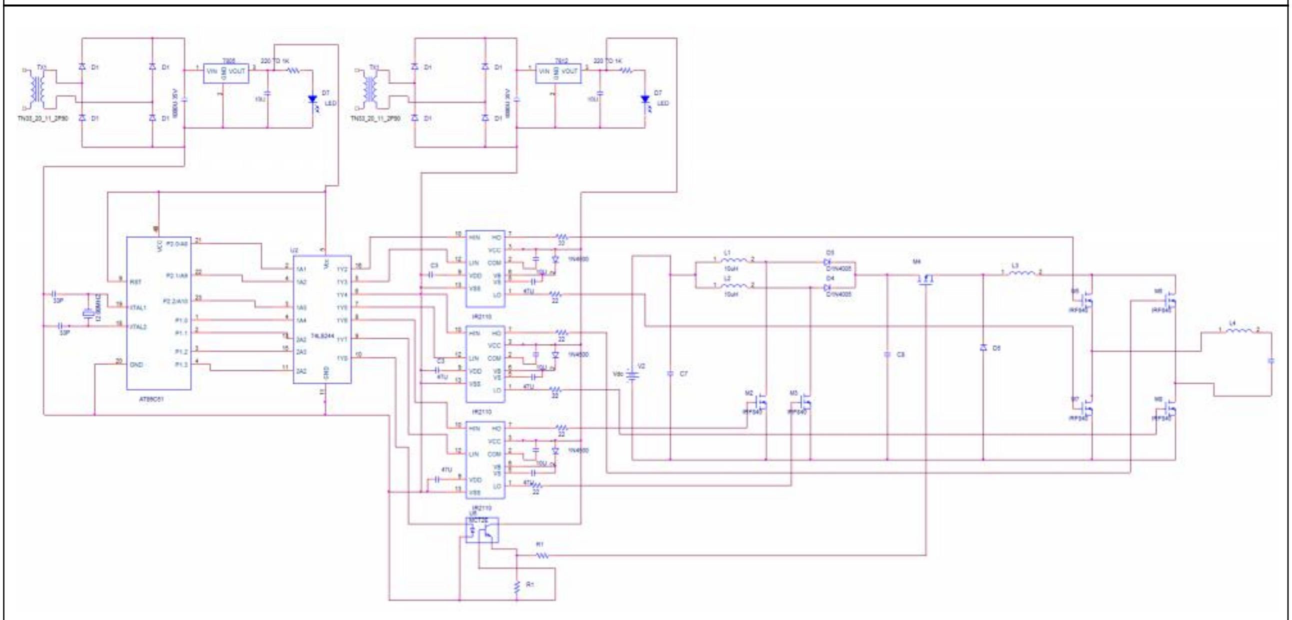
**Opto-Isolator:** It is used to isolate the power circuit and microcontroller circuit.

**Gate Driver:** A gate driver' is a power amplifier that accepts a low-power input from controller. IC and produces a high-current drive input for the gate of a high-power transistor such as an IGBT or power MOSFET.

## HARDWARE CIRCUIT

- A step-down transformer (230/15) V is used to give input supply to the power circuit.
- The 15 V AC input is rectified into 15 V pulsating DC with the help of full bridge rectifier circuit.

Figure 12: Hardware Circuit Of PV Inverter



- The ripples in the pulsating DC are removed and pure DC is obtained by using a capacitor filter.
- The positive terminal of the capacitor is connected to the input pin of the 7812 regulator for voltage regulation.
- An output voltage of 12 V obtained from the output pin of 7812 is fed as the supply to the pulse amplifier.
- An output voltage of 5 V obtained from the output pin of 7805 is fed as the supply to the micro controller.
- From the same output pin of the 7805, a LED is connected in series with the resistor to indicate that the power is ON, as shown in Figures 12 and 13.

The above Figure 12 shows the hardware circuit diagram of the PV Inverter.

Figure 13: Power Supply Circuit for Hardware Prototype of PV Inverter

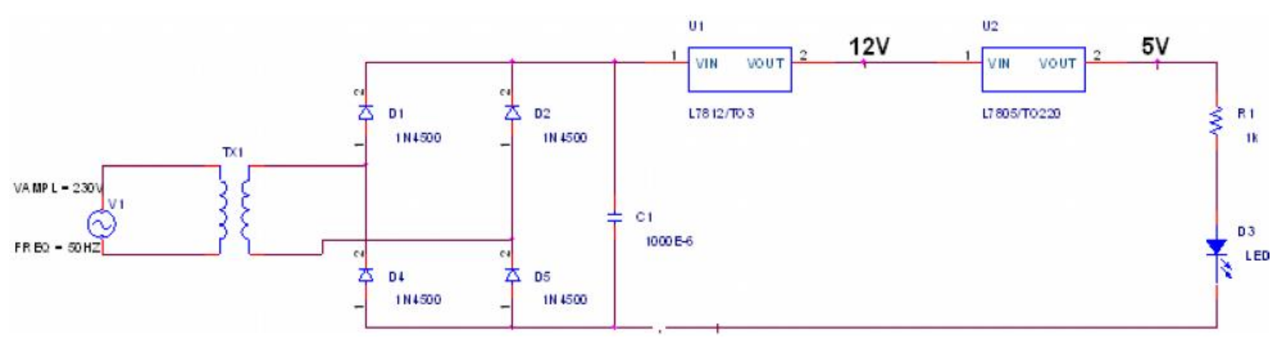



Figure 14: Hardware Prototype of the Boost Cascaded Buck Converter Based PV Inverter

The above Figure 13 shows the power supply circuit diagram of the PV Inverter.

## HARDWARE RESULTS

### Formulae

For Buck-Boost Converter, Output Voltage (Va) = (Vs x D)/(1 – D)

Table 1: Hardware Materials

| Component | Model | Specification |
|---|---|---|
| 1. Micro Controller | AT89C51 | 40 Pin, 12 Mhz |
| 2. Buffer | 74LS244 | 20 Pin, 5 V |
| 3. Gate Driver | IR2110 | 12 V |
| 4. Opto Isolator | MCT2E | 12 V |
| 5. PV Panel | SPV 120/156 mm cells | 12 V, 3 KW |
| 6. MOSFET | IRF840 | 12 V |
| 7. Voltage Regulator | L7805,L7812 | 5 V, 12 V |

where D => Duty Cycle Ratio, D = 0.5 (For this prototype)

For Buck mode: Va = Vs x D

For Boost mode: Va = Vs/(1 – D)

The input and output voltages of the prototype were measured using a Cathode Ray Oscilloscope (CRO) for the buck and boost modes.

Table 2: Buck Mode Output

| | | |
|---|---|---|
| Input Voltage | 12 V (Prac) | 12 V (Theo) |
| Output Voltage | 8 V (Prac) | 6 V (Theo) |

Table 3: Boost Mode Output

| | | |
|---|---|---|
| Input Voltage | 12 V (Prac) | 12 V (Theo) |
| Output Voltage | 110 V (Prac) | 24 V (Theo) |

## CONCLUSION

Thus, the Boost Cascaded Buck Converter based Photovoltaic Inverter has been implemented, simulated and tested with a hardware prototype using an interleaved multiphase structure. Finally, the results indicate that the efficiency of the proposed solution is higher than the conventional solution under the same condition.

## SCOPE FOR FUTURE

However it is clear from the above thesis that if a maximum power tracking system implemented using a DSP improves the efficiency of this method further. Maximum Power Point Tracking (MPPT) is a technique that grid-tie inverters, solar battery chargers and similar devices use to get the maximum possible power from one or more photovoltaic devices. Typically solar panels, through optical power transmission systems can benefit from similar technology.

## REFERENCES

1. Benner J P and Kazmerski L (1999), “Photovoltaics Gaining Greater Visibility”, *IEEE Spectrum*, Vol. 29, No. 9, pp. 34-42.
2. Bialasiewicz J T (2008), “Renewable Energy Systems with Photovoltaic Power Generators: Operation and Modeling”, *IEEE Trans. Ind. Electron.*, Vol. 55, No. 7, pp. 2752-2758.
3. Billinton R and Karki R (2001), “Capacity Expansion of Small Isolated Power Systems Using PV and Wind Energy”, *IEEE Trans. Power Syst.*, Vol. 16, No. 4, pp. 892-897.
4. Chen Y M, Wu H C, Chen Y C, Lee K Y and Shyu S S (2010), “The AC Line Current Regulation Strategy for the Grid-Connected PV System”, *IEEE Trans. Power Electron.*, Vol. 25, No. 1, pp. 209-218.
5. Guan X, Xu Z and Jia Q S (2010), “Energy-Efficient Buildings Facilitated by Microgrid”, *IEEE Trans. Smart Grid.*, Vol. 1, No. 3, pp. 243-252.
6. Koran A, Sano K, Kim R Y and Lai J S (2010), “Design of a Photovoltaic Simulator with a Novel Reference Signal Generator and Two-Stage LC Output Filter”, *IEEE Trans. Power Electron.*, Vol. 25, No. 5, pp. 1331-1338.
7. Laboure E, de Creteil I U F M, Cuniere A, Meynard T A, Forest F and Sarraute E (2008), “A Theoretical Approach to InterCell Transformers, Application to Interleaved Converters”, *IEEE Transactions on Power Electronics*, Vol. 23, No. 1, pp. 464-474.

8. Le Bolloch M, Cousineau M and Meynard T (2009), "Current-Sharing Control Technique for Interleaving VRMs Using Intercell Transformers", In Proceeding of Power Electronics and Applications, EPE'09.

9. Shinjo F, Wada K and Shimizu T (2007), "A Single-Phase Grid-Connected Inverter with a Power Decoupling Function", Proc. IEEE Power Electron. Spec. Conf., pp. 1245-1249.

10. Zheng Zhao, Ming Xu, Qiaoliang Chen, Jih-Sheng (Jason) Lai and Younghoon Cho (2012), "Derivation, Analysis, and Implementation of a Boost-Buck Converter-Based High-Efficiency PV Inverter", *IEEE Transactions on Power Electronics*, Vol. 27, No. 3, pp. 1304-1313.