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Design and Simulation of a Closed-Loop Non-Inverting Buck-Boost Converter for a PV System

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Abstract*— The use of solar energy has seen considerable development. Transformation in electric energy is one of its applications which attracts considerable interest, owing to the fact that it makes it possible to solve a major problem in isolated and remote places where grid power is not available. that lack electrical supply networks. Integrating solar photovoltaic (PV) generation is a suitable solution for sustainable energy production and management for the next energy grid model, such as DC microgrids. Although PV-battery-wind integration has been widely studied in DC microgrid applications, many integrations use legacy power electronics converter topologies such as DC-DC boost converters. The paper presents the Design and Control of a closed loop Non-Inverting Buck-Boost Converter. The PWM controller controls the voltage of the load terminal. The proposed topology has been simulated for a considered specification and the results obtained are presented.

Keywords: DC-DC Converter, Non-Inverting Buck-Boost Converter, Photovoltaic (PV) System, PWM Controller.

I. INTRODUCTION

Renewable energy such as solar, wind, hydro, biogas and nuclear are many of the promising solutions that can be used to address the lack of access to clean electricity. Renewable energy can help to reduce the greenhouse gas emissions produced by fossil fuels such as coal and diesel. Many rural parts of the continent still lack access to electricity and clean drinking water. As a result, most of these communities, still rely on fossil fuels to perform daily activities such as lighting, cooking and heating. Therefore, solar energy is one of the proposed methods of providing cleaner, safer and more reliable energy to rural communities, especially where communities are not connected to the power grid. Solar energy is free, abundant and cheaper for powering homes with enough energy. This can be achieved by proper planning and execution, through which all the energy requirements may be met cost-effectively.

Both research and technological development in the area of renewable energy sources are necessary to account for the increase in energy demand and environmental problems in the world. Stand-alone photovoltaic systems are the best solutions for applications such as communication systems, water pumping and low-power appliances in rural areas. Such systems consist of a PV generator, energy storage devices, AC or DC consumers and elements for power conditions. The PV module represents the fundamental power conversion unit of a PV generator system. The output characteristic of the PV module depending on the irradiance intensity and the cell's temperature is nonlinear. The availability of light, seasonal variations, and local characteristics are the uncertainties associated with the solar photovoltaic system. The DC-DC converters may be employed to supply constant voltage to the load.

There are different types of DC-DC converters such as the buck converter, boost converter, buck-boost converter, Cuk converter and SEPIC converter. Buck converters can only step down the input voltage. They are not suitable for applications requiring voltage step-up or inversion. Boost converters can deliver high output voltage but are limited in the output current they can provide. this drawback can be overcome by using a buck-boost converter but one of the disadvantages of using the is that its output voltage is negative. The Cuk converter and the SEPIC converter both output positive voltages. Cuk converters can provide a continuous current for both the input and output.

These topologies are efficient in stepping up a large voltage. However, they have the problem of generating large output voltage ripples and are made up of large components. The non-inverting buck-boost converter has the advantage over these converters in that it uses smaller components that are efficient and cost-effective. The output voltage is either higher or lower than the input voltage while maintaining the same polarity. This flexibility makes it useful in applications where the input voltage can vary above or below the desired output voltage. In this paper, the non-inverting closed-loop buck-boost converter is employed to maintain a regulated output voltage from the PV system.

II. ANALYSIS OF NON-INVERTING BUCK-BOOST CONVERTER

The supply system shown above is the figure of a switch mode power supply system, the DC input is connected to the DC-DC converter to give a regulated DC supply to the load.

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The DC-DC converter is been controlled by a controller. DC source is from a solar PV system, this source provides an unregulated voltage. This unregulated voltage is regulated utilizing a DC-DC converter. DC to DC converter provides varying voltage levels different from that supplied. These DC-DC converters are made to avail the needed voltage then the regulated voltage is supplied to the load. Figure 1 shows a non-inverting buck-boost converter. The noninverting buck-boost converter operates in three modes namely buck operation, boost operation, and buck-boost operation.

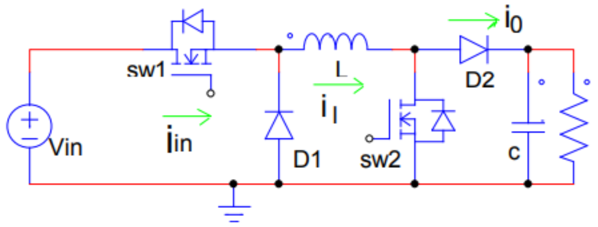

Figure 1. Non-Inverting Buck-Boost Converter

1. Buck Mode:

The buck converter steps down the output voltage. The switch (Sw1) is controlled through the gate pulses, and sw2 is completely OFF. The buck operates in two modes namely sw1 is on and when sw1 is off. The average output voltage is calculated in terms of the duty cycle. The duty cycle is given by

$$D = \frac{v_0}{v_{in}}$$

Mode 1: when to switch 1 is closed the input voltage Vin causes the diode D1 to go into the reverse bias region and open. The equivalent circuit is shown in Figure 2. Thus, the inductor charges linearly. The input supplies the load.

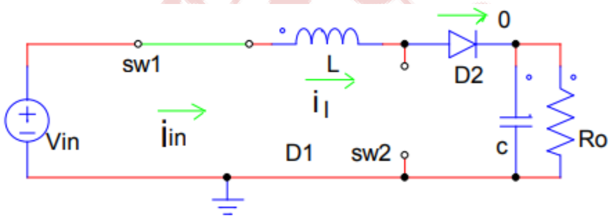

Figure 2. Equivalent circuit of the converter in buck mode with switch1 closed

Mode 2: the switch 1 will be off for a 1-DT period. Due to the inductor voltage diode D1 starts conducting thus inductor starts discharging energy stored during switch1 ON. The equivalent circuit is shown in Figure 3.

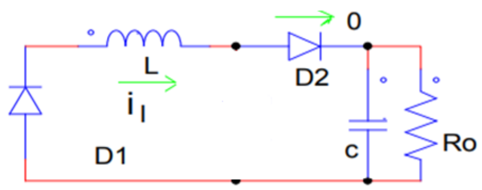

Figure 3. Equivalent circuit of the converter in buck mode with switch1 open

2. Boost Mode:

Boost converter always steps up the output voltage. In this mode the Sw1 will be continuously ON while D1 is off whereas the Sw2 will be given with the controlled gate pulses, the boost converter operates in two modes based on sw2 ON or OFF. The average output voltage is calculated in terms of the duty cycle. The duty cycle is given by

$$D = 1 - \frac{v_{in}}{v_0}$$

Mode 1: when sw2 is closed the diode D2 is reverse-biased and the current flows only through the inductor and the switch. Thus, the energy is stored in the inductor. The equivalent circuit is shown in Figure 4.

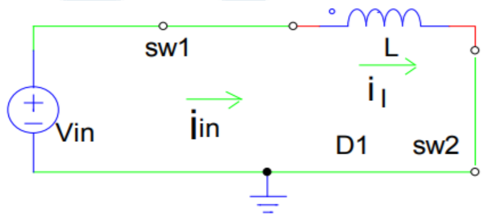

Figure 4. The equivalent circuit of the converter in boost mode when Sw1 and sw21 are closed

Mode 2: switch 2 is OFF and the equivalent circuit is shown in Figure 5. Now D2 will be forward-biased. The input current along with the current accumulated in the inductor starts flowing through the diode as well as the load.

3. Buck-Boost mode:

The Buck-Boost converter can increase or decrease the supply voltage, based on the switch's ON time and OFF time. Noninverting converter operating as buck-boost converter includes both the switches sw1 and sw2 on/off together and the pulse duty cycle is the same. The average output voltage is calculated in terms of the duty cycle. The duty cycle is given by

$$D = \frac{v_0}{v_0 + v_{in}}$$

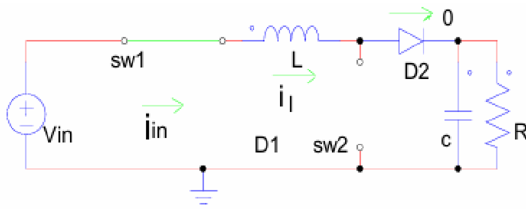

Figure 5. The equivalent circuit of the converter in boost mode when sw2 opened

Mode 1: when switches are ON the diodes are reverse-biased while the inductor gets charged linearly. The circuit is the same as the boost converter at this instant the circuit is a boost converter circuit. Figure 6 shows The equivalent circuit of the converter in buck-boost mode with both switches closed.

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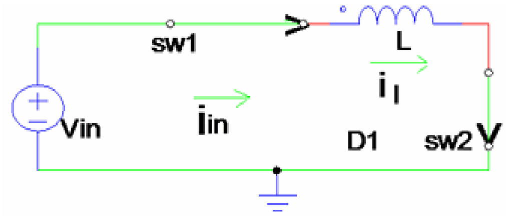


Figure 6. Equivalent circuit in buck-boost mode when both switches closed

Mode 2: when the switches are turned off, the diodes will be forward-biased thereby discharging the inductor through the load. The equivalent circuit is the same as that of the buck converter in the off-state. thus, the circuit is a buck converter circuit. Figure 7 shows The equivalent circuit of the converter in buck-boost mode with both switches opened.

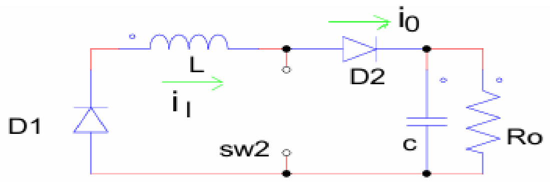


Figure 7. Equivalent circuit of buck-boost mode when both switches opened

III. DESIGN OF NON-INVERTING BUCK-BOOST CONVERTER

The design of a non-inverting buck-boost converter is the same as the inverting buck-boost converter. The converter is designed considering the data below,

Table 1. Specifications of the DC-DC converter

Component	Specification
Input DC Voltage	Vin = 200-250V
Output DC Voltage	Vout = 230V
Inductor	L1 = 10µH
Capacitor	CL = 200µF
Resistive load	R_L = 50Ω
Switching frequency	40khz

IV. PWM CONTROLLING

Since the output of the solar PV system, is not constant. This unregulated voltage is regulated through a DC-DC converter. To control the variation in voltage, a closed-loop control system is designed.

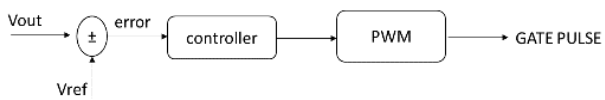


Figure 8. Closed Loop Control

A controlling technique is represented as shown in the figure., the values Vout and Vref are to be compared and error is calculated. If the value of Vout is less than Vref converter be in boost mode, if Vout is greater than Vref then it will go into buck mode. A controlling model is thus designed by using Simulink blocks as, PI controller, PWM & a constant block as shown in Figure 8.

V. SIMULATION

The simulation of the PV system is carried out using the SimPowerSystems toolbox in MATLAB/Simulink software shown in Figure. Figure shows the simulation results of the PV System & and the non-inverting DC-DC buck-boost converter in the closed loop. The solar panel input of designed parameters is simulated with variable irradiance and standard test conditions temperature of 25°C. The irradiance can be varied by using a knob. The Solar PV output is given to the Proposed DC-DC non-inverting Buck Boost converter and it is fed to the resistive load 50Ω. The specifications of the implemented circuit are presented in Table 1. The output waveforms are obtained as per the designed parameters.

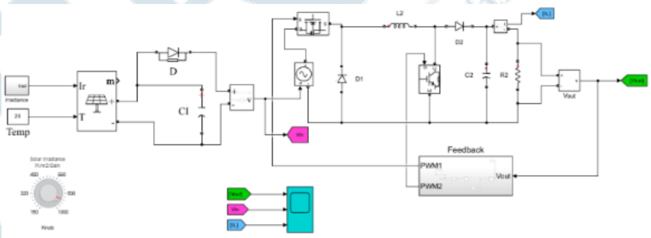
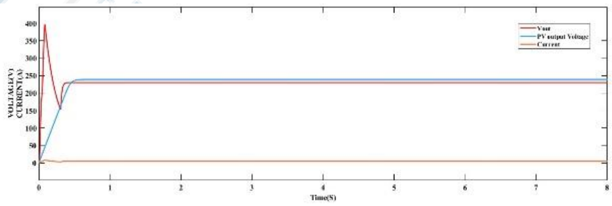


Figure 9. MATLAB/Simulink Model of Closed Loop of PV System and Proposed DC-DC non-inverting Buck-Boost Converter



VI. RESULTS & DISCUSSIONS

The closed-loop DC-DC converter under input voltage and load variation, where the circuit is varied at 200V to 250V input voltage. When circuits perform under load variation, the input voltage is fixed for both circuits; when circuits perform under the input voltage, the load is 50Ω fixed for both circuits.

Table 2. Performance Comparison Under Input Voltage and Load Variation

V_{in} =240			R_L = 50Ω		
R_L (Ω)	**V_O (V)**	**I_O (A)**	**V_{in} (V)**	**V_O (V)**	**I_O (A)**
10	230	3.194	**200**	230	0.64
20	230	1.6	**210**	230	0.64
30	230	1.06	**220**	230	0.64

V_{in} =240			R_L = 50Ω		
R_L (Ω)	**V_O (V)**	**I_O (A)**	**V_{in} (V)**	**V_O (V)**	**I_O (A)**
40	230	0.79	**230**	230	0.64
50	230	0.64	**240**	230	0.64
60	230	0.53	**250**	230	0.64

Table 2 shows the variation in the input voltage with load kept constant & variation in load with input voltage kept constant it is absorbed that in any variation in voltage and load, the output voltage remains constant. The closed-loop configuration allows the converter to actively respond to changes in the input voltage, providing better regulation. It can maintain a constant output voltage even in the presence of variations in operating conditions. The simulation of the PV System & and the DC-DC buck-boost converter in a closed-loop PV system is carried out

VII. CONCLUSION

In this paper, a novel control scheme for Solar PV systems was used. A control scheme was developed for maintaining a constant voltage. The constant DC voltage is found to be maintained constant by the use of the PWM controlling techniques. Closed-loop converters are widely used in various electronic devices and systems where precise voltage regulation is critical. They offer improved performance compared to open-loop converters, especially in applications with varying input voltages. The simulation results obtained verified the proposed control strategy. Thus, non-conventional energy resources have made the domain much more practical and efficient.

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