PV Based Modified Boost Converter with Closed loop Voltage Control for Constant Voltage Applications

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Abstract— Renewable energy resources have become one of the alternatives to the ever increasing energy demand. But the low voltage output of the renewable resources like wind, solar, hydro etc. must be boosted up to other voltage levels for various residential or industrial applications. DC-DC converters are used to convert the unregulated output voltage of the solar cells to regulated voltages. Most of the converter suffers from high ripple output voltages. This paper presents a modified boost converter which reduces the output ripple voltage thereby giving a constant DC output voltage. A closed loop voltage control with PI controller is used to maintain constant output voltage with variation in load. The converter topology is designed and simulated with MATLAB/Simulink to validate its theoretical result. ARDUINO platform is used to generate pulses for hardware implementation. The result obtained through the simulation is verified with the hardware.

Key words: DC to DC converter, closed-loop voltage control, boost converter, PI controller

I. INTRODUCTION

With the increasing human population and rapid growth of the economy, there has been a tremendous increase of using the energy resources especially electricity. The classical and conventional method of generating electricity is by burning fossil fuels which is no longer being able to fulfil the increasing electricity demand all around the globe. This conventional method is giving rise to environmental problems which is causing dramatic change to the world climate and this is calling upon a serious threat to the noble planet. In such circumstances, the conventional method can no longer be thought as the optimum solution for the energy crisis. Hence, the renewable energy sources have taken over the electricity generation process [2].

Among the renewable energy resources, solar energy is one of the most demanding energy sources over the globe. The PV modules comprise of several solar cells, which convert the energy of the sunlight directly into electricity, and are connected as required to provide desired levels of DC current and voltage [3]. These power sources have quite low-voltage output and require series connection of voltage booster to provide enough output voltage [4]-[6]. Many converter topologies have been proposed for maintaining a constant output voltage. DC-DC boost converter is generally used to boost the voltage to the required level [4]. But the output voltage of boost converter fluctuates with variation in load. In addition, the converter shown in Fig.1 requires a large electrolytic capacitor in order to compensate the power pulsation when the inverters are connected to the single-phase grid because the power is fluctuating at twice of the grid frequency.

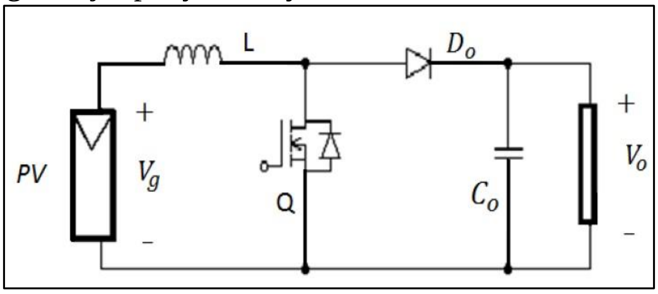

Fig. 1: Conventional boost converter [4]

Most of the residential applications work internally on DC like stereo, TV, DVD, LED require regulated and ripple-free voltage for smooth working. This paper proposes a new boost converter topology which maintains a constant output voltage even if the load is varied within a certain limit. The additional diode used regulates the output voltage and controls the charging and discharging of the capacitor. In addition these circuits can be used as buffer circuits for power decoupling in case of single phase PV inverters [1].

II. CIRCUIT TOPOLOGY

A. Circuit Configuration

Fig.2 presents the circuit structure of the proposed converter. The proposed converter is constructed based on the basic boost converter and it achieves low output dc-voltage ripple, operation on the inverter for an interconnection and power pulsation compensation with a small capacitance. A manual switch is provided such that load is connected only when required.

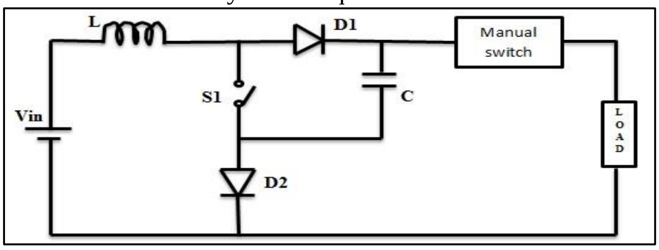

Fig. 2: Proposed boost converter

B. Operation Modes

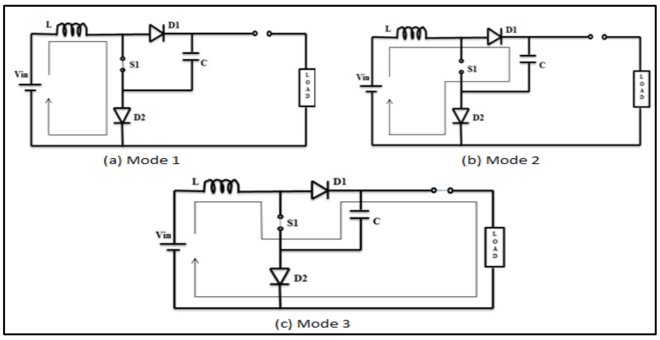

Fig. 3: Operating modes of modified boost converter

Fig. 3 illustrates the switching pattern of the proposed converter. To reduce the output voltage ripple a diode is

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used in series with the switch. The converter circuit consists of a voltage source, inductor, two diodes and a capacitor. The DC load is connected through a manual switch, which can be turned on or off according to the requirement. Assuming that the input current is continuous, the current pathways of the proposed converter have three modes. The capacitor stores energy when there is no load and discharges when a load is connected. The load is disconnected through the manual switch in modes 1 and 2. In Mode 1, the switch S1 is on and the inductor stores energy. Mode 2 is called as the capacitor charging mode. The switch S1 is in off state and the inductor discharges. During this period, capacitor charges to its maximum value. In Mode 3 the load is connected through the manual switch. The switch S1 is turned on and the capacitor discharges providing enough power to the load. No current flow occurs through the diode pathway of D1 and D2 as reverse bias appears across it.

III. CONTROL STRATEGY AND DESIGN EQUATIONS

Fig. 4 represents the basic control strategy for the modified boost converter.

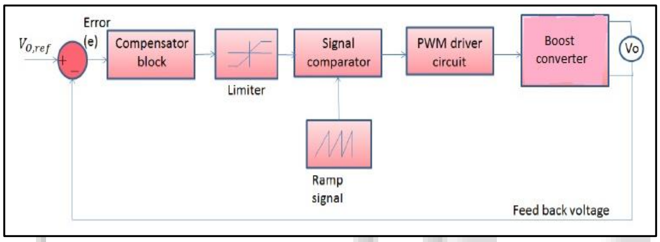


Fig. 4: Basic voltage control loop of the proposed converter [2]

A closed loop voltage controller is used for maintaining a constant output voltage irrespective of load variations. Closed-loop systems are more accurate even in the presence of non-linearity and highly accurate as any error arising is corrected due to presence of feedback signal [2]. A PI controller is used for providing the feedback signal and maintaining a constant output voltage.

Assuming continuous mode of operation of the modified boost converter, the capacitor and inductor values can be found from the following equations.

$$L = \frac{V_{in}D}{f_s i_L} \quad (1)$$

$$C = \frac{V_o D}{f_s V_o R} \quad (2)$$

D is the duty ratio of the switch; V_{in} and V_o represents input and output voltage respectively. f_s is the switching frequency which is taken as 5kHz.

IV. SIMULATION STUDIES

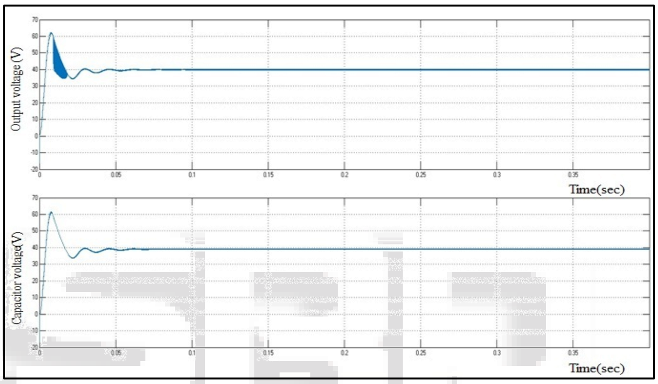
Complete circuit of the modified boost converter is simulated using MATLAB/Simulink environment. Output voltage ripple and efficiency of the modified converter is compared with that of conventional topology. A classical boost for a closed loop voltage regulation system is considered for comparison. The designed values used for modeling the modified boost converter are shown in Table I.

Items	Specifications
L	3mH
C	330 µF
R	40
Input voltage	17V
Input current	2.3A
Output voltage	40V

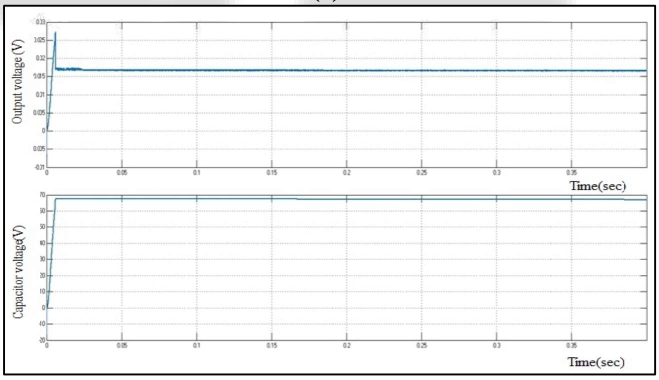
Table 1: Components and Specifications

A. Simulation Analysis of the Modified Boost Circuit

Output voltage and capacitor waveforms of the modified boost converter obtained are shown in Fig. 5(a) and Fig. 5(b). The output waveforms when the load is connected, and on no load is shown separately. When the load is not connected, the capacitor stores energy to its maximum. The capacitor provides the required output power once the load is connected. A closed loop voltage control is used to maintain the constant output voltage. Here the output voltage is sensed and compared with a reference value. The error output is provided as input to the PI controller which in turn sets the required duty ratio by comparing with a ramp signal. The pulse output of the controller is such that the control given to the power semiconductor switch always provides the required output of 40V when the load is connected. The gain values chosen for the PI controller is K_p = 0:0001 and K_i = 1.



(a)



(b)

Fig. 5: (a) Output voltage and capacitor waveforms when the manual switch is on (b) Output voltage and capacitor waveforms when the manual switch is off

B. Comparison with Conventional Boost Converter

For the classical boost converter, as the load is varied from full load condition, the output voltage ripple increases. The load is varied from 10W to 40W and the nature of output voltage is analyzed. The output voltage waveforms for the conventional topology and the modified boost converter for a load of 20W is shown in Fig. 6. From Fig. 6 it can be inferred that as load varies the output voltage ripple increase in conventional topology. The settling time to attain a constant voltage of 40V is also longer when compared to the

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modified circuit. The proposed topology has a much smoother constant DC output voltage.

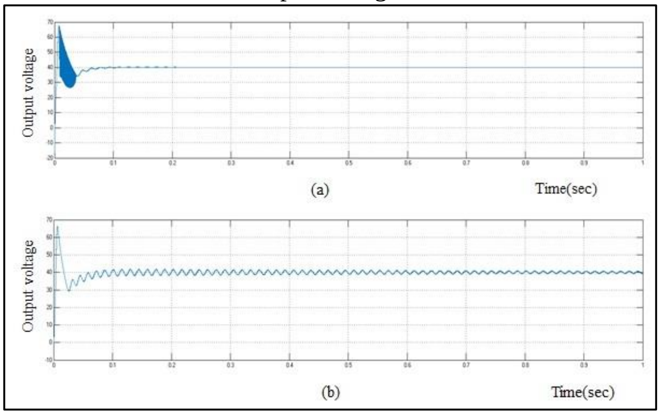

Fig. 6: (a) Output voltage of proposed converter for 20W (b) Output voltage for conventional boost converter for 20W

V. EXPERIMENTAL SETUP

Components	Specifications	Type
Inductor	3 mH	Air-cored
Capacitor	330 µF	Electrolytic
Diode, D1	IN4001	PN junction
Diode, D2	IN4001	PN junction

Table 2: Device Information of the Proposed Converter

In order to demonstrate the validity of the proposed inverter, a 40-W prototype circuit has been tested. The converter is implemented by ARDUINO mega2560 board. The power circuit of the enhanced boost circuit consists of 1 inductor, 1 capacitor, 2 diodes and a power semiconductor switch. Components used for the hardware implementation is shown in Table II.

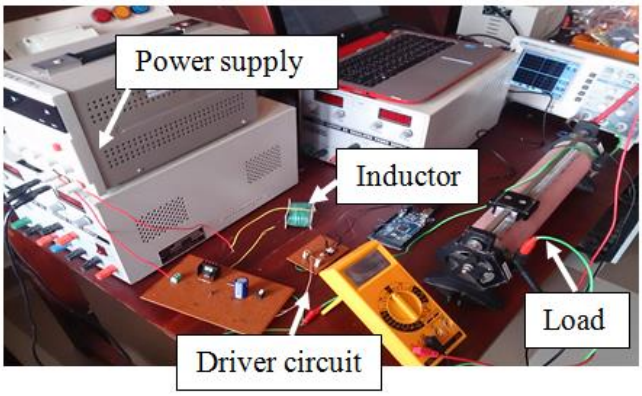

Fig. 7: Experimental setup of the proposed converter

The prototype model is designed for feeding a 40W load from 17V input and to provide a 40V boosted output irrespective of load variations. Allowable load variation is from 10W to 40W. In the laboratory, a variable DC source is used as the input source for providing a voltage of 17V. And it is found that the output voltage remains almost constant with reduced ripples. The experimental setup of the proposed converter is shown in Fig. 7.

VI. CONCLUSION

This paper has presented the design and development of a modified boost converter for constant voltage applications using a closed loop voltage control. The results obtained show that the output voltage ripple is reduced and provide a smooth DC output voltage irrespective of load variations when compared to the conventional boost converter. Filtering devices can be used to reduce the output transient which is of low nature, to a much lower value. A closed loop voltage control with PI controller is used to maintain the constant output voltage with load variations.

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