

Boost Converter Design with Stable Output Voltage for Wave Energy Conversion System

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ABSTRACT

This paper presents the design and simulation of the boost converter for a Wave Energy Conversion System (WECS). The system consists of wave energy conversion device, boost converter and DC Load. The converter is designed to ensure that the output voltage of WECS will be boosted up from a variable input voltage to a stable output voltage. The simulation models have been developed and tested in the MATLAB / SIMULINK. Simulation result has proven that, the proposed design is able to produce a constant output voltage from variable input voltage.

Keywords: Wave Energy Conversion System (WECS); Boost converter; MATLAB / SIMULINK.

1. INTRODUCTION

Renewable energies are getting significant attention due to the increase in oil prices and environmental concerns. Wave energy will play an important role in the near future. WEC technologies have been used to convert wave energy into electric energy; however they are not yet to be commercially competitive. More efficient WECS is expected to be developed soon. In order to achieve this goal, control engineering is believed to play an important role in this field [1]. Although several WECS technologies are available to convert ocean wave power into electric power, the winning technical approach is still unclear [2],[3].

In addition, a number of WEC technologies are under development, using different working principles and have been designed for different types of locations. Modeling and control play an important role in improving the efficiency of the WECS.

There are different configurations of wave energy conversion system (WECS) and each may use different converters design. These converters are used to adjust the varying input voltage of the system as compared to the desired output voltage. In some combination a diode rectifier and DC boost converter are used as an interface between the generator and DC-AC inverter [4].

This research work is generally about a Wave Energy Conversion System (WECS) connected to DC Load/ DC-AC. The block diagram of the WECS configuration is shown in Fig. 1. It is basically consists of combination of wave energy generator to generate DC voltage with random values; Boost converter which will be used to boost the DC voltage value coming from the DC generator output voltage and DC Load/ DC-AC Inverter. The main objective of this research work is to design and simulate a boost converter which is one of the main modules in the WECS. The purpose of the work is to develop a boost converter that is able to boost up a variable DC voltages to a controlled DC voltage with desired output voltage value. The main objectives of this work are designing and simulation a boost converter

with variable input voltages, 2-23 Volts and the output voltage, 24 Volts.

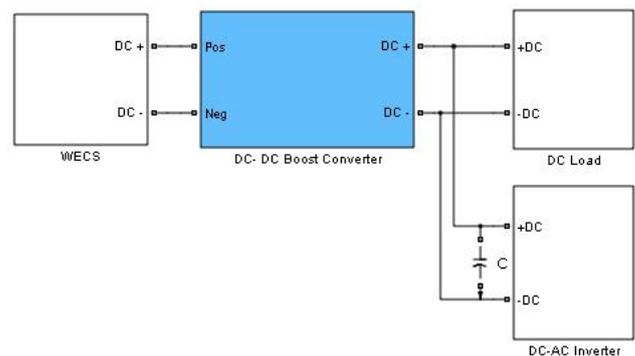


Figure 1. Block diagram of WECS

In this paper a boost converter is used to increase the small variable value of DC voltage generated from a DC generator of wave energy conversion system.

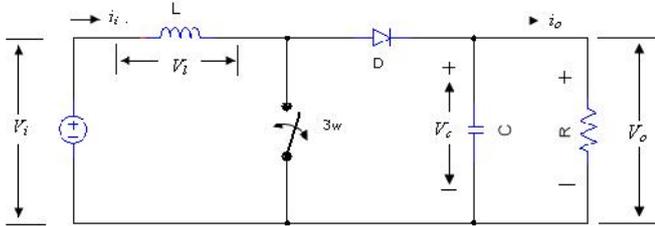
The paper is organized as follows: in section II, a brief background is reported, methodology of design the Boost Converter is explained in section III, and the simulation results are reported in section IV. The Conclusion and future direction of the research is provided in section V. The acknowledgement and reference list are at the end of this paper.

2. BACKGROUND

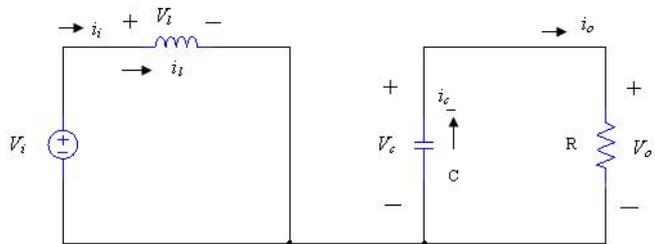
A. Boost Converter

Boost converters are being used extensively in regulating switch mode DC power supplies. Normally, the DC input voltage of the converter fluctuates, and therefore, the average output voltage must be controlled to be equated to the desired value [5].

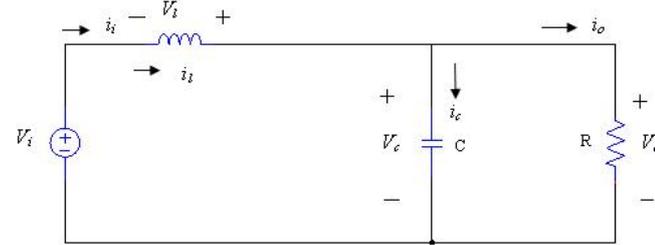
In another way, the boost converter output voltage is always greater than the input voltages [6][7]. As shown in Fig. 2, (a) the boost converter circuit, the output voltage (V_o) can be varied from the input voltage (V_i) up to several times of the input voltage [8][9].



(a) Converter circuit



(b) Switch on: 0 t T_{on}



(c) Switch off: T_{on} t T

Figure 2. Boost converter topologies: (a) Converter circuit
(b) Switch on: 0 t T_{on} (c) Switch off: T_{on} t T

As shown in Fig. 1 (b) when the switch Sw is closed, the energy is stored in the magnetic field of the inductor (L). The current (i_i) flows in the inductor (L) and the voltage (V_i) across the inductor is equal to the input voltage (V_i). When the switch is open as shown in Fig. 1 (c), the energy stored in the inductor is transferred to the capacitor (C) and the load (R) through the diode (D). The voltage (V_i) across the inductor reverses and add to the input voltage (V_i) to increase the output voltage (V_o) [7][8]. Under steady state operation, the average voltage across the inductor (L) during the time period T ($T = T_{on} + T_{off}$) must be equal to zero.

$$\frac{(V_c - V_i) * T_{off} - V_i * T_{on}}{T} = 0 \quad (1)$$

Therefore

$$V_c = V_i * \frac{T}{T_{off}} \quad (2)$$

and the duty cycle (D) can be described as in equation (3)

$$D = \frac{T_{on}}{T} = \frac{T - T_{off}}{T} = 1 - \frac{T_{off}}{T} \quad (3)$$

Or can be simplified as in equation (4)

$$\frac{T}{T_{off}} = \frac{1}{1-D} \quad (4)$$

Therefore, from equations (2) and (4) we can get

$$V_c = V_o = \frac{V_i}{1-D} \quad (5)$$

B. Duty Cycle (D)

Equation (3) shows the duty cycle or (duty ratio) which is the ratio of the pulse width (T_{on}) to the period of the waveform (T). If the duty cycle equals to zero ($T_{on} = 0$) then from the equation (5) we can equate

$$V_c = V_o = V_i \quad (6)$$

If the duty cycle equals unity ($T = T_{on}$), then from the equation (5) we can obtain

$$V_c = V_o = \frac{V_i}{0} \quad (7)$$

Theoretically the output voltage can be changed from 0 to when the duty cycle varies from 0 to 1 [7].

3. METHODOLOGY

A. Boost converter design for Continuous Conduction Mode (CCM)

The objectives are to design a boost converter with low cost, low power output (for low power application), stable output voltage, and output tolerance is within the $\pm 5\%$ and time taken to reach the steady state output voltage as low as possible.

Each component values of boost converter power stage are determined to meet the design specifications. The input voltage, the output voltage, the switching frequency and the ripple voltage are defined by the design specification operating in the Continuous Conduction Mode (CCM) and the parameters values are tabulated in Table 1. Equations 8-14 are used to calculate the output current, load resistance, maximum and minimum output power and the duty cycle.

TABLE 1 BOOST CONVERTER DESIGN SPECIFICATIONS

Design Specification for CCM		
Parameters	Symbols	Values
Input Voltage in (Volt)	V_i	2-23
Output Voltage in (Volt)	V_o	24
Switching Frequency in (kHz)	f_s	20
Output Power in (Watt)	P_o	100
The voltage ripple in Volt (V_r/V_o) = 1 %	V_r	0.24

The minimum output current I_{omin} is equal to 5% of the maximum output current and the maximum output current I_{omax} is expressed by equation (8);

$$I_{omax} = \frac{P_o}{V_o} \quad (8)$$

The minimum and maximum load resistance is represented by (9) and (10) respectively;

$$R_{min} = \frac{V_o}{I_{omax}} \quad (9)$$

$$R_{max} = \frac{V_o}{I_{omin}} \quad (10)$$

The minimum and maximum output power can be computed by (11) and (12) respectively;

$$P_{min} = V_o I_{omin} \quad (11)$$

$$P_{max} = V_o I_{omax} \quad (12)$$

The minimum and maximum duty cycles can be obtained by using (13) and (14) respectively;

$$D_{min} = 1 - \frac{V_{imax}}{V_o} \quad (13)$$

$$D_{max} = 1 - \frac{V_{imin}}{V_o} \quad (14)$$

The minimum or critical inductance value of CCM operation, is expressed by equation (15).

$$L_{crit} = \frac{R_{max} D_{max}}{2f_s} * (1 - D_{max})^2 \text{ for } D_{min} < \frac{1}{3} \quad (15)$$

To find the minimum capacitor value C_{min} ; Equation (16) has

been used:

$$C_{min} = \frac{D_{max} V_o}{f_s R_{min} V_r} \quad (16)$$

T, is the time period and can be determined as follows:

$$T = \frac{1}{f_s} \quad (17)$$

Therefore, in Table 2 are shown the calculated parameters of the proposed boost converter design for CCM.

TABLE 2 CALCULATED PARAMETERS

Designs Calculated Parameters		
Parameters	Symbols	Value
Output Current in (Amp)	I_{omin} - I_{omax}	0.2 – 4.2
Load resistance in (ohm)	R_{min} - R_{max}	5.7 - 120
Output power in (Watt)	P_{omin} - P_{omax}	4.8-100.8
Time period in (μ s)	T	$50 * 10^{-6}$
Duty cycle %	D_{min} - D_{max}	4 - 92
Critical Inductance value (H)	L_{crit}	$< 18 * 10^{-6}$
The Capacitor in (μ F)	C	< 807

B. Simulink Model of the Boost Converter

In order to assess the performance of the proposed boost converter design, in models in MATLAB/SIMULINK have been developed. As shown in Fig. 3 models of boost converter consists of inductor L, MOSFET switch S, Diode D and capacitor C. In addition to that, there are positive and negative DC input ports 3 and 4, respectively which received the signal from the DC generator, and positive and negative DC output ports 1 and 2, respectively which will be the input to the output load resistance or DC load. As shown in Fig. 4, scopes are used to display the output results.

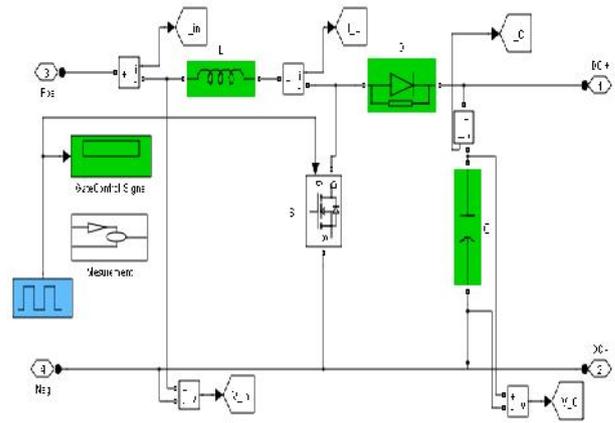


Figure 3. DC-DC Boost converters

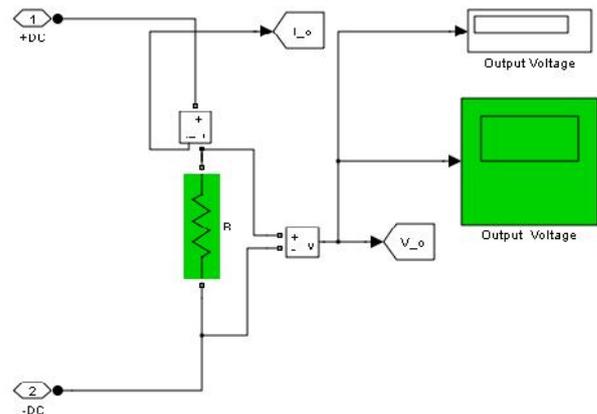


Figure 4. An output resistor of the Converter /DC Load

C. Full Bridge Diode Rectifier Connected at the DC Generator Terminal

Fig. 5 shows the output of the WECS connected to a full bridge diode rectifier. The diode bridge shown in Figure 4 is used to turn the negative and positive voltages into only positive outputs. As explained the output follows the wave movement and the DC generator is turned forth and back with the wave movement. When a DC generator is turned in one way it will produce a voltage with one polarity. Vice versa, when the DC generator is turned in the opposite direction the polarity of the voltage will be reversed.

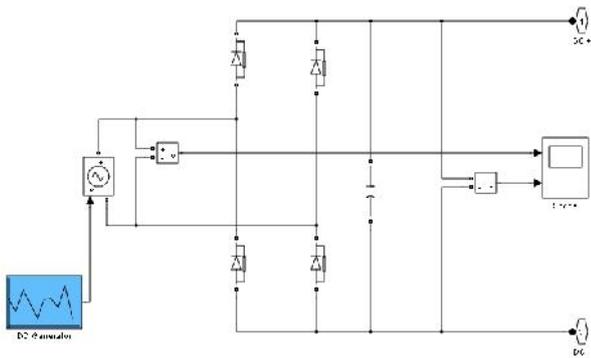


Figure 4. Simulation Output of WECS connected With Full Bridge diode rectifier

4. SIMULATION RESULTS & DISCUSSIONS

MATLAB 7.6 is used to simulate the system and the results of the input and output voltages, inductor and output current and input and output power have been reported.

Fig. 6 shows the Simulink model of the system which consists of output of WECS connected to a full bridge diode rectifier, boost converter and output load resistance or DC loads.

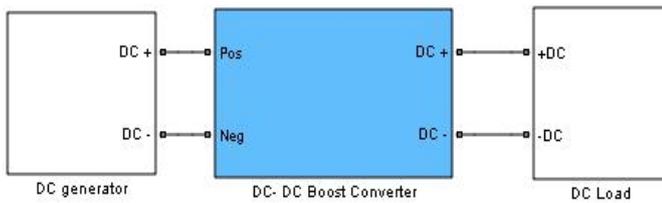
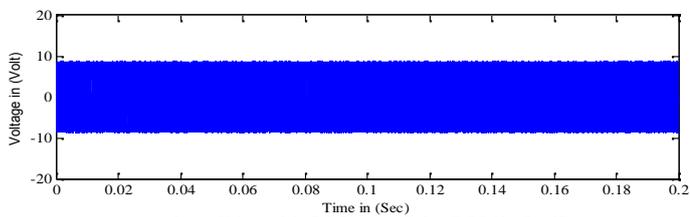
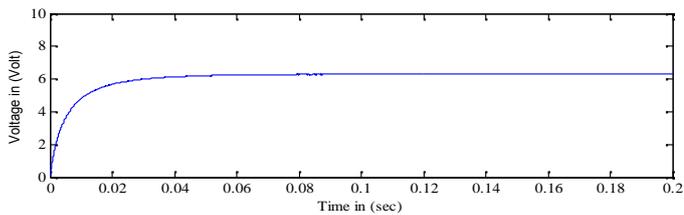


Figure 5. Simulink model of the system

Fig. 7 shows the simulation results, which are selected to demonstrate the most significant aspects of WECS when connected to a DC load through DC-DC boost converter. As shown in the Fig. 7 a, the output voltage of the DC generator is varied in the range between (+8.8 to -8.8) Volts. The voltage shown in Fig. 7 (b), has been stabilized to 6.2 Volt after passing through a full bridge diode rectifier which then will be the input to the DC-DC boost converter design.



(a) Output Voltage of the DC Generator Before Full Bridge Rectifier



(b) Output Voltage of the DC Generator After Full Bridge Rectifier

Figure 7. The output voltage of the DC generator

The input and output voltage of the proposed boost converter design for CCM is shown in Fig. 8. As shown in the figure when the DC input voltage is 6.2 Volt, the output voltage of the proposed boost converter has stabilized to values approximately 24 Volt after 0.06 sec from the starting of the simulation.

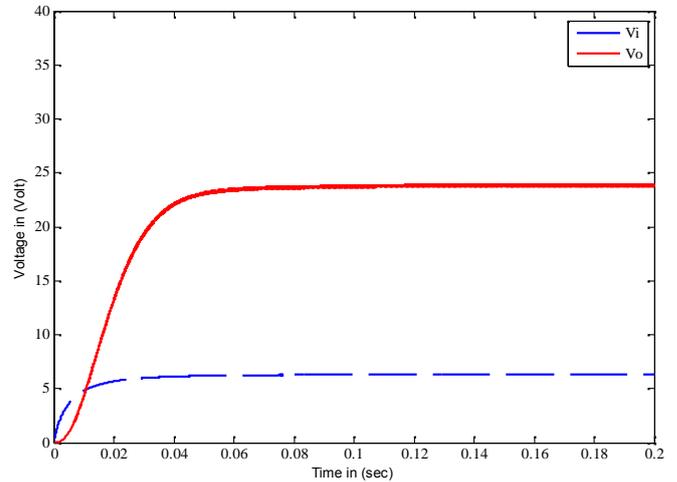


Figure 8 The input and output voltage of the DC-DC boost converter

The inductor and output current of the proposed DC-DC boost converter is shown in Fig. 9. As shown the output current is closed to the calculated value of 4.2 Amp, and the inductor current is approximately at 23 Amp after 0.05 sec from starting of the simulation.

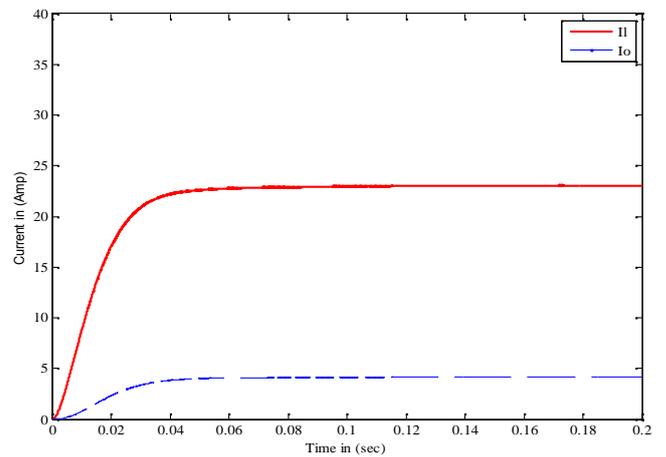


Figure 9. The inductor and output current

The input and output power of the proposed DC-DC boost converter is shown in Fig. 10. As will be seen, the output and input power are approximately similar to the calculated value of 100 Watt and 140 Watt respectively.

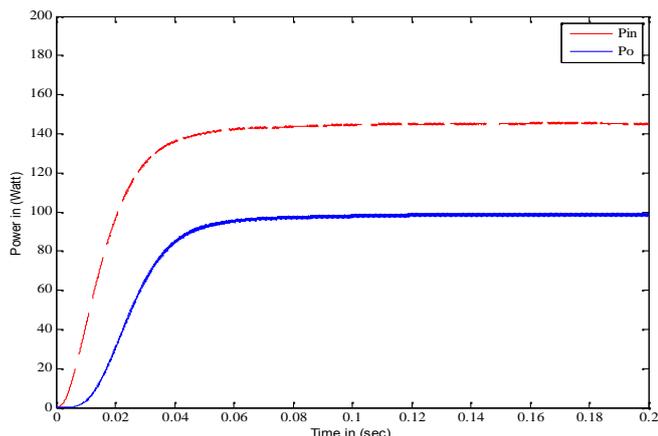


Figure 9. The input and output power in Watt

The simulation results of the proposed boost converter design with different values of the input voltages, and duty cycle are shown in Fig. 10. For the different input voltages the output voltage is almost constant within the average value of 24 Volt whereas the duty cycle has different values, it is still within the calculated range ie; 0.04 to 0.92. As observed from the simulation the highest input voltage needs the smaller duty cycle whereas the lowest input voltage needs the highest duty cycle.

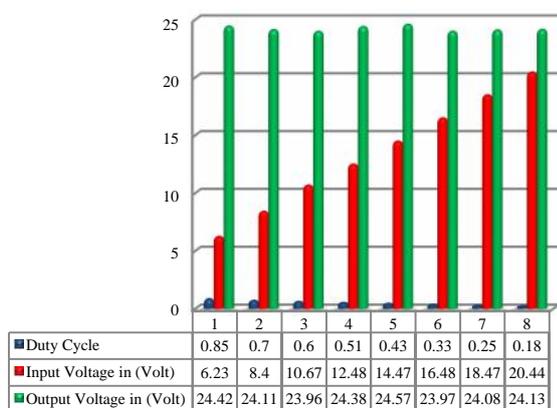


Figure 10. The duty cycle, input voltage and output voltage in Volt

5. CONCLUSION

This paper has addressed the design and simulation of a boost converter used to boost up variable values of DC voltage generated from WECS. The operating principles, converter design and simulation results have been reported. The proposed boost converter design is able to produce a stable output voltage for different values of the input voltage. Generally, this paper presents preliminary simulation results of WECS model connected to a DC load through boost converter. Future studies will be to explore and comprehend the problem of controlling the output voltages of the converters.

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