Mohanty et al. 2016. *Int. J. Vehicle Structures & Systems*, 8(1), 54-57
ISSN: 0975-3060 (Print), 0975-3540 (Online)
doi: 10.4273/ijvss.8.1.11

International Journal of Vehicle Structures & Systems
Available online at www.maftree.org/eja

Simulation and Experimentation of Fourth Order DC-DC Boost Converter for Renewable Energy Source Applications

Soumya Bhanu Mohanty, K.M. Ravi Eswar, D. Elangovan[a] and G. Arun Kumar

School of Electrical Engg., VIT University, Vellore, India
[a]Corresponding Author, Email: elangovan.devaraj@vit.ac.in

ABSTRACT:

In this paper, analysis and experimentation of a fourth order boost converter has been proposed for renewable energy source applications such as solar power. The output of proposed converter is fed to motor load of 220W. The main advantages of this converter are negligible current ripples at both source and load side and higher efficiency as compared to the conventional boost converter. The energy storage elements in circuit are designed and optimized using Bacterial Foraging Optimization Algorithm (BFOA) to solve the contradictory problems of steady state and dynamic performance of the system. The up-down glitch in control to output transfer function of system is reduced with the optimized values of energy storage elements in the proposed converter. Therefore dynamic response of system is analyzed with the designed values of inductor and capacitor. Closed loop control is introduced in the proposed system using proportional integral controller to maintain the output voltage constant when there is any load disturbance in the output side and wide variations in the input voltage. Simulation and hardware results of the proposed converter with input voltage of 60V and switching frequency of 100 kHz are presented.

KEYWORDS:

Bacterial Foraging Optimization Algorithm; Fourth order DC-DC boost converter; Proportional integral controller

CITATION:

S.B. Mohanty, K.M.R. Eswar, D. Elangovan and G.A. Kumar. 2016. Simulation and Experimentation of Fourth Order DC-DC Boost Converter for Renewable Energy Source Applications, *Int. J. Vehicle Structures & Systems*, 8(1), 54-57. doi:10.4273/ijvss.8.1.11

1. Introduction

In boost converters, the output voltage is greater than the input voltage. Hence, it is suitable for any renewable energy resources like solar power where the output voltage is low and it needs to be boosted up. The main disadvantages of conventional boost converters are low efficiency, high input and output ripple, high gain is not possible without high duty ratio and as duty ratio increases the chance of diode recovery losses increases [1]. In many applications, we need to have fewer ripples on both the load and source side of the converter so that the AC losses will be less. Also, fewer ripples mean less electromagnetic interference [2]. It is very difficult to satisfy these requirements at a time with the conventional second order converters without the use of any filters. The steady state performance of any system can be improved by adding energy storage elements. This makes the system higher order as in Cuk and SEPIC converters which results in more complex circuit and poor dynamic response.

The improvement in dynamic response will be a big task because of increase in the number of complex conjugate pole-zero locations. If we will take third order converter, this will have more source current ripple and poor steady state performance as compared to Fourth Order Boost Converter (FOBC) [3]. So we need to take care of both steady state and dynamic performance. Coupled inductors can be used to produce zero current ripples either on source or load side. So a boost converter of fourth order family which includes separate inductors without coupling has been proposed. In the proposed FOBC, due to the presence of additional inductor in the input, the input as well as the output current ripple is negligible. The low current and voltage stress on the converter switch is another advantage. Also, the gain similar to that of conventional converter is possible [4, 5]. The converter is operated for a wide range of duty ratio. This type of boost converter is used for battery charging applications since the ripple is negligible and we are getting a continuous current. In almost all the cases, the load on the converter is fluctuating. This may result in poor performance of the converter. Also, it will have a destabilizing effect [5, 6]. Hence, a controller should be designed to reduce these fluctuations. Thus, controllers reject the disturbance, regulate output voltage with respect to variation in load or other parameters.

Proportional integral controller is implemented for the closed loop operation of the converter. This maintains the output at the required value. In the following sections, the modes of operation, the simulation results of proposed DC-DC boost converter and the experimental results obtained using dSPACE are discussed. The dynamics in the output voltage of the proposed converter is given by the control to output transfer function of system. It consists of a complex conjugate zero pair at frequency fr3, complex conjugate pole pair at frequencies fr1 & fr2 and real zero at fr4. Compared to conventional boost converter, proposed converter has extra complex conjugate pole pair due to the presence of extra capacitor and inductor. Therefore there is up-down or down-up glitches as shown in Fig. 1. These glitches result in multiple unity gain crossovers, as a result the system becomes conditionally stable. To overcome this disadvantage we need to restrict the bandwidth of system and care should be taken such that the system has only one unity gain crossover frequency with desirable phase margin and gain margin. Therefore it is concluded that with up-down glitches in the system, loop gain bandwidth is restricted, finally dynamic response of converter will be deteriorated.

Our aim is to improve the dynamic response of system, therefore we need to increase the loop gain bandwidth of system. Some of the solutions for this are

- Magnitude of glitch should be reduced.
- Damping network should be connected across a capacitor C.
- The up-down glitch should be shifted to high frequency region.
- Complete elimination of up-down glitches.

The second solution can be implemented with reduced efficiency which is a disadvantage. The third solution can be implemented by reducing the size of inductor and capacitor which again increases the ripple content. Therefore the best solution is to reduce the magnitude of glitch by selecting optimal values of inductor and capacitor. This type of contradictory problems can be solved by probabilistic method, which is more preferable than deterministic method. In this paper we used Bacterial Foraging Optimization Algorithm (BFOA) to get the optimal values of inductor and capacitor to obtain a reduced ripple and at the same time fast dynamic response with reduced up-down glitch in the system [7].

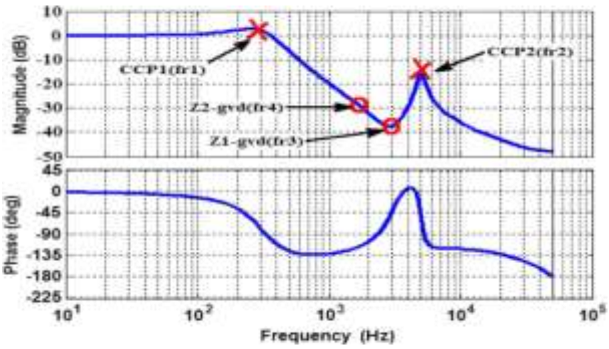

Fig. 1: Up-down glitches in control to output transfer function

2. Analysis of fourth order boost converter

Fig. 2 shows the modified fourth order boost converter. Rearrangement is done at the input side of the conventional boost converter which helped in achieving fewer ripples in the source current. During mode I, the switch is at on position and the diode is reverse biased because the input voltage is less than the capacitor voltage across C1. There are three loops in which the circuit is operated. The input current splits and flows through L2 and C1 as shown in Fig. 3. In mode 2, the switch is at off position and the diode is forward biased because the input voltage is greater than capacitor voltage. There are three loops in which the circuit is operated as shown in Fig. 4. By doing steady state analysis of the fourth order boost converter, the relation between input and output voltage is given by,

$$V_O = V_{in}/(1-D) \tag{1}$$

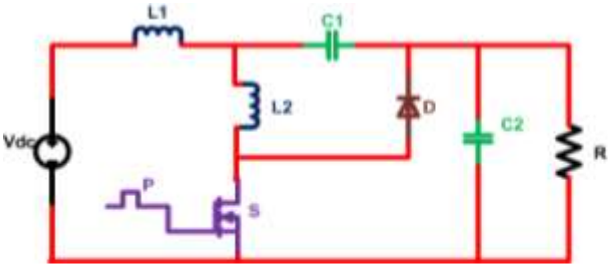

Fig. 2: Proposed FOBC model

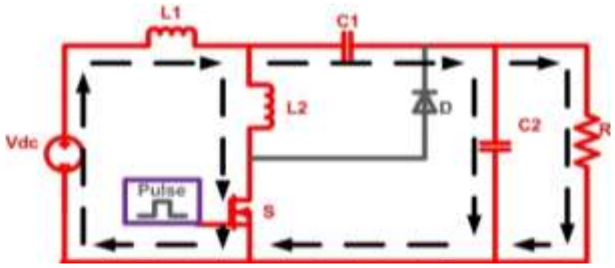

Fig. 3: Mode I

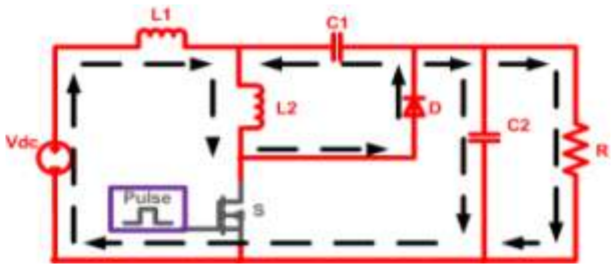

Fig. 4: Mode II

3. BFOA

An escherichia.Coli bacterium is having foraging behaviour which leads to the invention of BFOA. The biology which defines the foraging behaviour of E.Coli swarm is the optimization algorithm. The foraging decisions are taken after analyzing two things - search for nutrients in order to maximize the energy per unit time and then communicating with other bacteria through signals. The optimization consists of chemo-taxis, reproduction and elimination dispersal mechanisms. Chemo taxis is a process in which a bacterium moves in search of nutrients in steps. This idea is used in BFOA. After getting sufficient food, reproduction takes place in which bacteria increase its length and breaks at the middle. In this way formation of exact replica takes place in the presence of environment. If there is sudden change in environment, a swarm of bacteria move to other places or are eliminated. This involves elimination dispersal [8]. The BFOA is discussed in [8] - [10]. The parameters of BFOA used in this paper are given in Table 1. The obtained optimized parameters from BFOA are given in Table 2. Fig. 5 shows the bode plot for control to output transfer function of system with optimized parameters from

BFOA. From this, we can observe that there are no up-down glitches in system with optimized parameters.

Table 1: BFOA parameters

Parameter	Value
Size of population	20
Loop size of reproduction	8
Size of Chemo taxis	8
Elimination dispersal loop size	4
Length of swim	8
Probability	0.4

Table 2: BFOA results

L_1	L_2	C_1	C_2
10 µH	136 µH	40 µF	100 µF

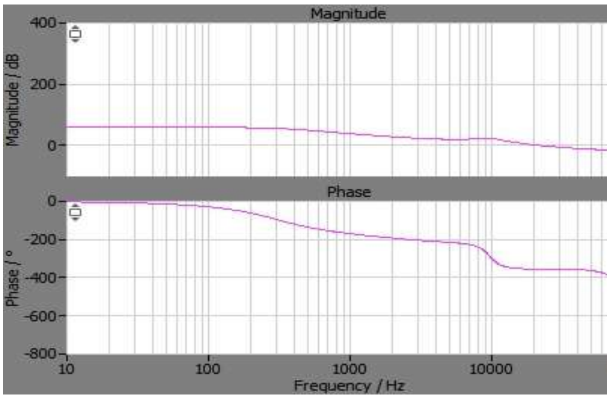

Fig. 5: Frequency response of proposed DC-DC boost converter with optimized parameters

4. Simulation results

The simulation of the proposed converter was done using MATLAB version 13a and is shown in Fig. 6. For an input voltage of 60 V, an output voltage of 220 V was obtained giving 220 W power. The switching frequency is 100 kHz. Table 3 gives simulation parameters. Here, the system is controlled with the help of proportional integral controller, so that errors and disturbances are eliminated and more accuracy is obtained. Closed loop control parameters are given in Table 4. The simulation results are shown in Fig. 7 and Fig. 8. To represent transient response of proposed converter we connected another load of 208 Ω in parallel with the existing load from 0.2 sec to 0.3 sec. We observed that there is no much difference in output voltage between these two loading conditions as shown in Fig. 9.

Table 3: Simulation parameters

Parameter	Value
V_{in}	60 V
C_1 & C_2	40 µF & 100 µF
L_1 & L_2	10 µH & 136 µH
Motor load	220 W
Switch	MOSFET
Internal resistance	0.1 Ω
Frequency	100 kHz
Duty ratio	0.7273
Resistive load	208 Ω

Table 4: Closed loop control parameters

Components	Range
K_p	0.000001
K_i	0.000005

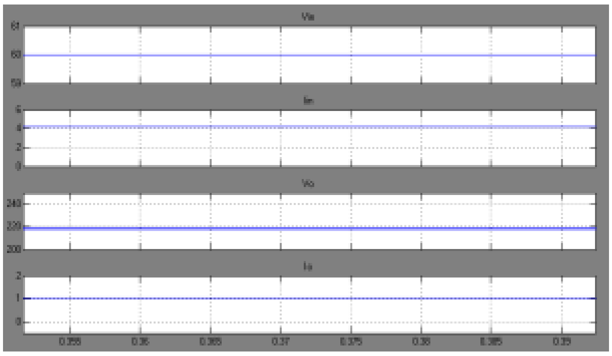

Fig. 7: Simulated waveforms of proposed converter - Input voltage and current, output voltage and current

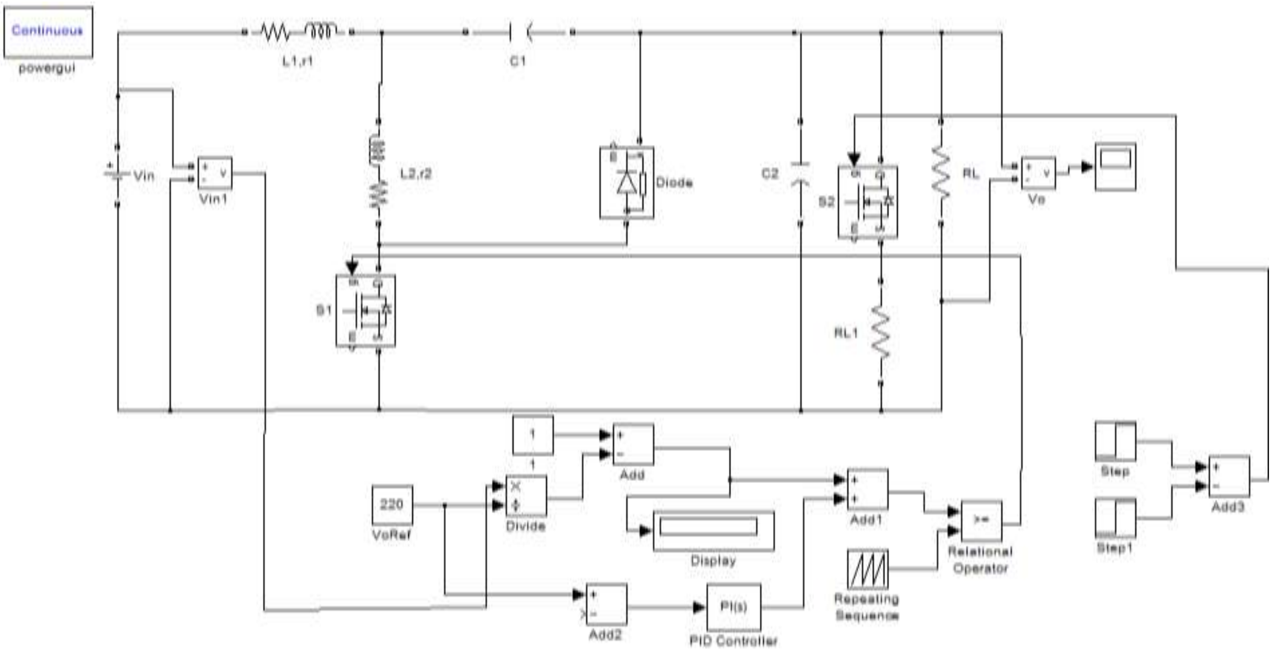

Fig. 6: MATLAB simulation circuit of proposed converter with closed loop system

Fig. 8: Simulated waveforms of proposed converter - Gate pulse, inductor currents (I_{L1} & I_{L2}) and capacitor voltages (V_{C1} & V_{C2})

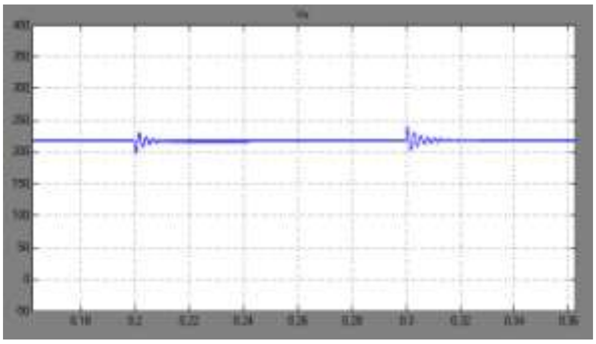

Fig. 9: Transient response of proposed converter

5. Experimentation results

The hardware implementation of the proposed model was done using dSPACE 1104 and the experimental setup is shown in Fig. 10. The various components used in this experimentation are converter circuit, opto isolator circuit, dSPACE, MOSFET, motor and resistive load. The proposed converter is tested with a motor load of 220 W and a resistive load of 208 Ω. The experimental results obtained are shown in Fig. 11 and 12. The input voltage (V_{in}), input current (I_{in}), output voltage (V_O) and output current (I_O) are shown for both steady state and transient responses.

Fig. 10: Experimental setup of the proposed converter

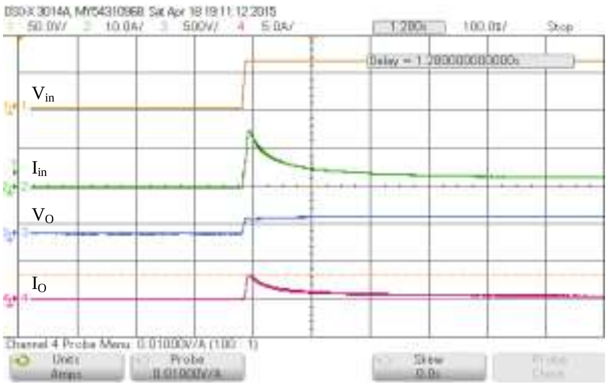

Fig. 11: Steady state response of proposed converter

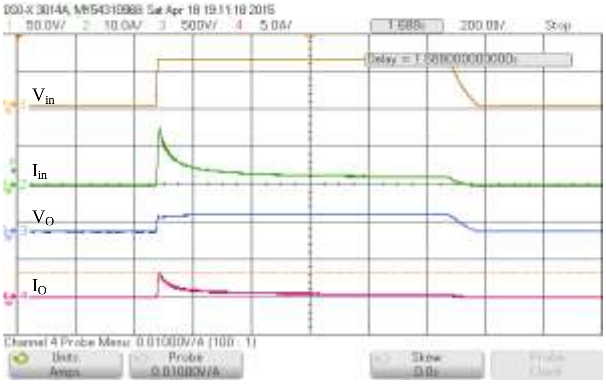

Fig. 12: Transient response of proposed converter

6. Conclusions

The proposed DC-DC boost converter is simulated using MATLAB with the optimized parameters of inductor and capacitor using BFOA to reduce up-down glitches in system. The proposed converter has been tested with a motor load of 220 W and resistive load of 208 Ω. For an input of 60 V, an output of 220 V is obtained. The input and output currents and voltages are having negligible ripples with high efficiency. So we concluded that this converter is better than conventional boost converters.

REFERENCES:

[1] V. Mummadi and B.K. Mohan. 2011. Robust digital voltage-mode controller for fifth-order boost converter, *IEEE Trans. Industrial Electronics*, 58(1), 263-277.

[2] M. Veerachary and A.R. Saxena. 2015. Optimized power stage design of low source current ripple fourth-order boost Dc–Dc converter: A PSO approach, *IEEE Trans. Industrial Electronics*, 62(3), 1491-1502.

[3] J.L. White and W.J. Muldoon. 1987. Two-inductor boost and buck converters, *Proc. Annual IEEE Power Electronics Specialists Conf.*, San Diego, California.

[4] D. Garinto. 2007. A new zero-ripple boost converter with separate inductors for power factor correction, *Proc. IEEE Power Electronics Specialists Conf.*, Orlando, Florida.

[5] J.A.M. Saldaña, J.L. Ramos, E.E.C. Gutiérrez and M.G.O. Lopez. 2008. Average current-mode control scheme for a quadratic buck converter with a single switch, *IEEE Trans. Power Electronics*, 23(1), 485-490.

[6] V. Mummadi and B.K. Mohan. 2011. Robust digital voltage-mode controller for fifth-order boost converter, *IEEE Trans. Industrial Electronics*, 58(1), 263-277.

[7] M. Veerachary. 2014. Digital controller design for low source current ripple fifth-order boost converter, *IEEE Trans. Industrial Electronics*, 61(1), 270-280.

[8] K.M. Passino. 2012. Bacterial foraging optimization, *Innovations and Developments of Swarm Intelligence Applications* (Edited by Shi Yuhui), IGI Global.

[9] R.H. Byrd and R.A. Waltz. 2011. An active-set algorithm for nonlinear programming using parametric linear programming, *Optimization Methods and Software*, 26(1), 47-66. http://dx.doi.org/10.1080/10556780903225880.

[10] K. Ponnambalam, V.H. Quintana and A. Vannelli. 1991. A fast algorithm for power system optimization problems using an interior point method, *Proc. IEEE Power Industry Computer Application Conf.*, 393-400.