Battery Charge Controller for Micro Inverter Applications using Buck-Boost and Push-Pull Converters

Pradeep S Vibhuti
Asst. Professor, Dept. of E&EE ,
Tontadarya college of Engineering, Bangalore
pradeepvibhu@gmail.com

Basavaraju S Hadapad
Assistant Professor, Dept. of E&EE
Tontadarya college of Engineering, Bangalore
hadapad.basavaraju@gmail.com

***Abstract*—This study is focused on integration and operation of a Buck-Boost and Push-Pull Converters for micro inverter applications. Since the photovoltaic (PV) array voltage can vary from 0 to 21 V, is achieved constant using buck-boost converter at 14 V reducing the voltage stress of its followed converter. This constant DC voltage is boosted to 200 V using push pull converter. This high DC voltage can be converter to 230V AC using single phase inverter for domestic applications. Both the buck-boost and pushpull converter are driven by TL494 IC which is simple to design as a controller hence making the circuit cost effective. The TTL logic driver is used for driving the mosfets. Experimental results the discussion and feasibility and are obtained for 30W input from solar panel.**

***Keywords*- Buck-Boost, current fed push-pull converter, DC-Dc step up converter, Tansistor-Transistor Logic**

I. INTRODUCTION

The "limited reserves of fossil fuels have significantly increased the interest in renewable energy sources. Solar energy is the most abundant and easily available renewable resource. "The solar energy is most widely used in relatively small load, in commercial, industrial sectors, and in rural areas where power shortage is chronic". "Using a solar panel or an array of panels without a controller will results in low output power, which ultimately results in the need to install more panels for the same power requirement"[1]. "For smaller/cheaper devices that have the battery connected directly to the panel, without charge controller will result low power transfer from panel to battery and also premature battery failure". However even with a

This paper describes the implementation of charge controller to solar system with battery storage, using the most popular switching power supply topologies. Charge controller is a technique that grid connected inverters, solar battery chargers and similar devices use to get the maximum possible power from one or more photovoltaic panels into the load". Controller actually matches the source (Solar Panel) and the load impedance, so that maximum power from source to load is transferred according to maximum power transfer theorem. The topology presented for charge controller is Buck-Boost converter. Buck-Boost converter and solar panel forms the internal impedance of source. Solar panel is given to input of the buck-boost converter which regulates the output to the desired value, and is set to get the output of 13.6V to enable the charging of a battery.

II. PROJECT DESCRIPTION

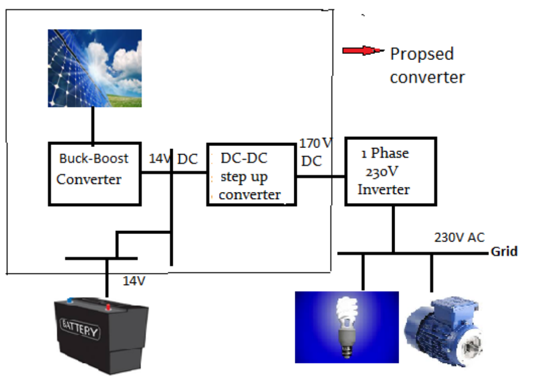

Fig1 Block diagram of proposed converter system integrated with 1-Phase inverter

This work describes the implementation of charge controller to solar photovoltaic with battery storage, "using the most popular switching power supply topologies"(Buck-Boost converter) and converting the DC voltage obtained [2] and to convert to 230V AC supply(beyond the scope of this paper), and also describe the design and control of current-fed push-pull converter for boosting the charge converter output in order to integrate charge controller to single phase inverter. The novelty is in driving the Buck-Boost topology which is a power electronic circuit to draw maximum possible power from panel is used to match the voltage and current of load with the solar panel using charge control, which essentially pushes the efficiency of Buck-Boost converter. The block diagram in figure shows the proposed work.

"With use of a well-designed switching power supply, it is expected that at least 85% of the panel's available power will end up in the battery", even more with MPPT charge controller. It is the purpose of the system to sample the output of the cells and apply the proper resistance (load) to supply any electrical device. "In this case, the simplest charge modifies the solar panel operating voltage by using a proportional integral (PI) control loop, which steers the voltage to the desired value". Finally to get the 230V(out of scope of this paper) ac from 14V dc, output of Buck-Boost is converted to high dc using dc-dc Current Fed Push-Pull (step-up) converter to achieve 200V dc, and can be given to single phase inverter to drive AC loads. TL494 16 pin ASIC base IC is used to implement Buck-Boost controller, the same TL494 pulse generator is used to push-pull converter to boost the voltage to 173V from 14V.

III. DESIGN OF PROPOSED CONVERTERS

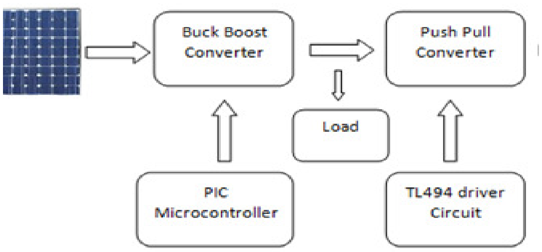

Fig 2. Block diagram of proposed converter system

In this paper buck-boost converter is used since the output of the converter required is between the ranges of input. Buck-Boost is a basic switched mode converter. The output of the buck boost converter can be either higher or lower than the input voltage. "Characteristics of buck boost are: Polarity of output voltage is opposite to that of input". For ideal converter output can vary from 0-to -∞ but practically buck boost output varies from 0 to V and V to ∞.

Assumptions made are while designing the converter are

- The circuits operate in a steady state
- "The inductor current is always positive" that is continuous
- The switching period is T and ON for DT and OFF for (1-D)T.
- The output voltage is held constant since the output capacitor considered is large.
- The components are Ideal.

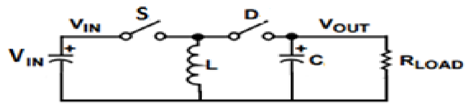

Fig 3.1 Buck-Boost Converter

Fig 3.2 Buck-Bosst converter switch closed

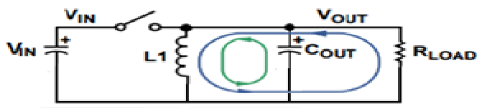

Fig 3.3 Buck-Boost Converter Switch open

"The basic principle of the buck boost converter is while in the on state, the input voltage source is directly connected to the inductor this results in accumulating energy in inductor L", during this stage capacitor supplies energy to the load. In Off state, the inductor is connected to the load and capacitor; hence energy is transferred to C and R.

Figure 3.2 and Figure 3.3 show the current flow diagrams during the on time and off time of buck-boost converter, respectively. During the on time, the primary switch (S) is conducting and current is flowing from the input and charging the inductor (L) while the output capacitor (C_{OUT}) provides energy to the load (R_{LOAD}). During the off time, the secondary switch (DS) is conducting and current is flowing through the inductor to the load and the output capacitor. Because this is an inverting topology, the current flows from ground to V_{OUT}, which is negative, through the load[3].

Applying the principles of inductor volt-second balance and capacitor charge balance on a lossless system[4], one finds the steady state dc conversion ratio specified in Equation 3.1 and the dc value of the inductor current in continuous conduction mode (CCM) specified in Equation 3.2.

$$\frac{V_{OUT}}{I_{IN}} = -\frac{D}{1-D}$$ ……………...............................(3,1)

$$I_{L1DC} = \frac{I_{out}}{1-D}$$ ……………….………….................(3.2)

The inductor current also has an ac component (ΔIL1), which is calculated in Equation 3.3

$$\Delta I_{L1} = \frac{V_{in} \times D}{L_1 \times f_{SW}}$$ …………………………….............(3.3)

The parameters governing the selection of the MOSFET are the minimum threshold voltage V_{th} (min), the on resistance R_{DS}(ON), gate-drain charge Q_{GD}, and the maximum drain to source voltage, V_{DS}(max)". Logic level or sub logic-level threshold MOSFETs should be used based on the gate drive voltage. The peak switch voltage is equal to Vin + Vout. The peak switch current is given by:

$$I_{Q1(pk)} = I_{L1(pk)} + I_{L2(pk)}$$ ……………………..... (3.4)

$$I_{Q1(rms)} = I_{OUT} \times \sqrt{\frac{(V_{OUT}+V_{IN(min)}) \times V_{OUT}}{V^2_{IN(min)}}}$$ ……(3.5)

Where f_{SW} is the fixed switching frequency of the power converter.

3.1 PUSH-PULL CONVERTER

The complete circuit consisting of main circuit and control circuit is as shown in figure 3.4. TL494 is used to generate the complementary gate signals for Q1 and Q2 of push-pull converter. "The output voltage is controlled through pulse width modulation (PWM), as in voltage fed converters, except that the pulse width applied to a switch should lie between duty cycle above 0.5 to below 1.0, to ensure operation in the overlap mode"[5]. Operation below 0.5 duty cycle implies discontinuous mode of operation. The hardware implementation of Current Fed Push-Pull Converter is shown in figure 4.1 below.

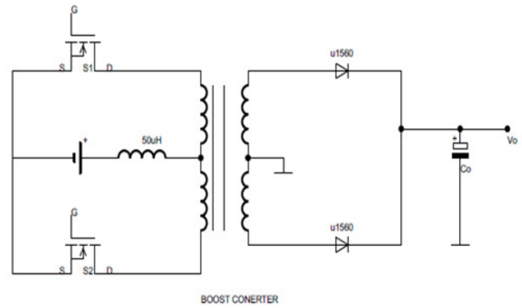

Fig. 3.4 current fed Push-Pull converter

Input voltage range, V_{in}= 14 to 28 V DC

output voltage, V_o=200 V DC

maximum output power, P_o=200w

switching frequency f_s=50 kHz.

Duty ratio determination:

Here , $V_{ct} \approx 1.05*14$

with $V_{in,min}$=14V, maximum duty cycle of a switch is given by[6]:

$$D_{max} = 1 - \frac{V_{in,min}}{2V_{ct}}$$ ………………..……………..….. (3.6)

with $V_{in,max}$=14V, minimum duty cycle of a switch is given by:

D_{min}=0.52

4.2.2 Transformers turns ratio:

$$n = \frac{N_P}{N_S} = \frac{V_{ct}}{V_o}$$ …………….……………….………..… (3.7)

Inductor Design

The design of the output inductor[7] is quite simple. Usually, a self-gapped toroid core is used. Gapped ferrite cores (the ones used for ferrite transformers, eg ETD39) can also be used with no difficulties.

The formula for calculating the output inductance is:

$$Lmin = \frac{[Vin(max) - Vout] \cdot Toff(est)}{1.4 \cdot Iout(\min)}$$ … (3.8)

From the datasheet of the core, you can find the AL value. This indicates the inductance per turns squared:

$$AL = L/N^2 \quad \text{……………………………………} (3.9)$$

L is the inductance and N is the number of turns. Making N the subject:

$$N = \sqrt{\frac{L}{AL}} \quad \text{……………………………………} (3.10)$$

Where N in turns

So, that's the formula used to calculate the number of turns once we know the required inductance.

3.2 PUSH-PULL TRANSFORMER DESIGN

An output inductor is found at the output of every forward-mode converter. Converters utilizing the forward, push-pull, half-bridge and full-bridge topologies are all forward-mode converters. So, calculation of the output inductance follows the same methodology for all four of these popular topologies. The purpose of the output inductor is to store energy for the load during the time each switching cycle when the power switches (BJTs, MOSFETs or IGBTs) are turned off. The electrical function of the output inductor is to integrate the rectangular switching pulses (pulse width modulated signals with varying duty cycle) into DC. The capacitor following the inductor smooths the DC into clean DC [8].

$$N_{pri} = \frac{V_{in(nom)} \cdot 10^8}{4 \cdot f \cdot B_{max} \cdot A_c} \quad \text{……………………} (3.11)$$

$$Bmax = \frac{0.5 * Vinnom * 10^8}{4 * f * Npri * Ac} \quad \text{…………………} (3.12)$$

Nsec = Npri / N

IV. Experimental Setup and Results

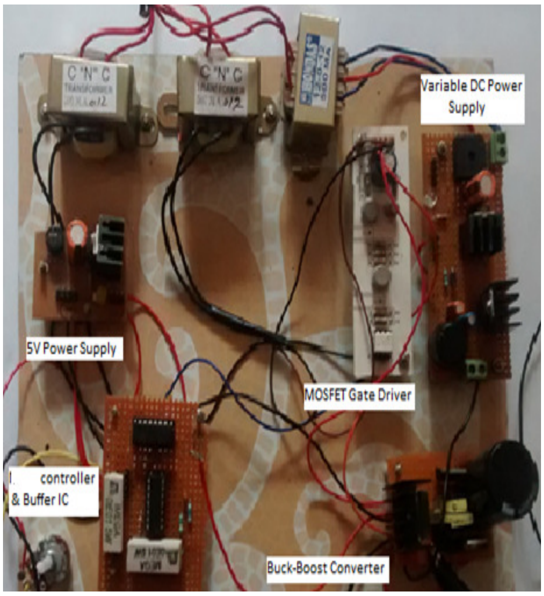

Fig.4.1: Buck Boost MPPT Converter

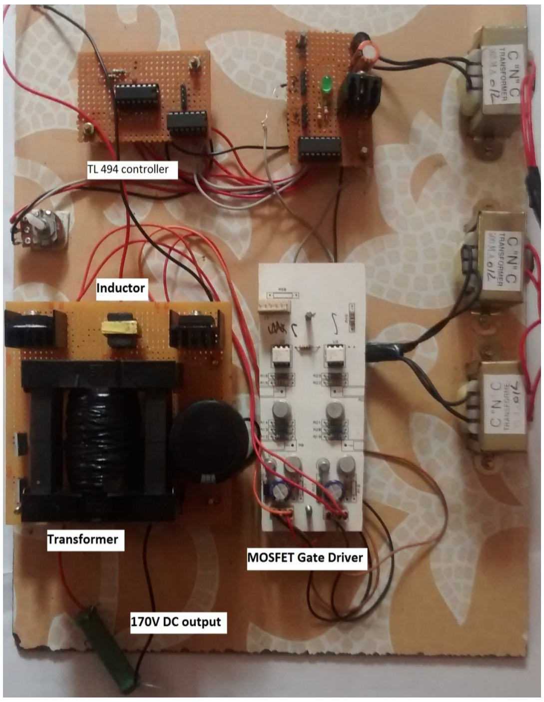

Fig.4.2: Push-Pull MPPT Converter

Sl.	Voltage(	Current(I)	Power(W
1	**0.0**	**1.98**	0.0
2	2.0	2.00	4.0
3	3.0	1.95	5.85
4	4.0	1.96	7.8
5	5.0	1.89	9.45
6	6.0	1.86	11.16
7	8.0	1.8	14.4
8	9.0	1.77	15.93
9	10.0	1.70	17
10	11.0	1.6	17.6
11	13.0	1.52	20.41
12	14.0	1.53	22.04
14	15.0	1.5	22.5
15	15.5	1.49	23.09
16	16.0	1.47	23.52
17	16.5	1.43	23.59
18	17.0	1.41	23.8(Max
19	17.5	1.32	23.1
20	18.0	1.1	19.8
21	19.0	0.67	12.73
22	19.5	0.31	6.045
23	20	0.1	2

Table: 4.1: Measured waveform of output from Buck Boost controller

Table4.1 shows the readings of the duty cycle. For the input voltage from solar panel below the output (13.6 V) of buck-boost converter the duty cycle is more than the 0.5. And for the input voltage above the output of buck-boost converter the duty cycle is less than 0.5.

Sl N	**Input Voltage**	**Duty Cycle (D)**	**Output voltage of Buck-Boost**
1	7	0.68	13.6
2	9	0.6	13.6
3	10	0.58	13.6
4	12	0.53	13.6
5	14	0.5	13.6
6	16	0.47	13.6
7	20	0.4	13.6

Table: 4.2:Output power measurement of buck- boost converter

Sl.No	**Solar Panel**	**Buck-Boost**	Push-pull
1	8	13.6	200
2	10	13.5	188
3	12	13.6	200
4	14	13.7	200
5	16	13.6	206
6	18	13.5	200
7	20	13.6	200

Table: 4.3: Output voltage measurement of converters

Table 4.2 gives the reading of measured quantities at the output of buck-boost converter. From readings it implies that the measured power is near to the maximum possible power drawn from the 30W solar panel. And due to MPP tracking the efficiency is about 86%.

Table 4.3 shows the output voltages at buck-boost and push-pull converter for different input voltages from solar panel to the buck-boost converter. Since the controlled converter provides the constant output voltage which is input for the push-pull, converter the output it is constant.

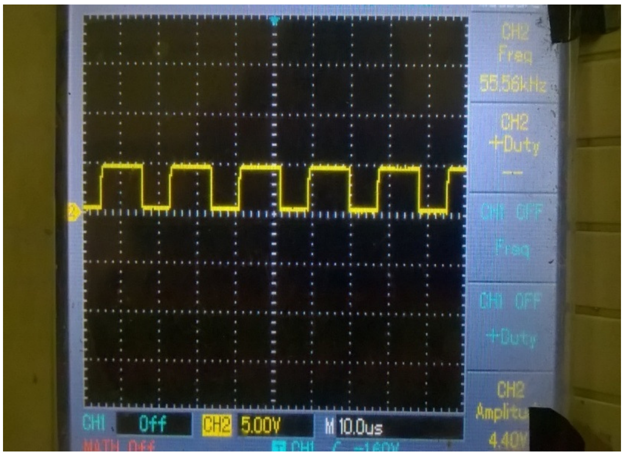

Fig. 4.4:Input signal to MOSFET gate driver (Transistor-Transistor logic)

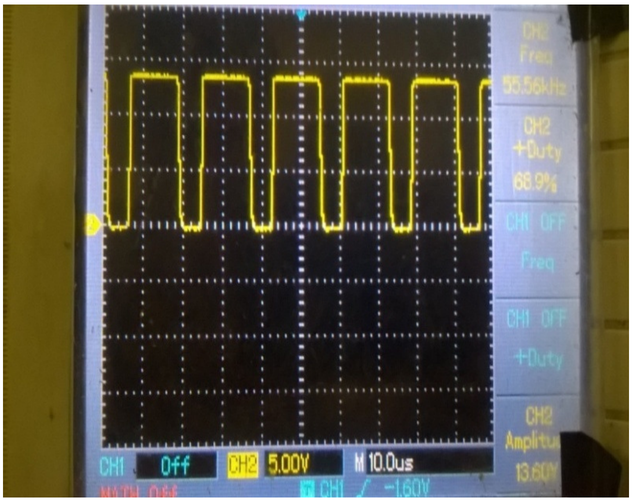

Fig. 4.5: Output waveform from of MOSFET gate driver 12 V p-p (Transistor-Transistor logic) to be given to gate of buck boost converter

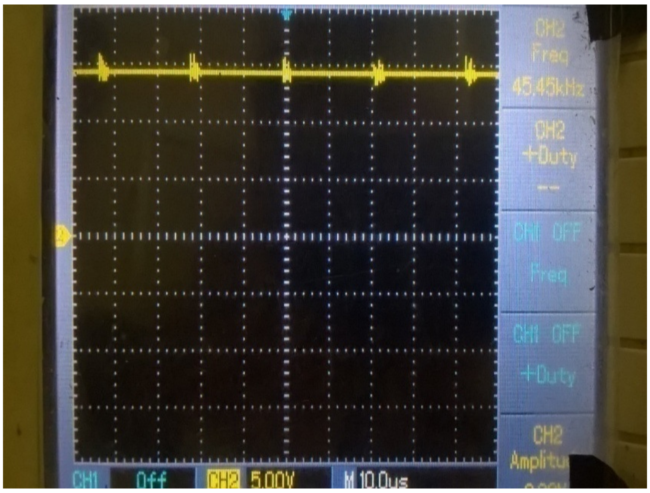

Fig. 4.6:Output waveform of Buck Boost converter for battery charging(14.2 V)

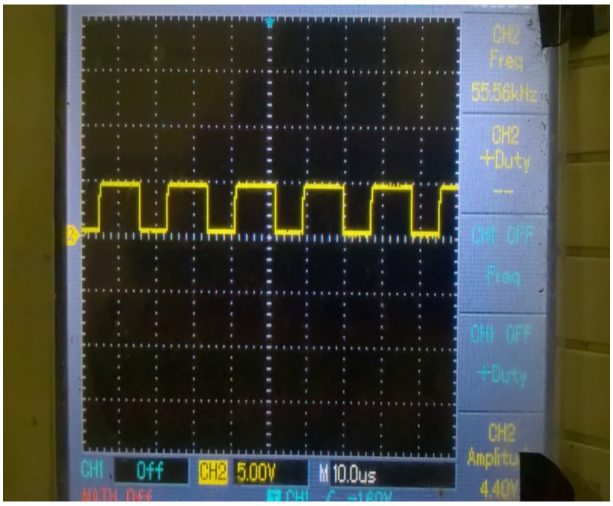

Fig. 4.7: Output waveform from TL494 I C controller for Push-Pull Boost converter

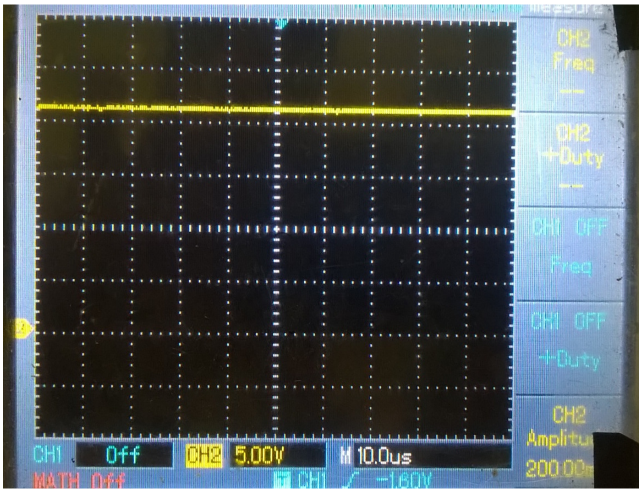

Fig. 4.8: Output waveform of Push-Pull Boost converter of 200V with measuring probe set to multiplier 10

VI. CONCLUSION

Using charge controller with solar panel installations has clear advantages. The initial investment is smaller because smaller panel wattage is required and adding correct battery-charging algorithms will also decrease operating costs (batteries are protected and last longer).

The aim of this work was to propose a design of converter PV system and to realize a simple analog controller capable of optimizing the amount of power recovered from a solar panel over a range of environmental conditions. The basic design of the power tracker is to sense the voltage and current levels at the solar panel output, process these values using the feedback loop, and then adjust the duty cycle in order to obtain maximum power. The obtained results and theoretical operation are confirmed the effectiveness of power tracking technique.

The battery charging using is implemented to Buck-Boost converter to achieve 13.6V. The power of 30W solar panel is measured with and without controller to observe the tracking of power and the results clearly indicate efficiency is increased to 86% by implementing controlled converter.

The same output of Buck Boost converter after charging the battery is used as input to the Push-Pull converter so as to boost to 200V. The TL494 pulse generator is used to gate the two switches of the current fed Push-Pull converter and to avoid saturation in the transformer and to flux imbalance problem in voltage-fed converters current fed Push-Pull converter is used.

FUTURE WORK PROPOSED

Since this paper mainly concentrated on buck boost solar converter, it does not provide DC Isolation from input panel and load(battery). It can be provided by using Inverse SEPIC or ZETA converter which provides coupled inductor.

To increase the efficiency of the converter synchronous rectification can be implemented by employing switch(MOSFET) in place of freewheeling diode. This is possible in case of SEPIC converter where two switches are used.

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