Circuits and Systems, 2016, 7, 4009-4023
http://www.scirp.org/journal/cs
ISSN Online: 2153-1293
ISSN Print: 2153-1285

Output Voltage Ripple (OVR) Reduction of Boost Converter Using Particle Swarm Optimization

K. Prithivi[1*], M. Sathyapriya[1], L. Ashok Kumar[2]

[1]Department of Electrical and Electronics Engineering, Kongu Engineering College, Erode, India
[2]Department of Electrical and Electronics Engineering, PSG College of Technology, Coimbatore, India
Email: *k.prthv@gmail.com, priyaeee93@gmail.com, askipsg@gmail.com

How to cite this paper: Prithivi, K., Sathyapriya, M. and Kumar L.A. (2016) Output Voltage Ripple (OVR) Reduction of Boost Converter Using Particle Swarm Optimization. *Circuits and Systems*, **7**, 4009-4023.
http://dx.doi.org/10.4236/cs.2016.712332

Received: May 10, 2016
Accepted: May 21, 2016
Published: October 28, 2016

Abstract

KY Boost Converter, a modern invention in the field of non-isolated DC-DC boost converter is identified for minimum voltage ripple. KY boost converter is the combination of KY converter and traditional boost converter. Such a converter has continuous input and output inductor current, different from the traditional boost converter. And hence this converter is very suitable for very low-ripple applications. The Particle Swarm Optimization (PSO) based controller, FUZZY based controller and open loop KY boost converter are designed in MATLAB/Simulink model. The simulated results show a reduction in output ripple from 1.18 V of the existing open loop KY boost converter output to 0.54 V in the FUZZY logic controlled converter output. Further reduction in output ripple to 0.29 V is achieved in the proposed PSO based converter. The simulated results also show the variation of switching pulses based on the different existing and proposed method.

Keywords

Boost Converter, Particle Swarm Optimization (PSO), Output Voltage Ripple (OVR) Reduction

1. Introduction

For the function of the power supply using the low voltage battery, analog circuits, such as radio-frequency (RF) amplifier, audio amplifier, often need very high voltage to obtain enough output power and voltage amplitude. This is done by boosting the minimum voltage to the required high voltage. For such applications, the output voltage ripple must be taken into account purposefully. Regarding the conventional non-isolated voltage-boosting converter, their output currents are pulsating; thereby the corresponding output voltage ripple tends to be large. As generally approved, to overcome this problem, one way is the usage and low equivalent series resistance (ESR), another way is to add inductance-capacitance (LC) filter. In [1], the interleaved control scheme is employed in the dual buck-boost converters. In the literature [2] [3] [4], the voltage-lift technique is utilized to boost the output voltage. Also several controlling techniques like coupling inductors [5], sliding mode converter [6] and loop bandwidth control [7] were used for voltage ripple reduction. But these converters [2]-[7] have one right-half plane zero in CCM mode. So it is not easy to achieve required boosted output voltage. And hence the KY boost converter [8] [9] [10] is presented to overcome this problem. But these converters [8] [9] [10] do not obtain the expected output voltage and also having large amount of output voltage ripple. The FUZZY logic controller based converter [11] is presented to overcome this problem. The FUZZY based converter [11] can produce the expected output voltage but the ripple reduction performance is not so good. To reduce the ripple in a very effective manner PSO based controller is used and the detailed illustration of the proposed converter is described herein, along with some experimental results to justify the effectiveness of such a converter.

2. System Overview

Figure 1 shows the overall block diagram of the controlled converter. Reduction of the output voltage ripple can be achieved by giving the proper switching pulse for the converter switch. The proper switching pulse is given by the proper controller design for PWM generator. Here the actual voltage (V_{act}) and reference voltage (V_{ref}) are taken as a feedback parameters for controller design. The output of the controller is a control signal which is compared with the reference signal in the PWM generator for producing the proper switching pulse to operate the KY boost converter. Based on the controller design the switching pulse get vary and based on the switching pulse variation the output voltage ripple reduces and output voltage increases. Here the supply for KY converter is given by battery source.

3. KY Boost Converter

Figure 2 shows the proposed positive-voltage KY boost converter composed of the KY converter combined with the traditional boost converter. The KY converter consist of

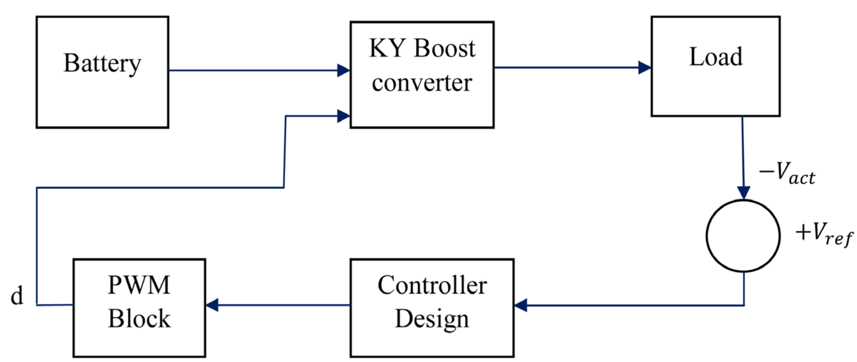


Figure 1. Block diagram of overall system.

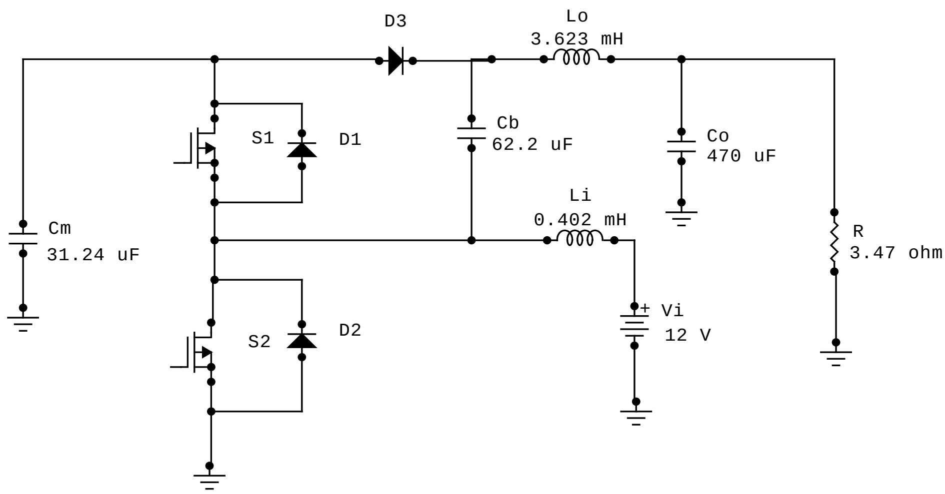


Figure 2. KY boost converter.

the switches S_1 and S_2, the diode D_b, the energy-transferring capacitor C_b, the output inductor L_0 and the output capacitor C_0. The input of the KY converter is retrieved by the buffer capacitor C_m. On the other hand, the traditional boost converter consists of the switches S_1 and S_2, the input inductor L_i. The output of the conventional boost converter is replaced by the buffer capacitor C_m. The buffer capacitor C_m is a buffer between the KY converter and the traditional boost converter. The output load is represented by the load resistor R.

3.1. Mode 1 Operation of KY Boost Converter

In Figure 3, S_1 is turned off and S_2 is turned on. In this case, the negative terminal of C_b is pulled to the ground and hence D_b is forward biased and turned on. During this mode, C_m is discharged whereas C_b is charged. Therefore, the voltage across L_i is V_i, thereby causing L_i to be magnetized, whereas the voltage across L_0 is V_0 subtracted from V_{C_m}, thereby causing L_0 to be demagnetized. Also, the current flowing through C_0 is equal to i_{Lo} minus the current flowing through R. And hence, the corresponding differential equations are given by (1) to (4).

$$L_i \frac{\partial i_{L_i}}{\partial t} = V_{L_i} \tag{1}$$

$$L_0 \frac{\partial i_0}{\partial t} = V_{C_m} - V_0 \tag{2}$$

$$C_m \frac{\partial V_{Cm}}{\partial t} = -i_{Cb} - i_{Lo} \tag{3}$$

$$C_o \frac{\partial V_o}{\partial t} = i_{Lo} - \frac{V_o}{R_L} \tag{4}$$

3.2. Mode 2 Operation of KY Boost Converter

In Figure 4, S_1 is turned on and S_2 is turned off. In this case, S_1 is in the on-state

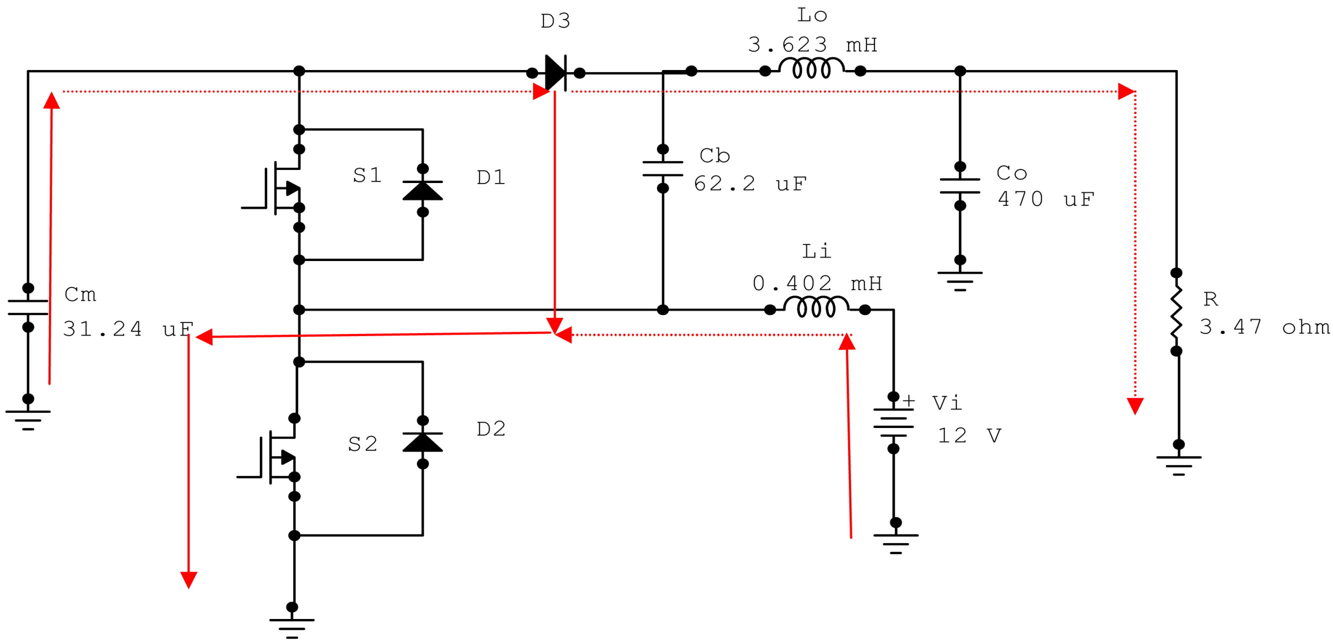


Figure 3. Power flow of mode 1 operation.

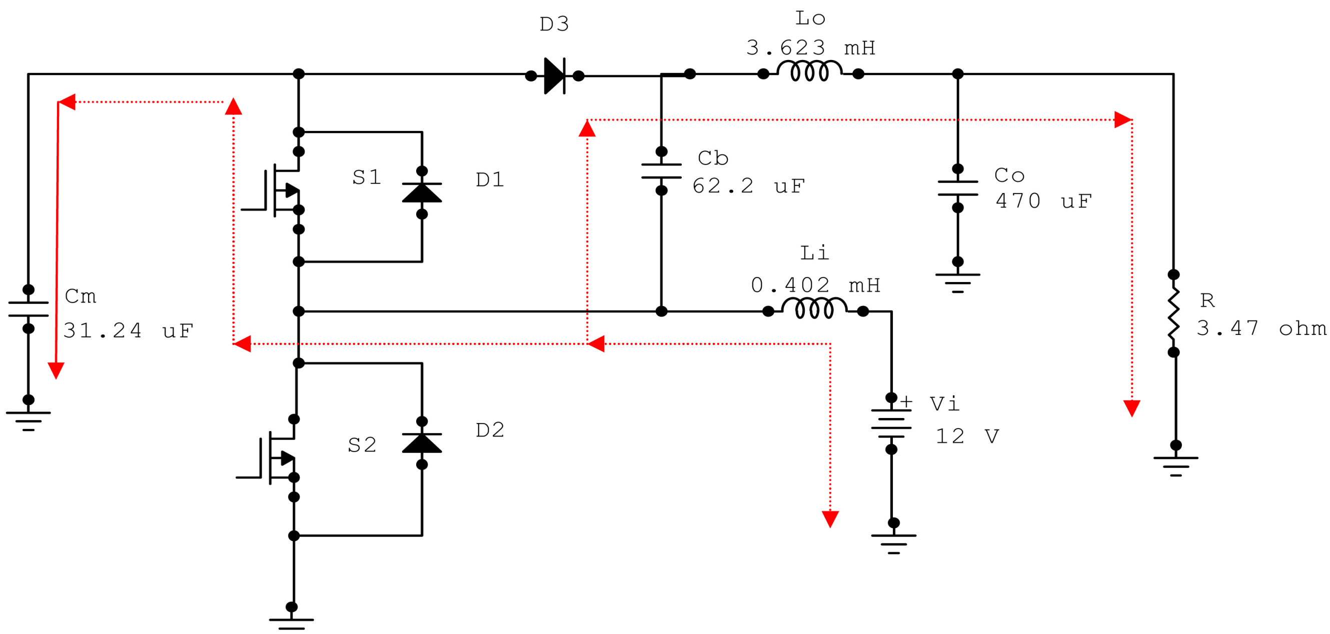


Figure 4. Power flow of mode 2 operation.

and hence D_b is reverse biased and turned off. During this mode, C_m is charged whereas C_b is discharged. Therefore, the voltage across L_i is V_{Cm} subtracted from V_i, thereby causing L_i to be demagnetized, whereas the voltage across L_0 is V_0 subtracted from sum of V_{Cm} and V_{Cb}, thereby causing L_0 to be magnetized. Also, the current flowing through Co is equal to i_{Lo} minus the current flowing through i_{Lo}. And hence, the corresponding differential equations are given by (5) to (8).

$$L_i \frac{\partial i_{Li}}{\partial t} = V_i - V_{Cm} \quad (5)$$

$$L_o \frac{\partial i_{Lo}}{\partial t} = 2V_{Cm} - V_0 \quad (6)$$

$$C_m \frac{\partial V_{Cm}}{\partial t} = i_{Li} - i_{Lo} \quad (7)$$

$$C_o \frac{\partial V_o}{\partial t} = i_{Lo} - \frac{V_o}{R_L} \quad (8)$$

The average equations which are obtained from Equation (1) to Equation (8), are given by (9) to (13).

$$L_i \frac{\partial iL_i}{\partial t} = (V_i) - (1-d)(V_{cm}) \quad (9)$$

$$C_o \frac{\partial V_o}{\partial t} = (iL_o) - \left(\frac{V_o}{R_L}\right) \quad (10)$$

$$\frac{\partial i_{Lo}}{\partial t} = (2-d)(V_{Cm}) - (V_o) \quad (11)$$

$$C_m \frac{\partial (V_{Cm})}{\partial t} = (-i_{Lo}) + (1-d)(i_{Li}) - d(i_{Cb}) \quad (12)$$

$$\frac{C_b}{C_m} = \frac{\left(\left(\frac{1-d}{d}\right)(i_{Lo})\right)}{\left(-\left(\frac{1-d}{d}\right)(i_{Lo}) + i_{Li}(1-d) - (i_{Lo})\right)} \quad (13)$$

where,

$\frac{\partial iL_i}{\partial t}$ = 2% of i_{Li}

$\frac{\partial i_{Lo}}{\partial t}$ = 2% of i_{Lo}

$\frac{\partial (V_{Cm})}{\partial t}$ = 2% of V_{Cm}

$\frac{\partial V_o}{\partial t}$ = 2% of V_o

According to the small-ripple approximation and the voltage-second balance, the voltage ratio can be obtained to be

$$\frac{V_0}{V_i} = \frac{2-d}{1-d} \quad (14)$$

where,

d = Duty cycle.

V_o = Output voltage in Volts.

V_i = input voltage in Volts.

From Equations (9) to (14), we can obtain the specification values for KY boost converter. Here 2% of ripple will be taken for finding the specification values for KY boost converter.

3.3. KY Boost Converter Specifications

Table 1 gives a detailed specification adopted for analyzing the performance of KY boost converter.

3.4. KY Boost Converter Simulink Modeling

The KY boost converter realized in Simulink model is represented by Figure 5, in which switches are represented by S_1 and S_2 with interrelated body diodes D_1 and

Table 1. Specifications adopted for KY boost converter.

Parameter	Symbol	Value	Unit
Input voltage	V_i	12	V
Rated output voltage	V_o	36	V
Rated load current	i_0	10.36	A
Output inductance	L_o	3.623	mH
Buffer capacitance	C_m	31.24	mF
Energy transferring capacitor	C_b	62.2	mF
Output capacitance	C_0	470	μF
Load	Separately excited motor	0.5	Hp
Switching frequency	f_s	195	kHz
Input inductance	L_i	0.402	mH

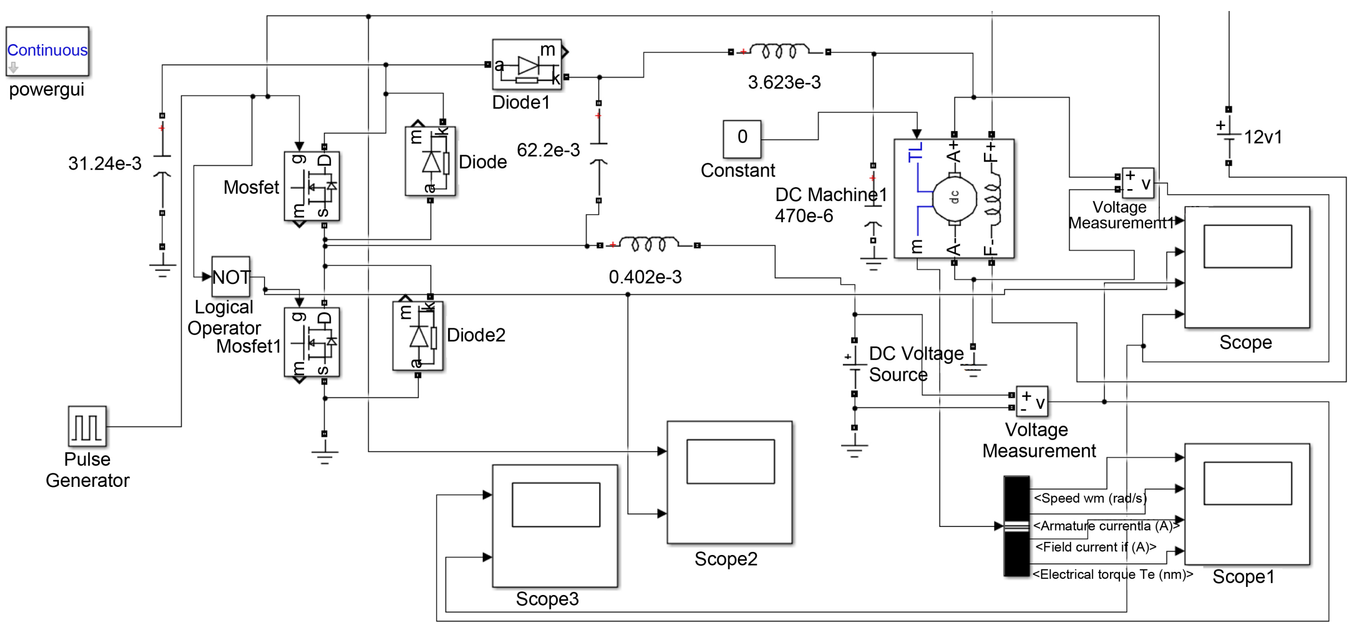


Figure 5. KY boost converter Simulink model.

D_2. L_i represents input inductor; L_o represent output inductor; C_m represent buffer capacitance; C_b represent energy transferring capacitor; C_0 is output diode; D_b is forward diode. The switching signal is fed through the connector M and the output voltage taken to Matlab workspace by connector V_0.

4. Modeling of Fuzzy

Fuzzy controller is designed to control the output voltage ripple of the KY boost converter. The input to the Fuzzy controller is error (e) and change in error (ce), where the error (e) is the deviation of output voltage V_0 and reference voltage V_{ref}. The output of Fuzzy controller is duty cycle (d). To generate the switching signal for KY boost converter, the duty cycle (d) is given to a PWM generator. Figure 6 shows the Simulink model of the Fuzzy controller for KY boost converter which subsists of Fuzzy controller, PWM generator block with KY boost converter block with reference output voltage of 36 V. The switching frequency generated by the PWM generator block is 195 kHz which is fed to the KY boost converter switches.

Fuzzy Controller Simulink Modeling

The Fuzzy logic controller consists of Mamdani fuzzy inference system. The fuzzifier consists of two inputs (*i.e.*) error (e) and change in error (ce). The triangular membership function is used to represent the inputs and the output. The defuzzifier consists of output duty cycle (d). The Fuzzy rule base consists of 8 fuzzy rules which are used to produce duty cycle (d) for KY boost converter switches.

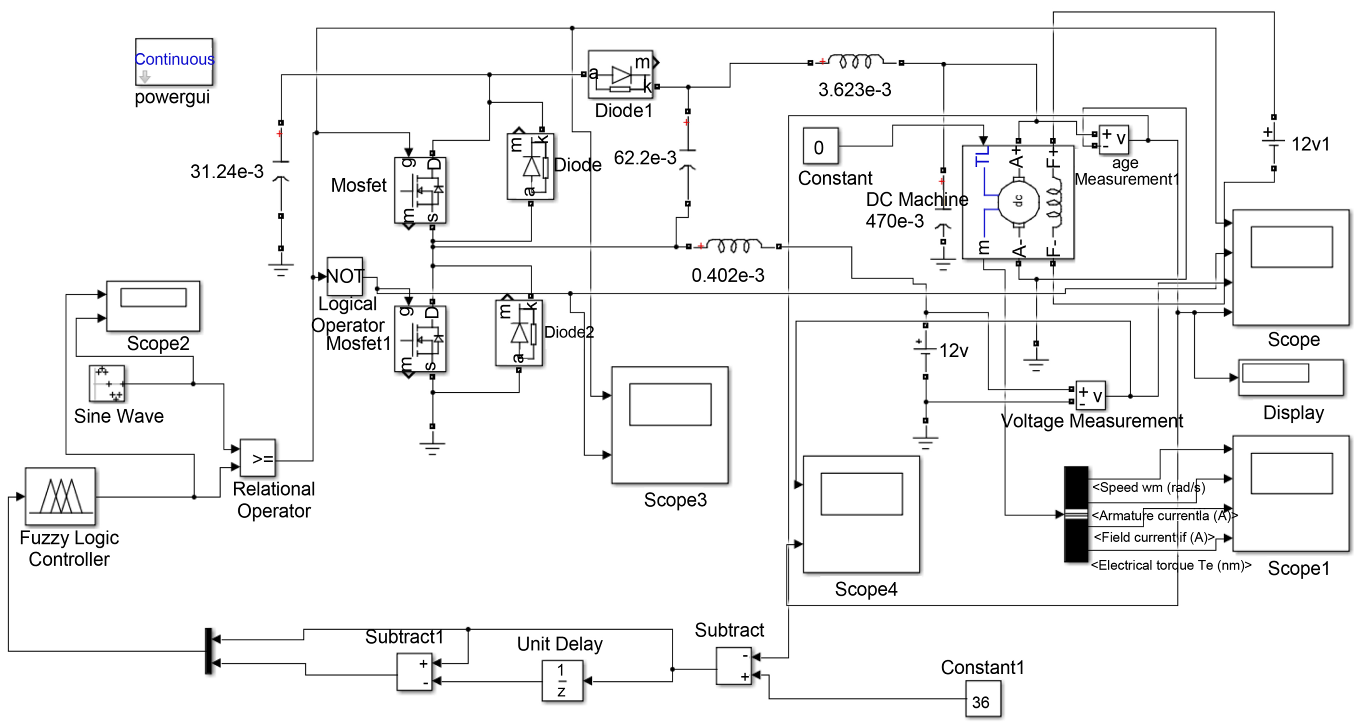


Figure 6. KY fuzzy controller Simulink model.

5. Modeling of PSO

Particle Swarm Optimization (PSO) comes from the research on the bird and fish flock movement behavior which is used to find the global minimum of the proposed objective function. In this method a swarm of particles describe a candidate solution move in the search space. Each particle position represents the objective function which is depending on the variables defined by the optimization problem. It is simple and easy to implement. It does not require any specific information about the converter model as well as the system parameters. And the calculation is very simple but the step for the calculation is high. Figure 7 shows the steps to be adapted for PSO.

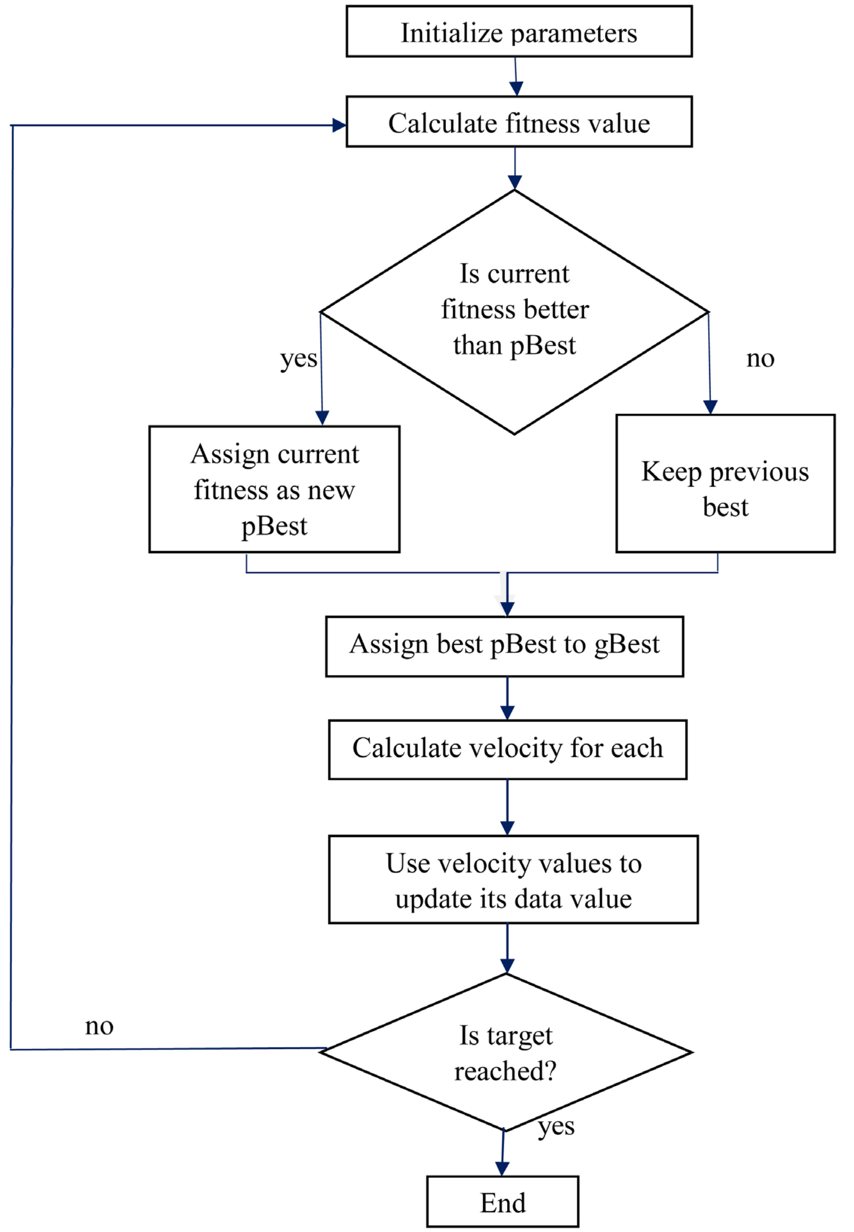


Figure 7. Flow chart for PSO.

PSO Controller Simulink Modeling

The aim of the present work is to find out the optimized vector of the switching angles, for which the ripple components are limited to acceptable low level or even to be eliminated. On the other side, the obtained average value has to be equal or closer to the reference or desired output voltage. To fulfill these requirements an objective function which has to be minimized is proposed as follows:

$$f(d) = e \tag{15}$$

where,

$$e = V_{ref} - V_{avg}$$

$$V_{ref} = 36$$

$$V_{ripple} = 0.02$$

This function contains two terms, the error between the desired average voltage and the obtained output average voltage and the output voltage ripple which is to be eliminated. For reducing the output voltage ripple the output voltage should satisfy the following Constrain.

$$d = 0 \text{ to } 1 \tag{16}$$

6. Simulation Results and Discussion

The simulated results of the KY boost converter with input voltage 12 V and the rated output voltage of 36 V for a load current of 10.36 A is simulated with Matlab/Simulink R2013a as shown in Figure 8. Figure 9 shows the switching pulse of KY boost converter for S1 and S2. The inverted switching pulse of S1 is given to S2.

Figure 10 shows the output voltage for 12 V input voltage in open loop condition of KY boost converter. It clearly shows that the output voltage ripple for an output voltage of 32.18 V in open loop condition is about 1.18 V.

$$\text{OUTPUT VOLTAGE RIPPLE} = V_{\max} - V_{\min} = 32.18\text{ V} - 31\text{ V} = 1.18\text{ V}$$

Figure 11 shows the switching pulse of closed loop KY boost converter using fuzzy logic controller for S1 and S2. The inverted pulse of S1 is given to S2. From this it is observed that the duty cycle will be varied based on error and change in error of output voltage.

Figure 12 shows the output voltage for 12 V input voltage in closed loop condition of KY boost converter using FUZZY controller. It clearly shows that the output voltage ripple for an output voltage of 36 V is about 0.54 V.

Figure 13 shows the switching pulse of KY boost converter using PSO algorithm based controller for S1 and S2. The inverted pulse of S1 is given to S2. From this it is observed that the duty cycle will be varied based on the updating of position and velocity.

Figure 14 shows the output voltage for 12 V input voltage in closed loop condition of KY boost converter using PSO based controller. It clearly shows that the output

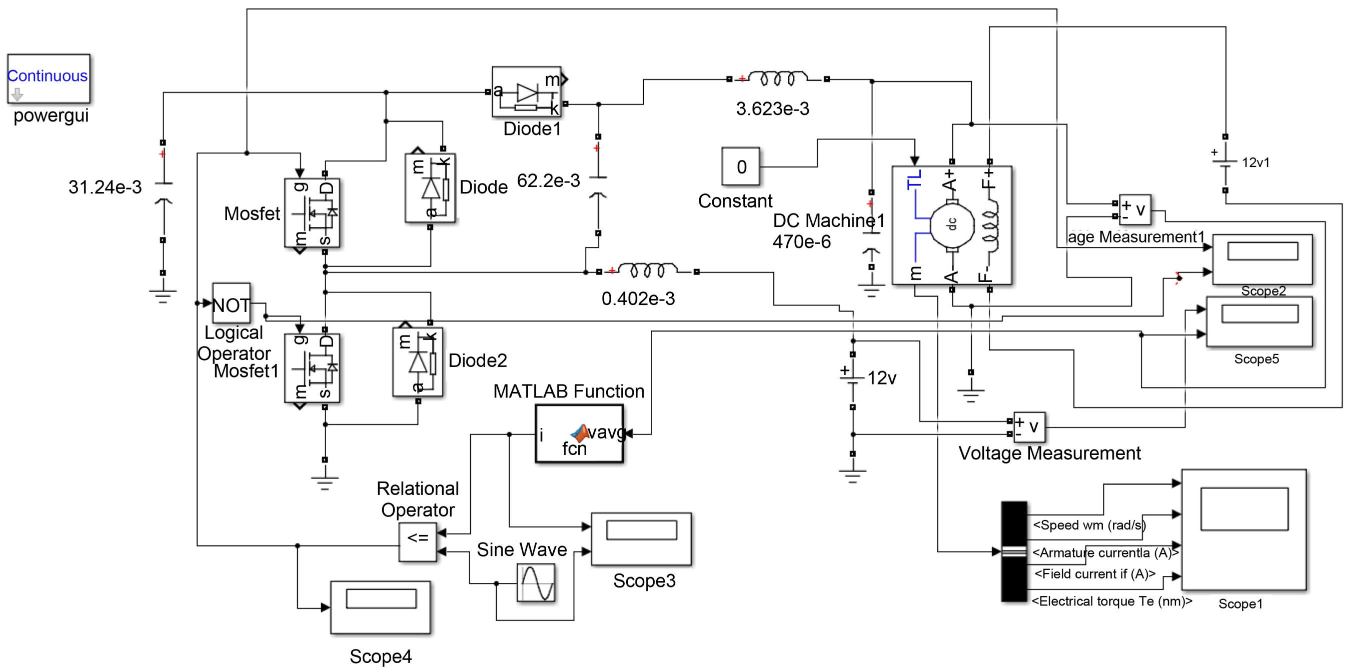


Figure 8. KY PSO controller Simulink model.

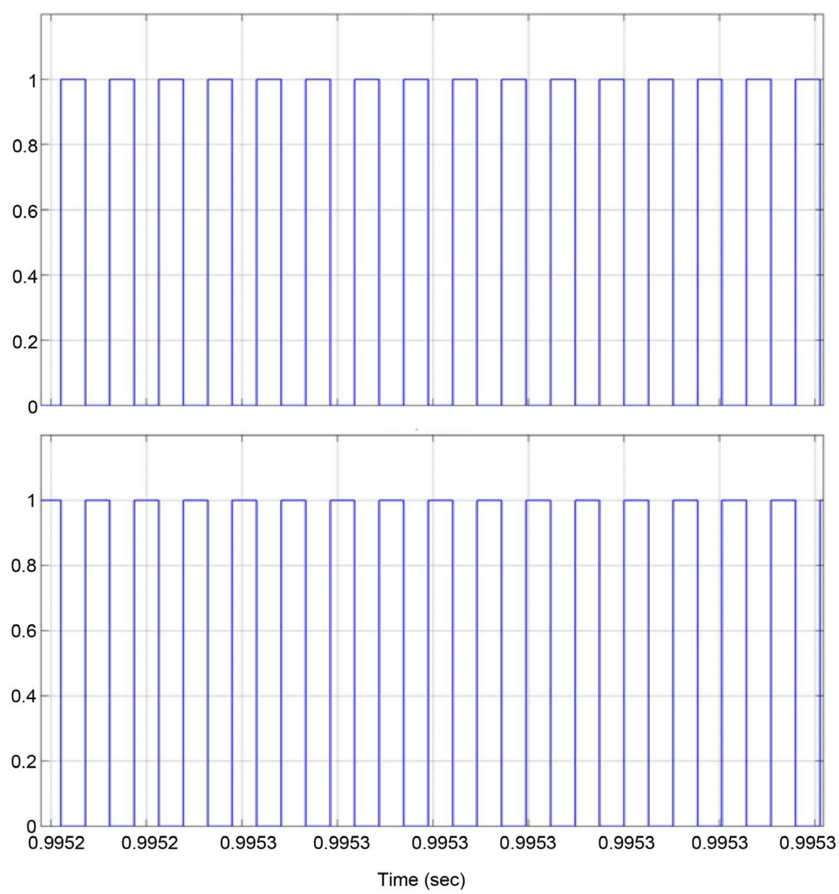


Figure 9. Switching pulse for KY boost converter in open loop condition.

voltage ripple for an output voltage of 36 V is about 0.29 V.

$$\text{OUTPUT VOLTAGE RIPPLE} = V_{max} - V_{min} = 36\text{ V} - 35.71\text{ V} = 0.29\text{ V}$$

7. Conclusion

The problem of the KY Boost converter output voltage ripple is presented in this paper. The Particle Swarm Optimization PSO algorithm is used to solve this problem using an objective function. This objective function contains a defined number of switching angles pattern depending on the degree of ripple reduction. The resulting output values of the proposed PSO Controller are compared with the existing FUZZY logic controller

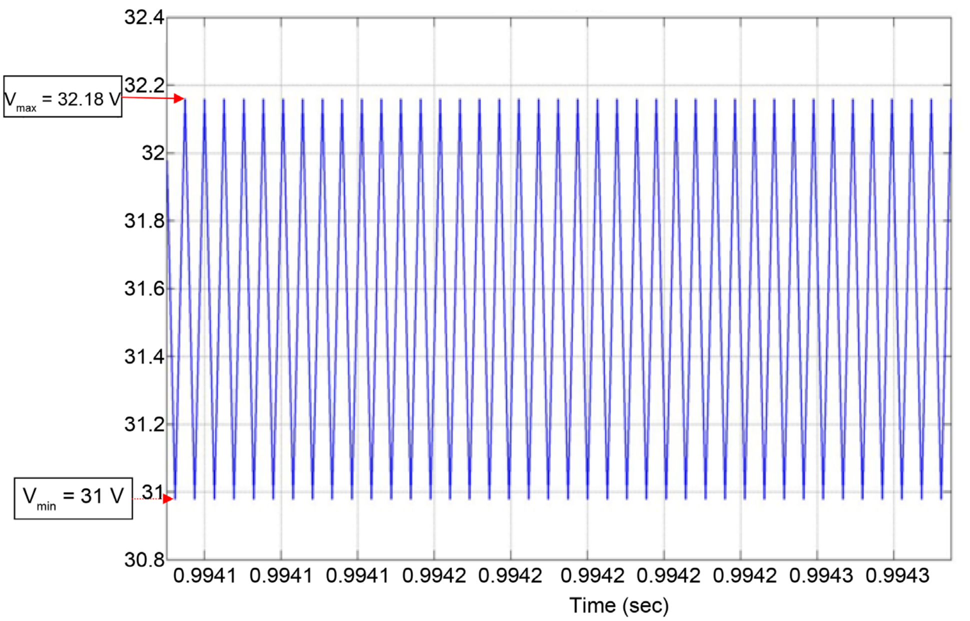
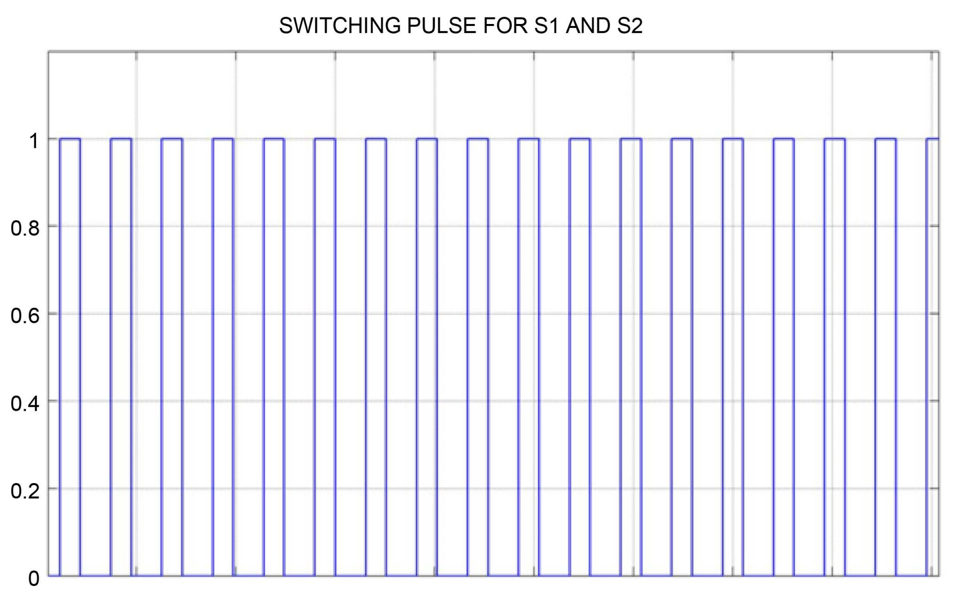


Figure 10. Output voltage waveform of open loop KY boost converter.



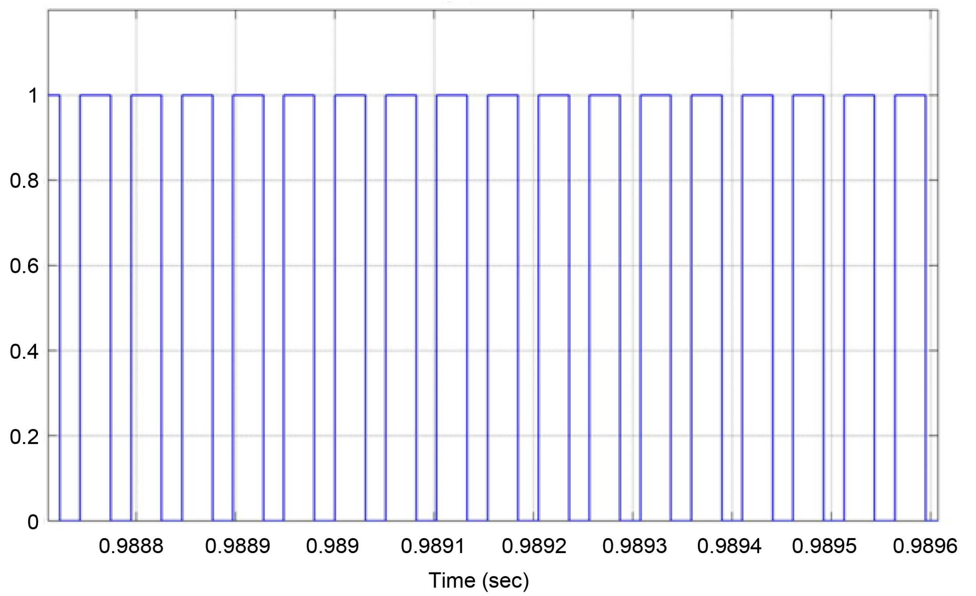


Figure 11. Switching pulse for KY boost converter in closed loop condition using FUZZY logic controller.

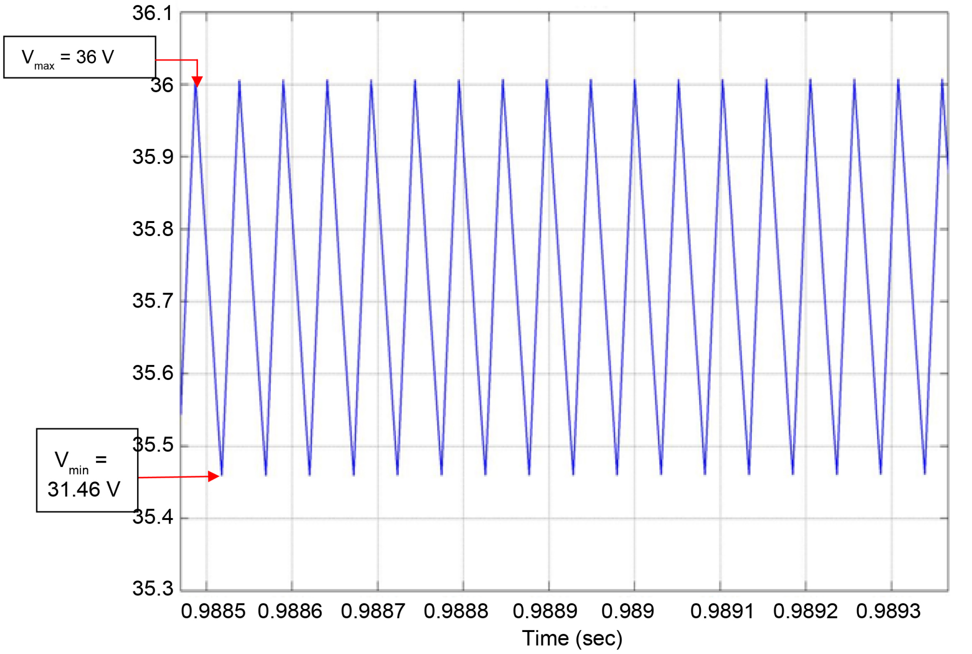


Figure 12. Output voltage waveform of closed loop KY boost converter using FUZZY logic controller.

output and the open loop system. The minimization of output voltage ripple from 1.18 V in open loop system to 0.54 V in FUZZY based converter and further minimization to 0.29 V in PSO based converter is proved by the simulation results comparison shown in Table 2. And the future work could be continued by using various renewable sources as an input voltage source instead of constant voltage source like battery and can be

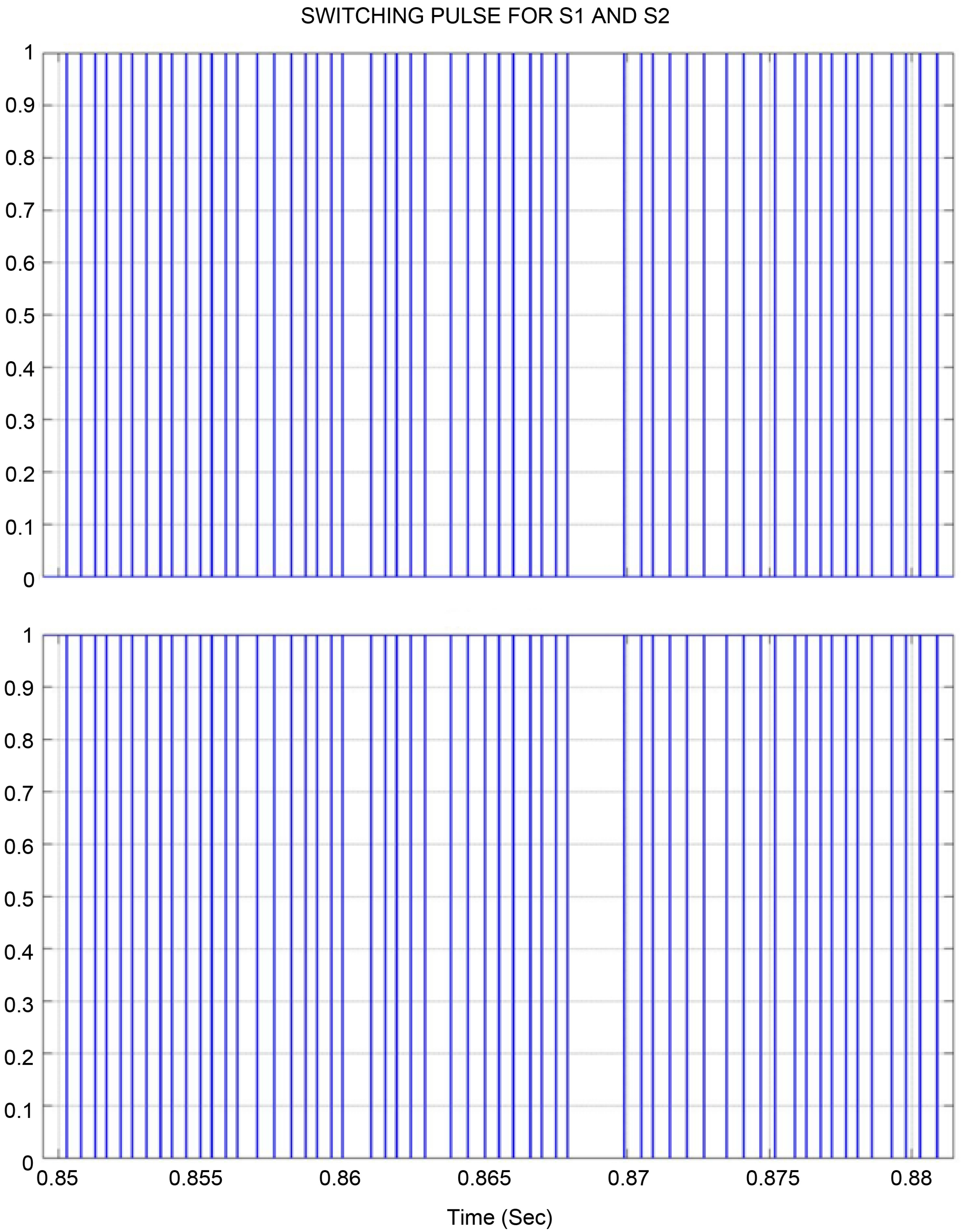


Figure 13. Switching pulse for KY boost converter in closed loop condition using PSO based controller.

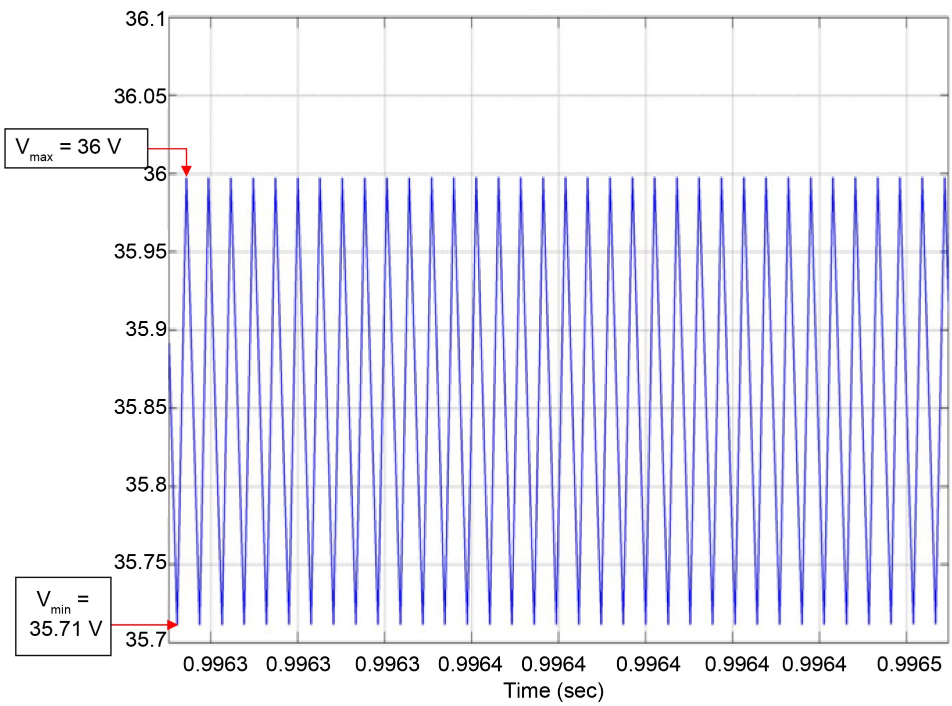


Figure 14. Output voltage waveform of closed loop KY boost converter using PSO based controller.

Table 2. Comparison of existing and proposed technique output.

Parameter	Existing open loop system	Existing FUZZY logic controller	Proposed PSO based controller
Output voltage ripple	1.18 V	0.54 V	0.29 V

compared in hybrid condition.

References

[1] Giral, R., Arango E., Calvente, J. and Martinez-Salamero, L. (2002) Inherent DCM Operation of the Asymmetrical Interleaved Dual Buck-Boost. *Proceedings IEEE IECON Conference*, **1**, 129-134.

[2] Luo, F.L. and Ye, H. (2003) Negative Output Super-Lift Converters. *IEEE Transactions on Power Electronics*, **18**, 1113-1121. http://dx.doi.org/10.1109/TPEL.2003.816185

[3] Luo, F.L. and Ye, H. (2003) Positive Output Super-Lift Converters. *IEEE Transactions on Power Electronics*, **18**, 105-113. http://dx.doi.org/10.1109/TPEL.2002.807198

[4] Luo, F.L. (1999) Positive Output Luo Converters Voltage Lift Technique. *IEE Proceedings Electric Power Applications*, **146**, 415-432. http://dx.doi.org/10.1049/ip-epa:19990291

[5] Shin, H.B., Park, J.G., Chung, S.K., Lee, H.W. and Lipo, T.A. (2005) Generalized Steady-State Analysis of Multiphase Interleaved Boost Converter with Coupled Inductors. *IEE Proceedings Electric Power Applications*, **152**, 584-594. http://dx.doi.org/10.1049/ip-epa:20045052

[6] Savu, C., Radoi, A. and Florescu, A. (2010) Sliding Mode PWM Control for a Buck Con-

verter under DCM/CCM Boundary. *International Review of Electrical Engineering*, **5**, 1963-1971.

[7] Hong, Y.U., Jung, S.H., Woo, Y.J., Choi, B.K. and Cho, G.H. (2005) Single Chip Quasi-PWM DC-DC Converter with Fast Transient Response Comprising Loop-Bandwidth Control. *IEEE Letters*, **41**, 501-503. http://dx.doi.org/10.1049/el:20058183

[8] Hwu, K.I. and Yau, Y.T. (2010) A KY Boost Converter. *IEEE Transactions on Power Electronics*, **25**, 2699-2703. http://dx.doi.org/10.1109/TPEL.2010.2051235

[9] Hwu, K.I. and Jiang, W.Z. (2014) Voltage Gain Enhancement for a Step-Up Converter Constructed by KY and Buck-Boost Converters. *IEEE Transaction on Industrial Electronics*, **61**, 1758-1768. http://dx.doi.org/10.1109/TIE.2013.2263779

[10] Hwu, K.I. and Yau, Y.T. (2009) KY Boost Converter and Its Derivatives. *IEEE Transactions on Power Electronics*, **24**, 128-137. http://dx.doi.org/10.1109/TPEL.2008.2009178

[11] Karthikumar, S., Mahendran, N. and Sriraman, S. (2012) Design of Fuzzy Logic Controller for Output Voltage Ripple (OVR) Reduction of KY Boost Converter. *IEEE Proceedings Emerging Trends in Electrical Engineering and Energy Management*, 181-185. http://ieeexplore.ieee.org/document/6494468/