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A Single Switch Integrated Dual Output Converter with PFM+PWM Control

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Abstract*: A single switch integrated dual output converter for a standalone photovoltaic (PV) - battery – powered motor system is proposed in this paper. The converter is formed by combining a boost converter with a buck converter. With only a single transistor, the converter is able to perform three tasks simultaneously, namely, maximum-power point tracking (MPPT), battery charging and driving the motor at uniform speed. To achieve these control objectives, the two inductors operate in different modes such that variable switching frequency control and duty cycle control can be used to manage MPPT and output voltage regulation, respectively.*

Simulation results of the proposed converter are presented to serve the proof of concept.

Keywords: *DC motor, Maximum Power Point (MPP) Tracking (MPPT), Photovoltaic (PV) systems, Variable frequency control, Duty cycle control.*

I. Introduction

Shortage in power, depleting non – renewable resources has started a revolution towards the use of renewable energy sources [4]. More than quantity the rate of energy conversion or the quality /efficiency of energy conversion plays an important role. Solar energy being globally found, if harnessed to full potential would lead to an out surge of power removing the entire energy crisis of the world. One problem with the solar energy is the conversion factor, when solar panel absorbs the solar energy it gives out un-regulated DC output, which cannot be used for further applications. In order to overcome this or obtain regulated DC output we can use DC-DC converters. The three basic DC-DC converters are buck, boost, and buck-boost converters. All the basic three converters are designed for a standard application need. We had considered a solar panel as the input. Among the various applications of photovoltaic technology, a stand-alone photovoltaic- battery powered motor system can be utilized in many areas. A rechargeable battery is used in the system to store energy from the solar panel. This stored energy is used to drive a DC Motor and can also be applied to provide energy for other loads and applications such as LED lighting.

The main objective of this project is to develop an integrated dual output converter operating with single switch. The converter is formed by combining a boost converter with a buck converter. Boost converter is used for battery charging and buck converter is used to drive a DC motor. With only a single transistor the converter is able to perform three tasks simultaneously, namely, maximum power point tracking (MPPT), battery charging, and driving the motor at constant speed. To achieve these control objectives, the two inductors operate in different modes such that variable switching frequency control and duty cycle control can be used to manage MPPT and output voltage regulation, respectively [1]. The battery in the converter provides a steadier dc-link voltage.

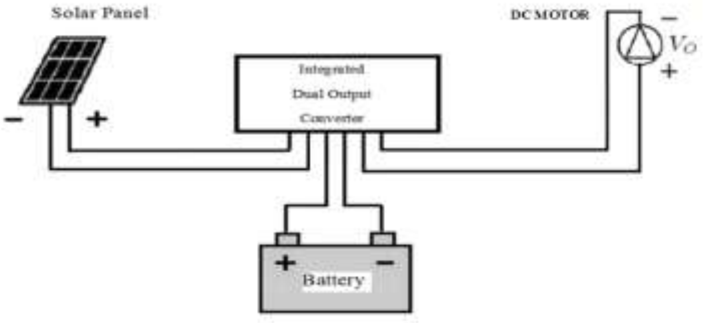


Fig. 1 Proposed Topology

II. Proposed System

The proposed integrated dual output converter, shown in fig 2 is derived through the integration of a boost converter into a buck converter. It consists of an input inductor L1 for charging the battery and MPPT, a rechargeable battery V_b to drive the load, which is a DC motor in this application, a capacitor Co is used to hold the PV (Photovoltaic) source voltage when the switch is OFF, M is the manual switch, capacitor C_1 is used to absorb the ac current ripple of the battery, an output inductor L2 to supply the load. Switch 'S' provides current paths for both the battery and the PV source during the ON period.

PFM (Pulse frequency modulation) for MPPT& PWM (Pulse width modulation) for output voltage regulation

For the single switch converter shown in fig 2, the objectives are to track the maximum power of the PV panel while regulating the output voltage. The DC motor can maintain a constant power level with any MPP if the output voltage is regulated and controlled. The output voltage regulation can be realized by adjusting the duty cycle of the switch with the output voltage feedback. Since there is only one switch in the converter, one more control variable is needed to achieve the MPPT control objective. If the two inductors are designed to operate in different modes, for example, L1 in DCM (Discontinuous conduction mode) and L2 in CCM (Continuous conduction mode), the output voltage will be expressed as,

$$V_o/V_b=D$$

Since the battery voltage V_b is constant, the output voltage will only change with the duty cycle D as long as inductor L2 stays in CCM. A duty cycle range of 0.4 - 0.5 can guarantee the normal functionality of a 12V DC motor load.

To achieve the pulse frequency modulation control, it is necessary to maintain two inductors in different conduction modes. The switching frequency has to stay within an upper bound and a lower bound to keep L1 in DCM and L2 in CCM. The efficiency will change when frequency varies. The duty cycle shows a larger control range and better performance as compared to frequency. Designing L1 in DCM and L2 in CCM and using the duty cycle to control the output will give a larger output voltage range and a limited MPPT performance. If other applications require better MPPT performance and do not require precise output control, L1 and L2 can be designed in CCM and DCM, respectively, and use the frequency control to achieve output voltage regulation.

Operation principle

Since the constant voltage control method is used for MPPT in this design, the PV input voltage is controlled to operate within a range by adjusting the switching frequency. To simplify the analysis of the operation of the converter, both the PV module and the battery are assumed to be constant DC voltage sources within a switching period, under the assumption that the input capacitor is large enough to hold the PV source voltage when the switch is OFF. The capacitance of C2 is large enough so that the output voltage ripple is negligible and the output can be treated as a constant DC voltage source as well. All the semiconductor devices are assumed to be ideal. The input boost inductor L1 works in discontinuous conduction mode (DCM), where as the output buck inductor L2 operates in continuous conduction mode (CCM).

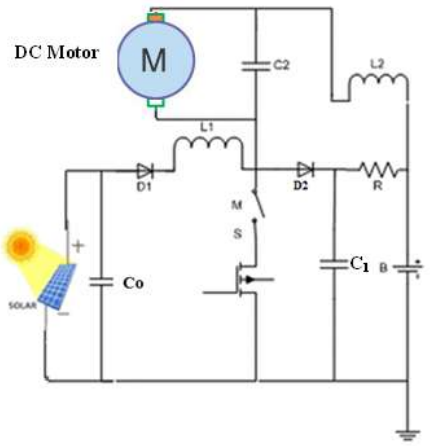


Fig. 2 Integrated dual output converter

Mode1: (T0-T1)
During this stage, switch ‘S’ is ‘ON’, diode D1 is forward biased and diode D2 is reverse biased. The input inductor L1 is charged up by the PV source, as shown in fig (3).

Mode 2: (T1-T2)
This mode happens when the switch ‘S’ is OFF. During this mode, the energy from PV source and the inductor is used to charge the battery (Shown in fig (3)). In this mode both the diodes D1 and D2 are forward biased.

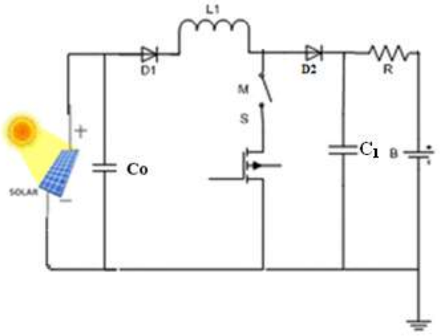


Fig. 3 boost converter in Mode 1&2 operation

Mode 3: (T2-T3)
Mode 3 starts when PV is OFF. The operation stage is illustrated in fig (4).Switches ‘S’ and ‘M’ are ON during this period and diode D2 is reverse biased. The stored energy in the battery is used to charge inductor L1 and to drive DC motor.

Mode 4 (T3-T4)
In Mode 4 operation, inductor L2 is discharging. Diode D2 is forward biased during this period. L2-C2-D2-R is the discharging path (shown in fig 4)

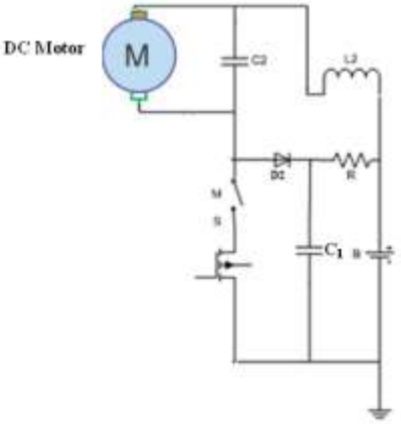


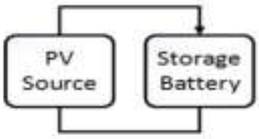
Fig .4 Buck converter in mode 3&4 operation

Battery operation modes

In the proposed design, the battery serves two functions: 1) Stores energy from PV panel and maintain a steady DC link voltage 2) Discharge energy to drive DC motor. The charging / discharging of the battery is determined by the PV input power and load output power.

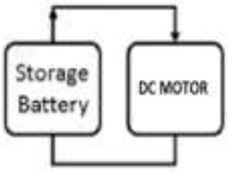
Mode A

This situation happens when the battery charge is very low, which is insufficient to drive DC motor. Therefore the buck converter is disabled and only the boost converter works to track the MPP. The battery is charged by the PV input source.



Mode B

This situation happens when no power can be provided from the PV input, usually during night time. In this case, the front boost stage of the converter is disabled, and only the buck converter is working. All the energy for the motor is provided by the battery. If the PV panel does not have protection circuitry, a diode can be added after the PV panel to prevent the reverse current flowing in to the PV panel.



III. Simulink Model and Simulation Results

The Simulations are done in MATLAB SIMULINK Software. The integrated dual output converter is designed with a PV input voltage of 12 V, battery voltage Vb of 24V, and a 12 V DC Motor load with a switching frequency of 10 KHz.

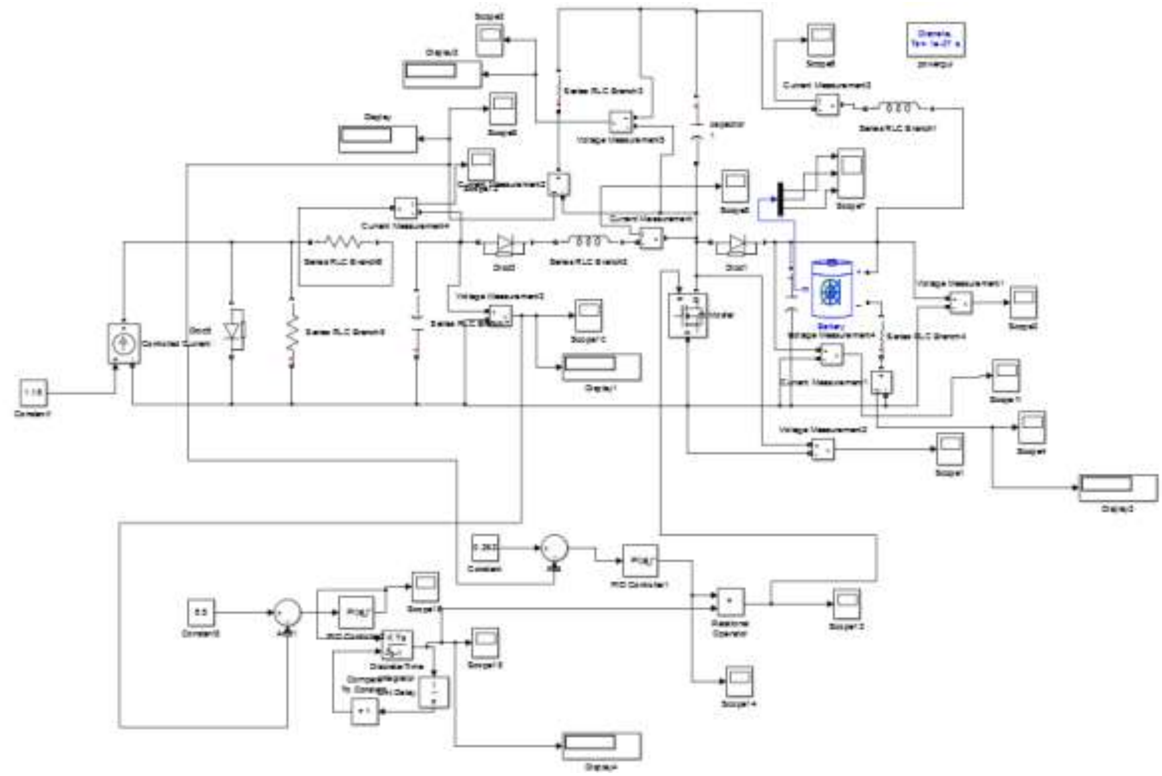


Fig.3 Simulation model of Proposed Configuration

By using PFM Control, an output voltage of 8.5 is generated across PV Panel. This is shown in fig 4. The figure shown in 5 is the waveforms of switching pulses, current through inductor L1, source current, current through diode D1. The figure shown in 6 is the waveforms of load voltage, load current, current through inductor L2. Fig 7 is the simulation results of state of charge, current and voltage of the battery. When the battery is fully charged, the voltage across the battery is 28V.

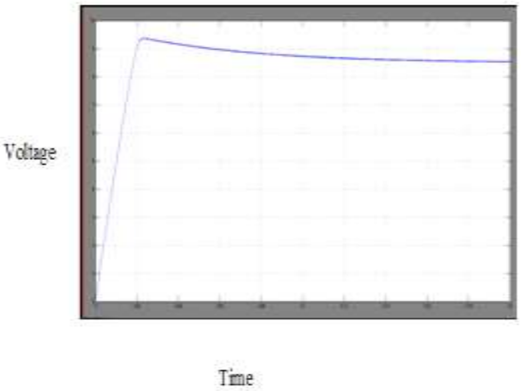


Fig. 4 PV Panel output voltage

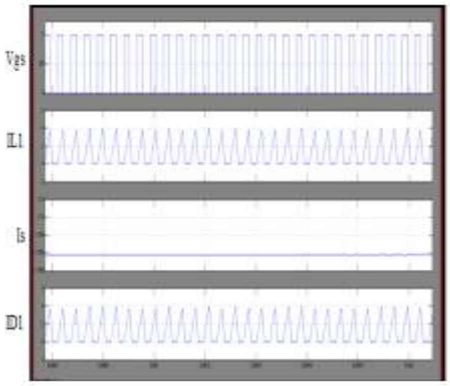


Fig.5 Waveforms of switching pulses, current through inductor L1, source current, current through diode D1.

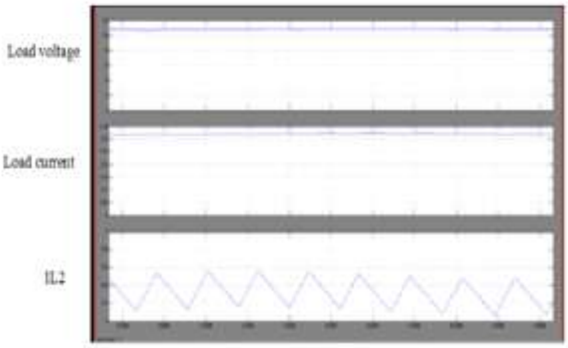


Fig.6 Waveforms of load voltage, load current, Current through inductor L2

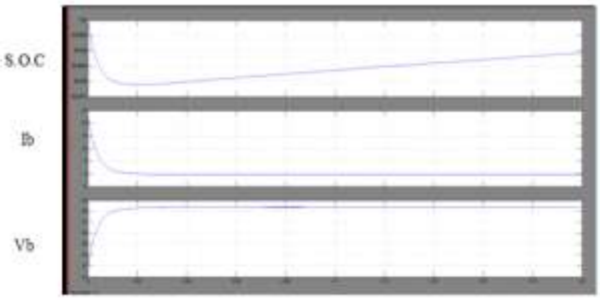


Fig 7 Simulation results of battery

III. Experimental Results

The experimental set up of the proposed converter is shown in 8. The main components of hardware is DC-DC converters, KA 3525A for controlling the switching of the dc-dc converter and a driver IC IR2110 is used in between the MOSFET and KA3525A. Power supply is provided for each of these components according to their requirements.

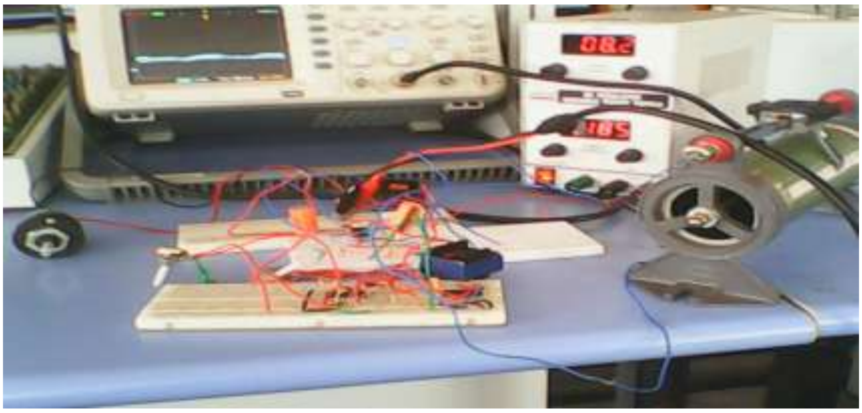


Fig. 8 Hardware Setup

<u>Hardware results</u>

The waveform shown in fig 9 is the switching pulses generated from KA3525A (PWM IC). The duty cycle of the switching pulse is 0.45.

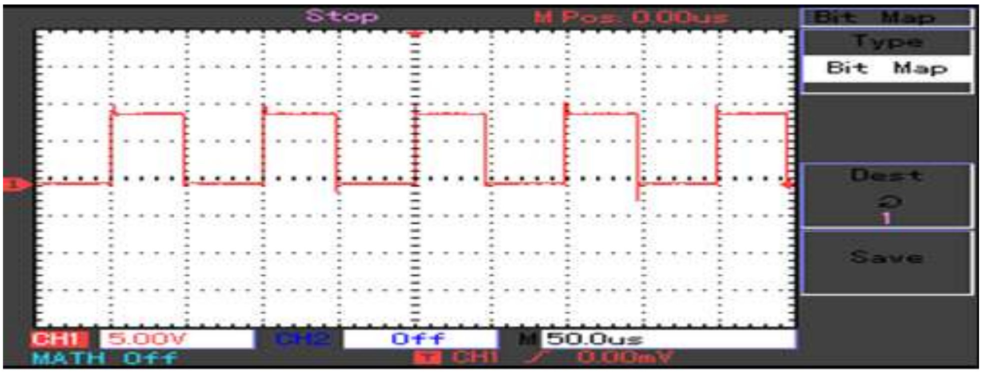


Fig.9 Switching pulses from KA3525A

The waveform shown in fig 10 is the switching pulses generated from IR2110.
IR2110 is a MOSFET driver IC. The output from KA3525A is connected as the input to this IC.

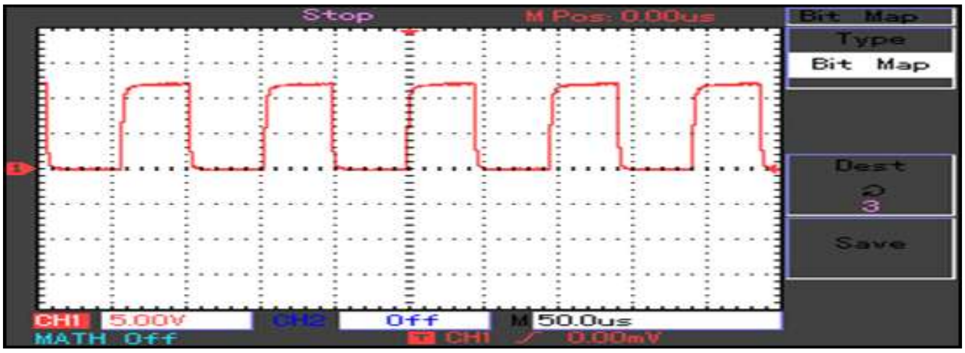


Fig.10 Switching pulses from IR2110

The waveform shown in fig 11 is the output from boost converter, which is 24 V as shown in figure. This is used to charge the battery.

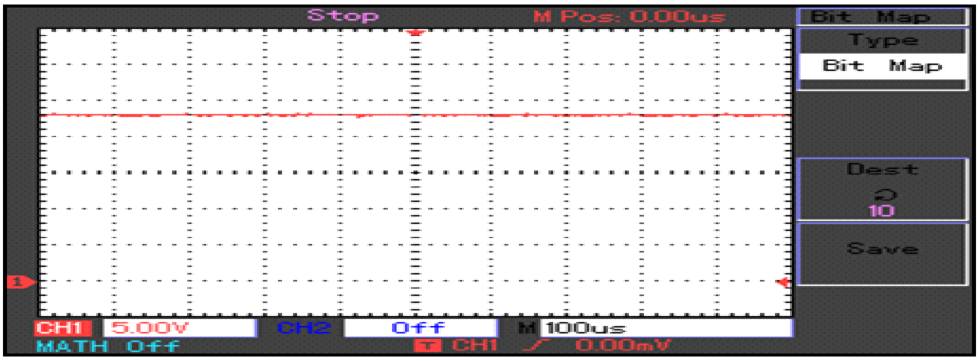


Fig.11 Output from boost converter

The waveform shown in fig 12 is the output from buck converter, which is 12 V as shown in figure. This is used to drive a DC Motor.

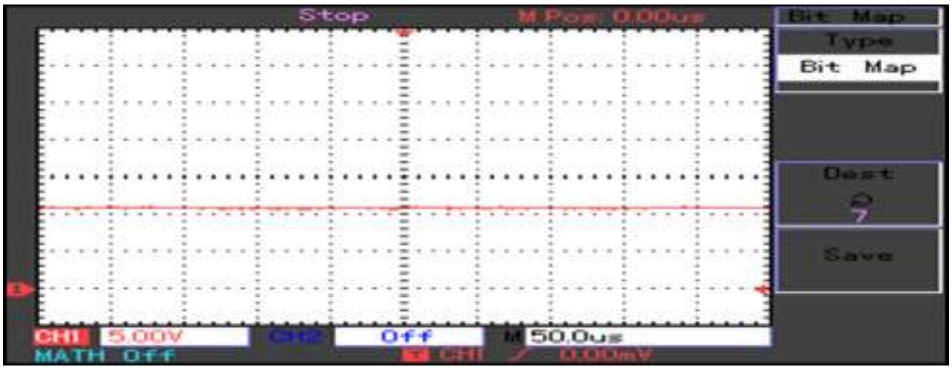


Fig.12 Output from buck converter

IV. Conclusion

This paper has presented a design of an integrated dual output converter for a PV-battery-powered motor system with experimental verification. The proposed converter is the integration of buck and boost converter which provides simultaneous step up and step down outputs. By using the variable frequency control, the main functions such as MPPT and driving the motor with specific speed can be realized with a reduced number of active switches. The voltage stress problem is eliminated by using a battery.

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