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RESEARCH ARTICLE

Design of Full Bridge Buck Converter with a Fly back Snubber for High Power Applications

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ABSTRACT

This article deals with the design of a full bridge buck converter along with fly back snubber for high power applications. A fly back snubber is a combination of a diode, a capacitor and a fly back converter. A fly back snubber circuit is used to clamp the voltage spike originating from the current difference between the leakage inductance and current-fed inductor of the isolation transformer. The fly back snubber reduces the current passing at the current-fed side associated with the active switches. The full bridge buck converter along with a fly back snubber has been simulated using MATLAB software and is checked for feasibility with the simulated results of the conventional circuit without a fly back snubber.

Keywords: Fly back converter, Isolated full-bridge bidirectional converter, Soft start-up, Clamping Capacitor, RCD Snubber, Transformer Winding.

1. INTRODUCTION

In a buck converter, it is required for the DC output voltage to be lower than the corresponding input voltage [1]. They find their application in switched mode power supply circuits. The DC input can be obtained from rectified AC or DC supply [2]. Electrical isolation is not required between the output and switching circuit. However the input is from rectified AC source. A transformer could be used for isolation between the AC source and the rectifier [3]. The switching transistor between the input and output of the buck converter tends to switch on and off at high frequencies. To maintain a continuous output and to continue the supply of load during off periods, the energy is stored in the inductor L during the on periods of the switching transistor. Figure A1 shows a normal buck converter.

[4] In DC-supply systems which are renewable, to back-up power for electronic equipment, batteries are generally used. Bi-directional converters are used in place where battery charging and regenerative braking is required.Most of the DC-DC converters incorporate high frequency transformers as a component.[5] A buck mode operation can be defined as that process during regenerative braking, where there is flow back of power to the low voltage bus for the purpose of recharging the batteries. Owing to circulation current, there is reduction of current and voltage stress, switching loss and conduction loss [6]. During switching transition, one of the significant issues is the leakage inductance of the isolation transformer as the leakage inductance raises conduction loss and reduces effective duty cycle by the current freewheeling [7].

2. FLY BACK SNUBBER

The fly back snubber is a group of clamping capacitor C_c, diode D and fly back converter. The energy captivated in the clamping capacitor is fed back to the source

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[8]. Voltage stress is reduced as current do not circulate through the switches. The RCD snubber is used for clamping the voltage spike, but the efficiency is reduced as the energy stored in the clamping capacitor is dissipated in resistors [9]. In the clamping capacitor, fly back snubber is used to recycle the absorbed energy. Regulation of the voltage of the clamping capacitor can be operated by the fly back snubber [10]. The fly back snubber can compress the voltage to a desired level which ismarginally higher than the voltage across the low-side transformer winding [11]. The current stresses can be reduced in heavy-load condition as the current do not circulate through the full-bridge switches. The fly back snubbercan be controlled for pre-charging thehigh-side capacitor during startup thereby improving visibility [12]. Figure A2 shows a fly back converter.

[13] The fly back converter is a step down and step up converter composed of an inductor which is split to form a transformer. The voltage ratio is multiplied for an additional advantage of isolation. The fly back converter consists of two modes of operation. [14] proposed a DC-DC converter control unit for a variable speed wind turbine. Diode rectifier, DC chopper and load were the three main components of the system. Dynamic models and control loop performances were tested under various conditions.

2.1. Mode 1

During mode 1 operation, the conducting switch or diode is acting as a shorted switch and the device that is not conducting act as an open switch.

This representation of switch is in line with our statement where the switches and diodes are assumed to have ideal state, having zero voltage drops during conduction and zero leakage current during off state. Figure A3 shows the current path during mode 1 of circuit operation.

2.2. Mode 2

During mode 2 operation, for some time after conduction, when switch ‘S’ is turned off, the current path of the primary winding is damaged. As a result, the voltage polarities across the windings reverse owing to magnetic induction laws.During the forward biased condition of the secondary circuit the diode is made up of the reversal of voltage polarities. Figure A4 shows the current path during mode 2 of circuit operation.

3. CIRCUIT CONFIGURATION

The converter is operated in two modes. They can be notified as buck mode and boost mode. It is composed of a current-fed switch bridge as well as a voltage-fed bridge. A fly back snubber at the low-voltage side, current-fed switch bridge, and a voltage-fed bridge at the high-voltage side form an important part of it. When power flows from the high-voltage side to the batteries inductor L_m performs output filtering in buck mode. A boost mode can be defined as that mode where power is transferred from the batteries to the high-voltage side. Figure A5 shows a buck converter.

Additionally, to absorb the current difference between current-fed inductor and leakage inductance of the transformer during switching commutation, clamp branch capacitor and diode are used. The fly back snubber can be used to control and regulate the capacitor voltage V_c to the desired value, which is just slightly higher than V_{AB} independently.

Hence, the voltage stress of MOSFET switches M1–M4 can be narrowed to a low level. The significant advantage of the converter configuration is that the power switches do not circulate spike current and the system reliability is improved due to clamping of the voltage across MOSFET switches M1–M4. The high spike current can result inover current density, charge migration and extra magnetic force which will depreciate channel width, MOSFET carrier density and wire bonding which in turn increase its conduction resistance.

4. CIRCUIT OPERATION

4.1. Step-down conversion

In step down conversion, the transformer leakage inductance at the low-voltage side is reflected to the high-voltage side. The equivalent inductance L_{eq}^* equals $(L_{lh}+ L_{ll}(N_p^2/N_s^2))$. This circuit is called a phase-shift full-bridge converter. In the step-down conversion, MOSFET switches M5–M8 are operated as a buck converter, in which MOSFET switch pairs (M5, M8) and (M6 , M7) are consecutively turned ON to transfer power from high voltage side to low voltage side. Figure A6 shows the operation waveform of step down mode.

4.1.1. Mode 1 [$t_0 \leq t < t_1$]

In mode 1 operation, MOSFET switches M5 and M8 are in ON state, while M6 and M7 are in OFF state. The high-side voltage $V_{HV}$is immediately applied on the transformer and the whole voltage is used on the equivalent leakage inductance and causes the current to rise with the slope of V_{HV}/L_{eq}.

At t_1,the transformer current increases linearly towards the load current level, the switch pair (M1 , M4) are conducting to transfer power and from the current-fed side the voltage across the transformer terminals change immediately to reflect the voltage from the voltage-fed side, i.e., ($V_{HV}(N_p/N_s)$). Figure A7 shows mode 1.

4.1.2. Mode 2 [$t_1 \leq t < t_2$]

In mode 2 operation, MOSFET switchM8 remains conducting, whileM5 is turned OFF at t_1.The diode of M6starts to conduct the freewheeling leakage current. At t_1, the transformer current touches the load-current level, and V_{AB} increase to the reflected voltage ($V_{HV}(N_p/N_s)$).

The clamping diode starts to conduct the resonant current of clamp capacitor and equivalent inductance L_{eq}.Att_2,when the resonance goes through a half resonant cycle it is blocked by the clamping diode D_c. Figure A8 shows mode 2.

4.1.3. Mode 3 [$t_2 \leq t < t_3$]

In mode 3 operation, the diode of MOSFET switch M6 conducting at t_2 andZero-Voltage Switching (ZVS) can turn on MOSFET switch M6. Figure A9 shows mode 3.

4.1.4. Mode 4 [$t_3 \leq t < t_4$]

In mode 4 operation, MOSFET switchM6 remains conducting, while switch M8 is turned to OFF state, at t_3.The body diode corresponding to switch M7 then start to conduct the freewheeling leakage current. Figure A10 shows mode 4.

4.1.5. Mode 5 [$t_4 \leq t < t_5$]

In mode 5, the body diode of switch M7 is conducting and zero voltage switching (ZVS) can turn on M7 att_4. In order to balance flux at the end of this interval, the active switches change to the other pair of diagonal switches, and the voltage on the transformer reverses its polarity. It stops and completes a half-switching cycle operation, at t_5. Figure A11 shows mode 5.

5. SIMULATION RESULTS

In a buck converter, DC output voltage is lower than the dc input voltage considering the buck mode, which has to step down an input voltage of 365V to an output of 47.95V. Figure A12 shows the simulink of buck converter.

Table 1 shows the system parameters used for simulation. The performance of Buck converter was tested.

Figure A13 shows that the DC input voltage of buck mode is 365V. Figure A14 shows the driving pulse for switches M1 and M2.Figure A15 and Figure A16 shows the transformer windings of primary and secondary side voltages.Figure A17 shows that the DC input voltage of buck mode is 47.95V.

Table 1.System parameters

S.NO	Parameters	Values of simulation
1	Switching Frequency	25kHZ
2	HF Transformer Turns Ratio	4.26
3	Input Voltage	365V
4	Current-fed inductor	L=500μH
5	Clamping capacitor C_c	C=10μF
6	Filter capacitance	C=670μF
7	Output Voltage	47.95V
8	Output Power	1.5kW
9	Output Current	3.7Ampere

6. CONCLUSION

This project discussed a design of full-bridge buck converter with a fly back snubber with special reference to high-power applications. The fly back snubber is used for clamping the voltage spike caused by the current difference between the leakage inductance of the transformer and current-fed inductor. The current flowing through the active switches at the current-fed side can be reduced by the fly back snubber. System reliability can be improved significantly because under heavy-load condition, the current does not circulate through the full-bridge switches. Also their current stresses can be reduced. The fly back snubber is controlled to achieve a soft switching capability. In buck converter, DC output voltage is lower than the DC input voltage. A 1.5-kW prototype with input and output voltage of 365V and 47.95V respectively has been implemented.

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APPENDIX A

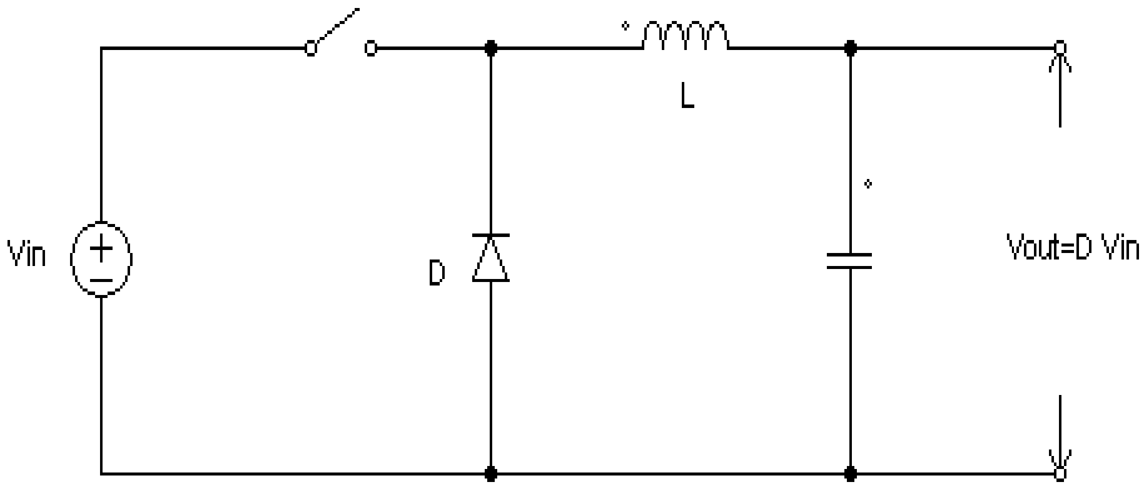

Figure A1.Normal buck converter

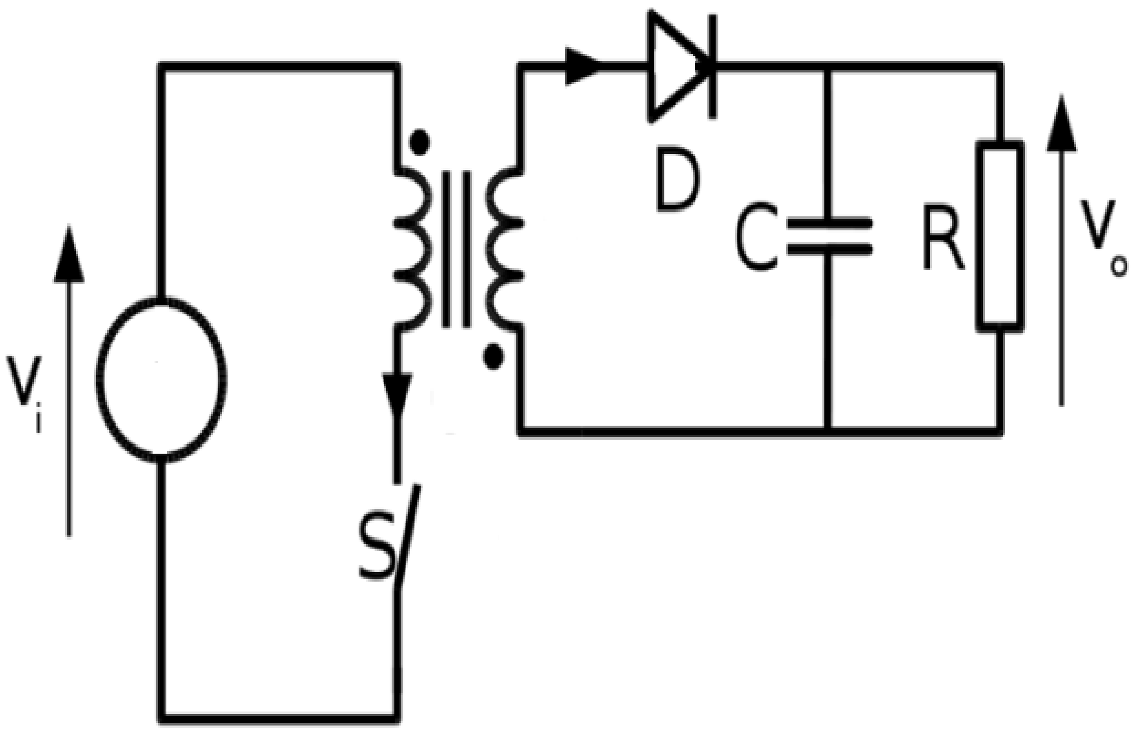

Figure A2.Flyback converter

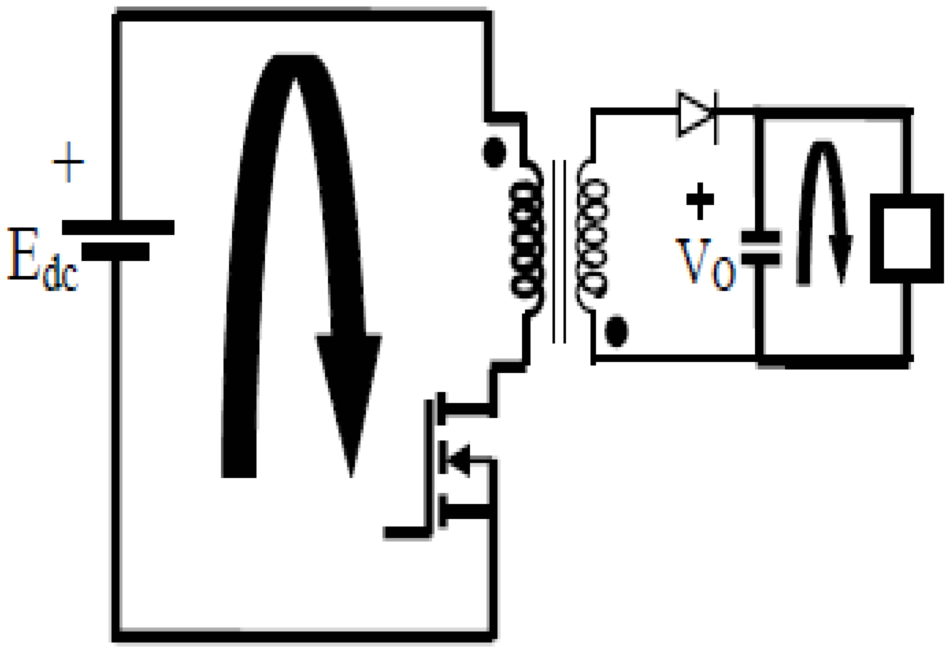

Figure A3.Current path during mode-1 of circuit operation

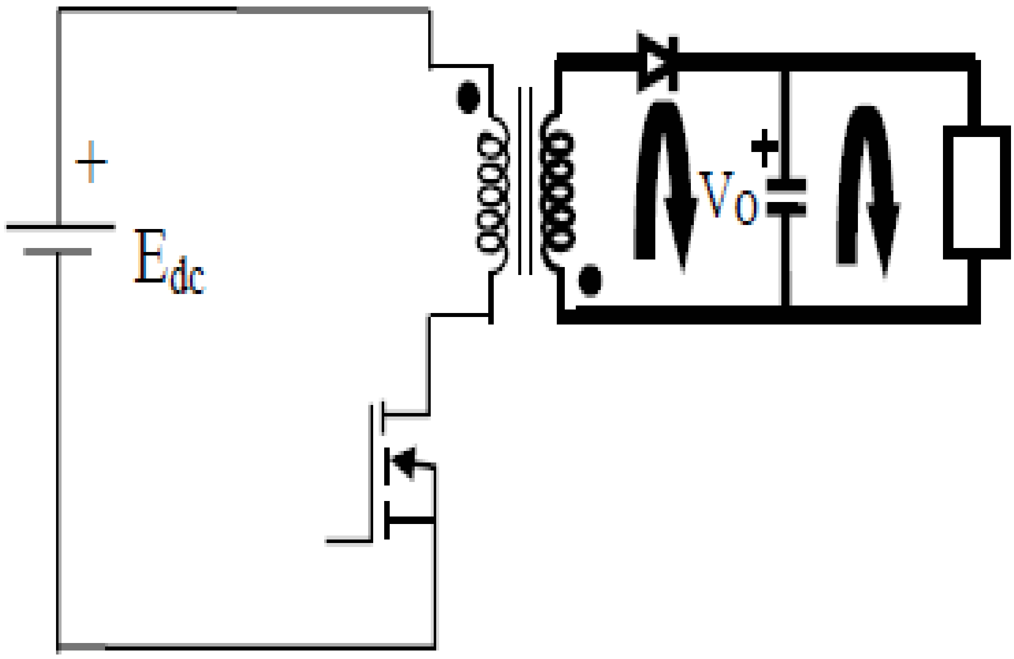

Figure A4.Current path during mode-2 of circuit operation

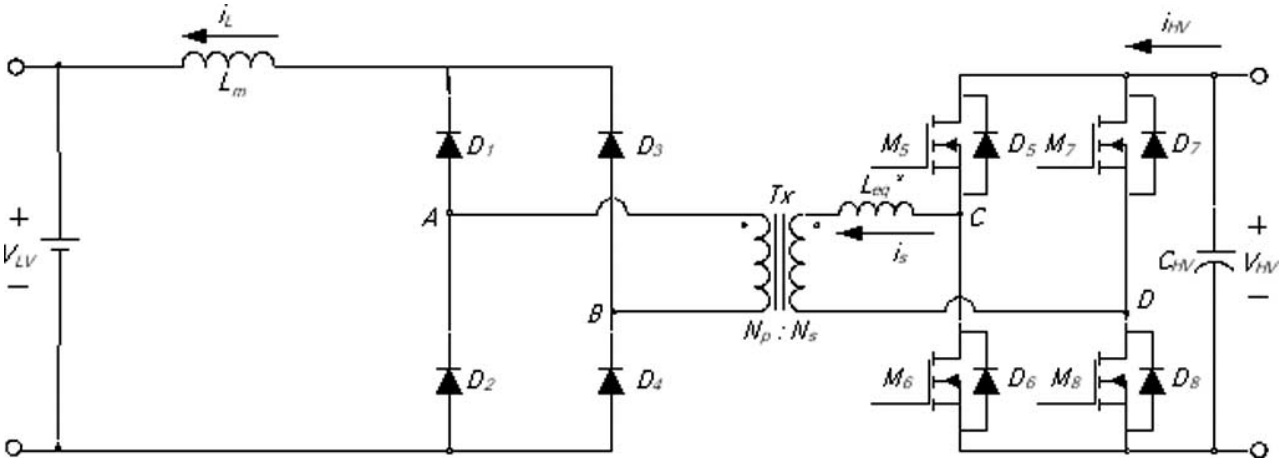

Figure A5.Buck converter

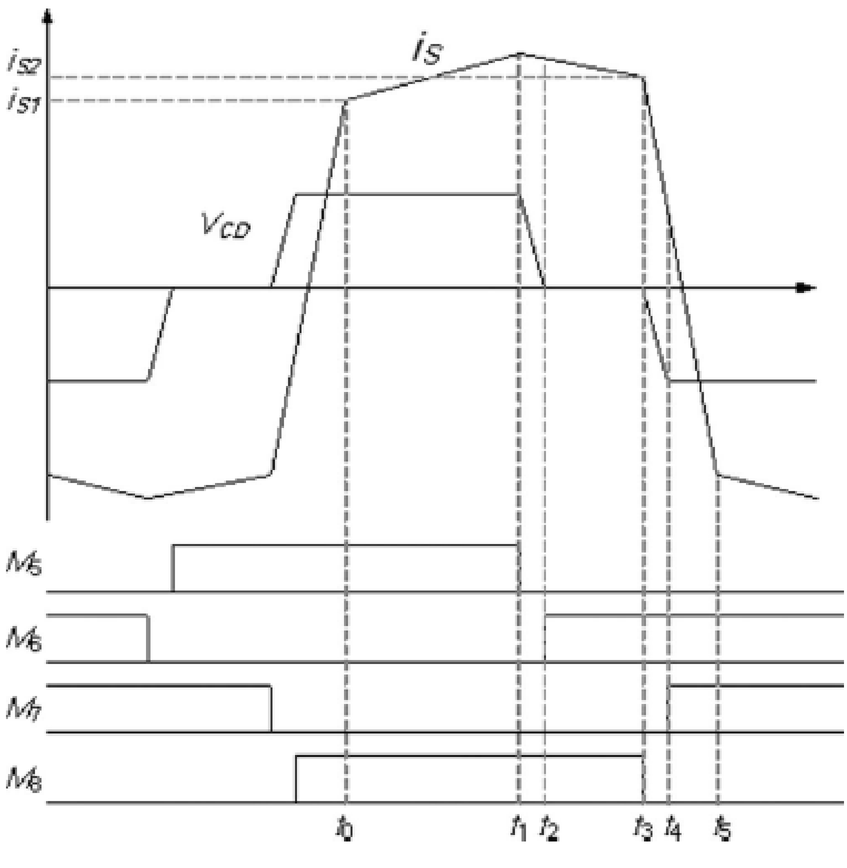

Figure A6.Operation waveform of step down mode

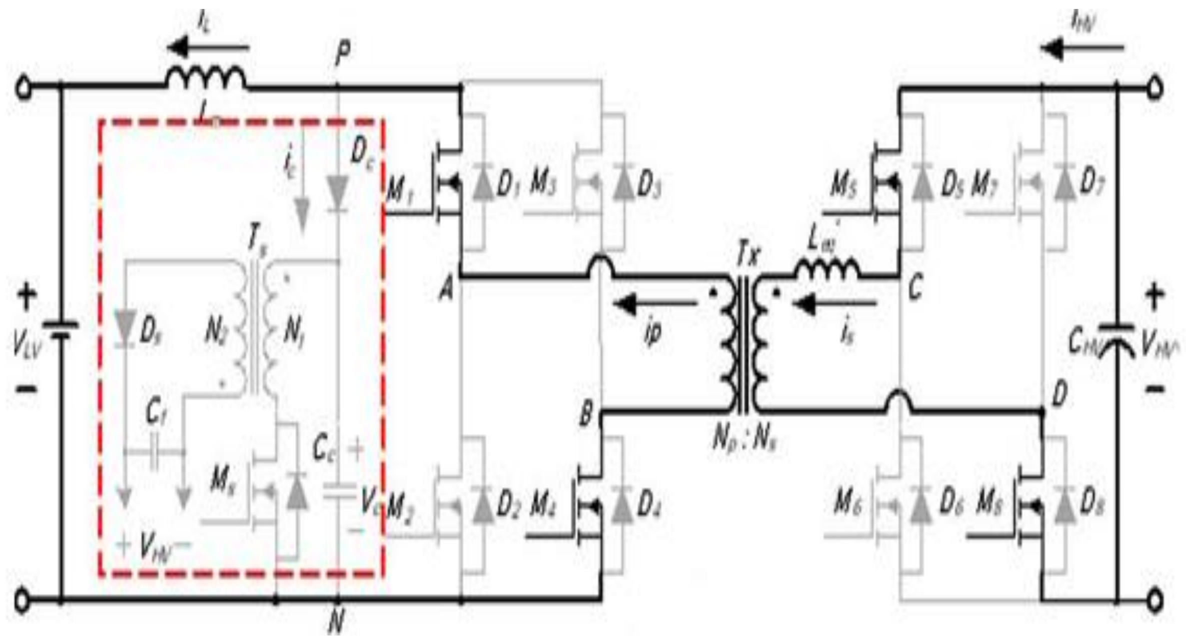

Figure A7.Mode 1

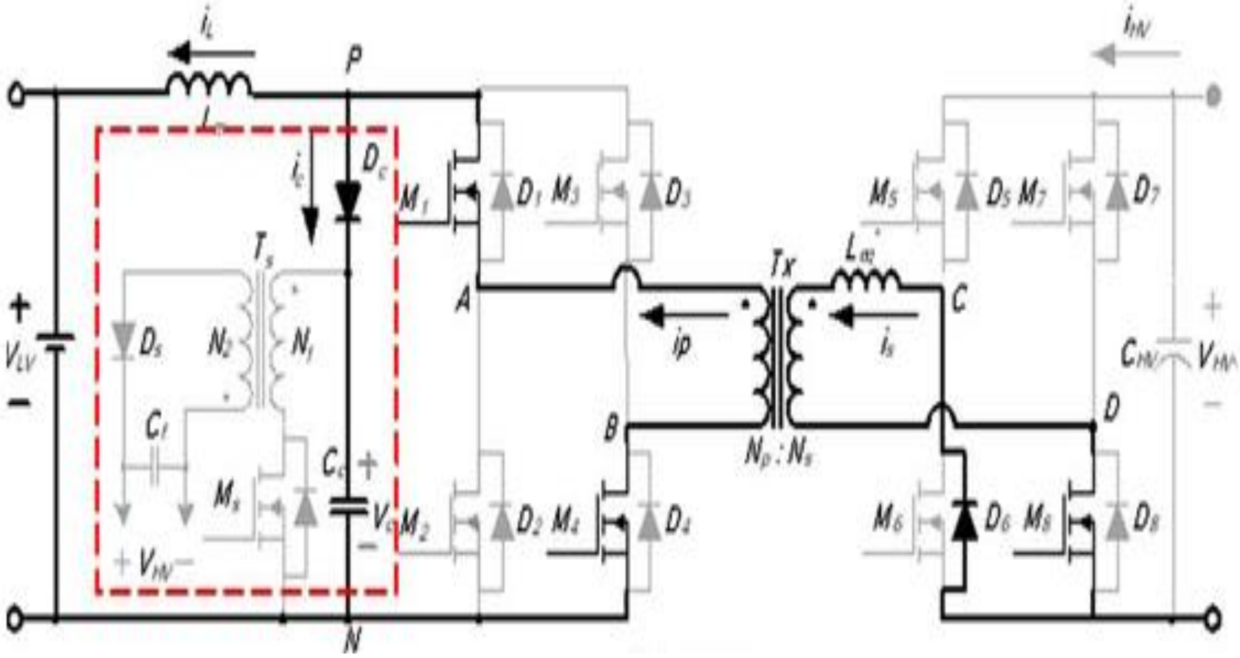

Figure A8.Mode 2

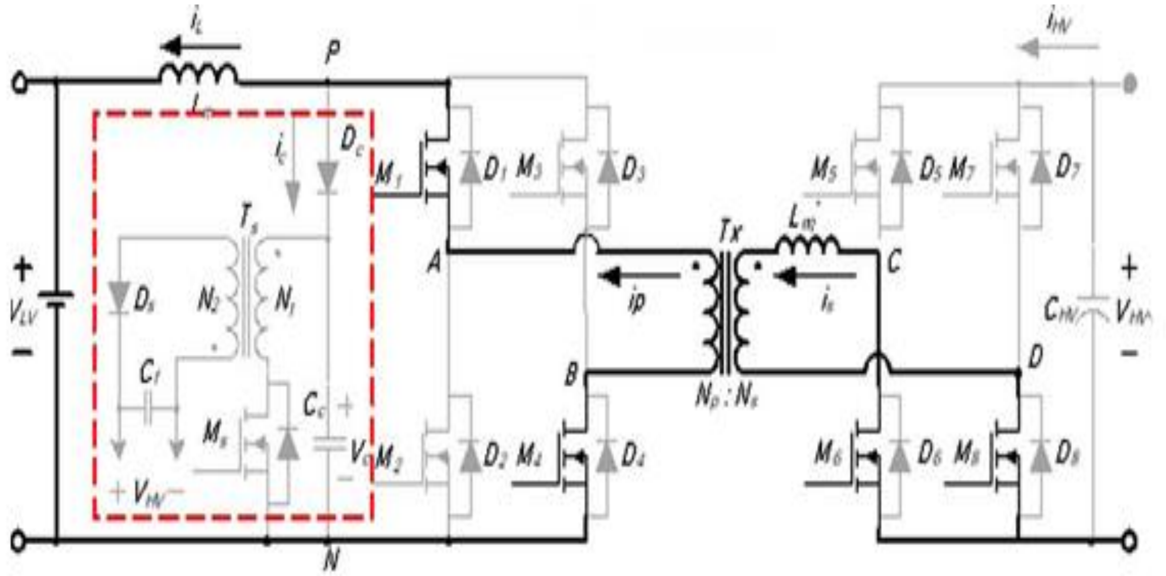

Figure A9.Mode 3

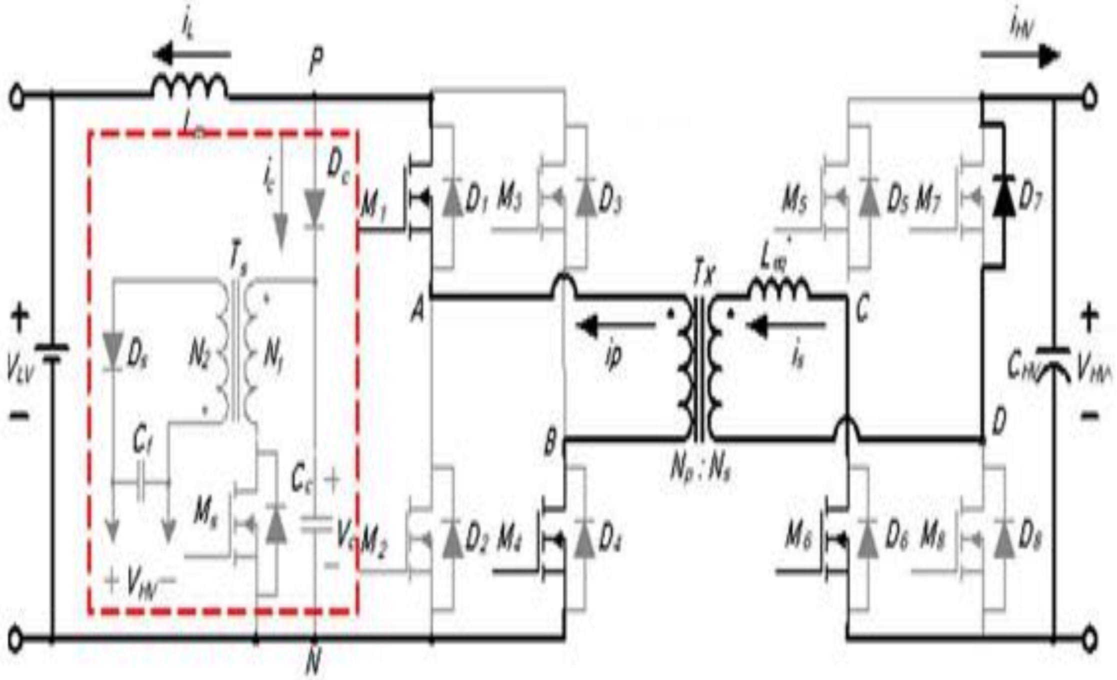

Figure A10.Mode 4

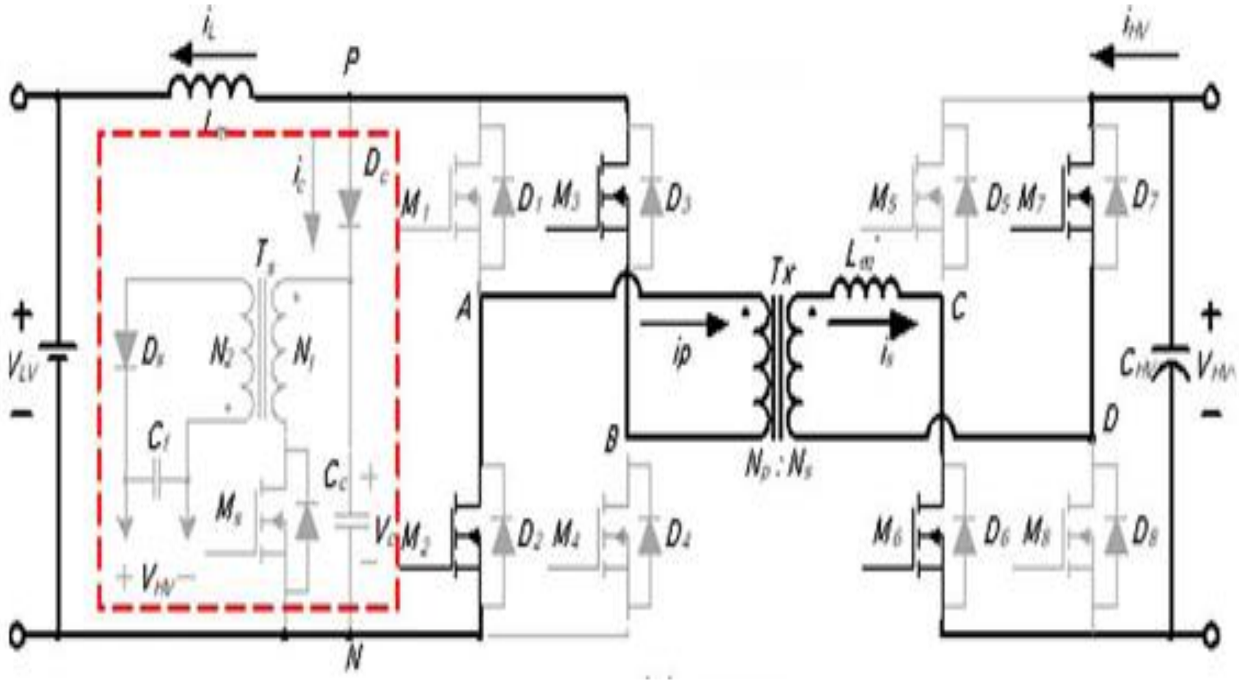

Figure A11.Mode 5

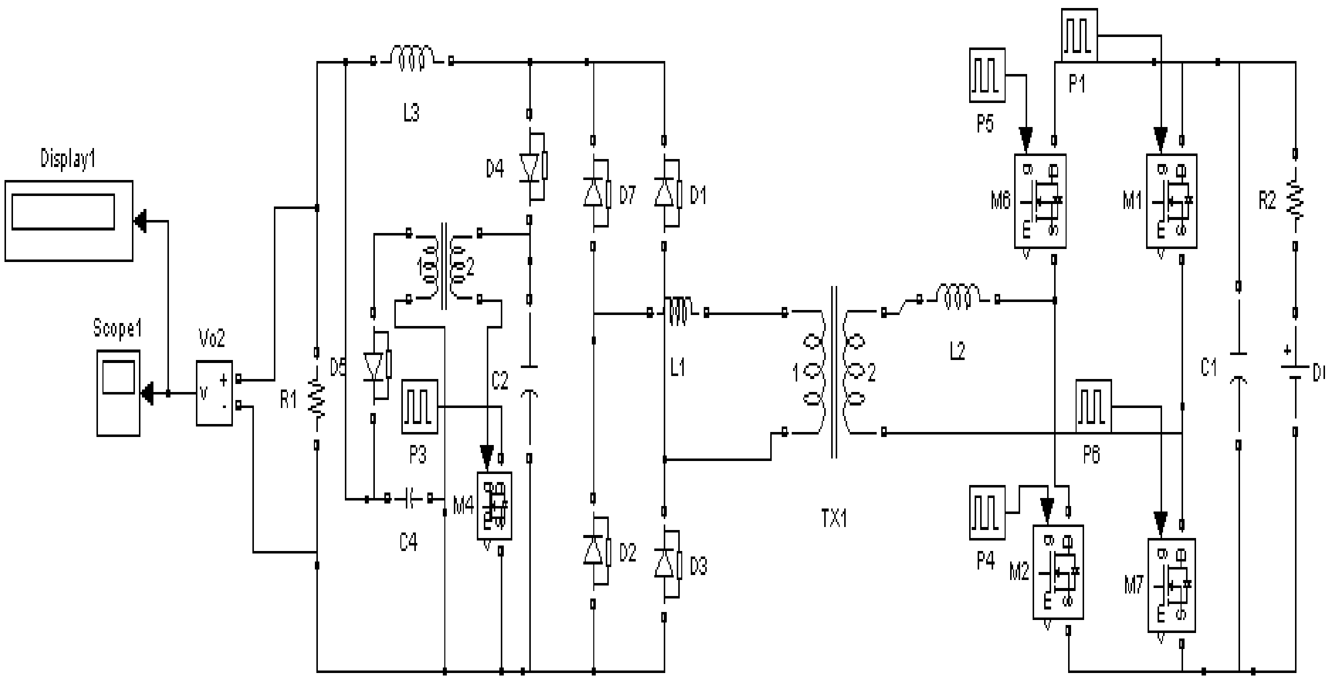

Figure A12.Simulink of buck converter

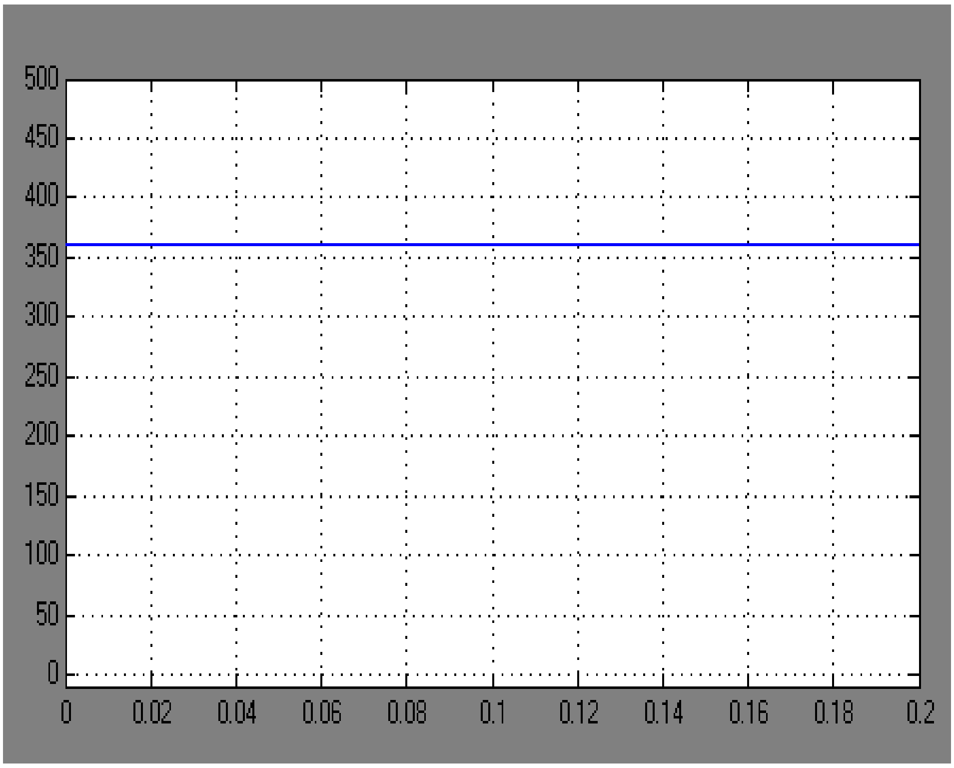

Figure A13.DC input voltage

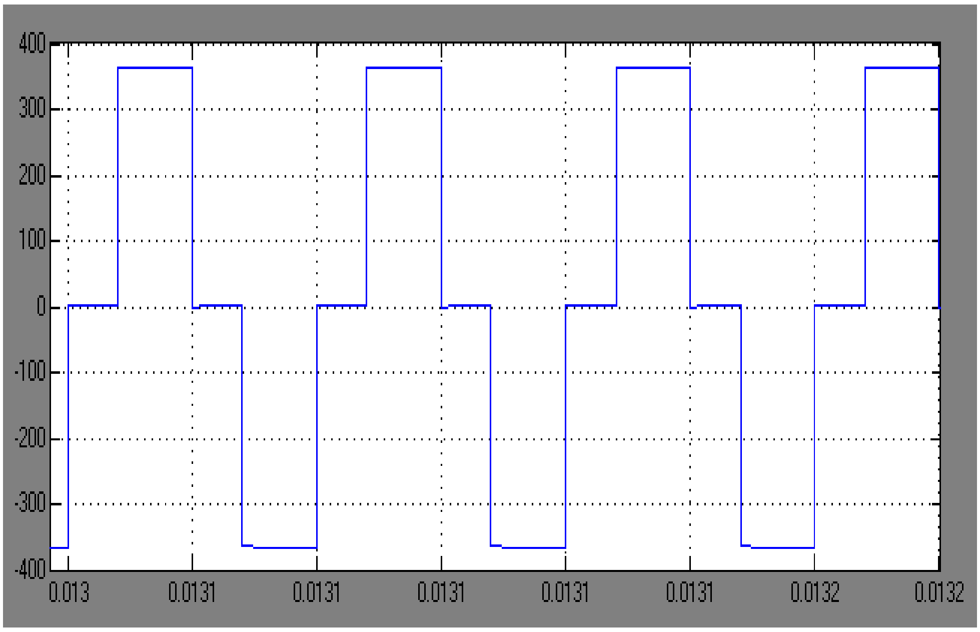

Figure A14.Driving pulse for switches M1 and M2

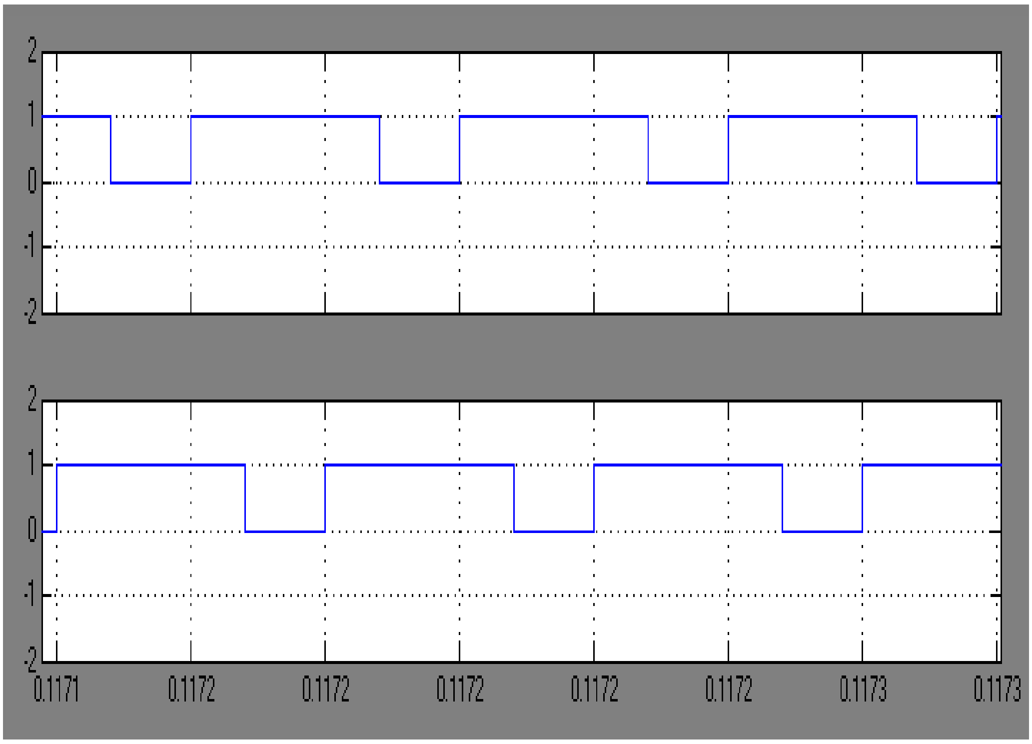

Figure A15.Transformer primary side voltage

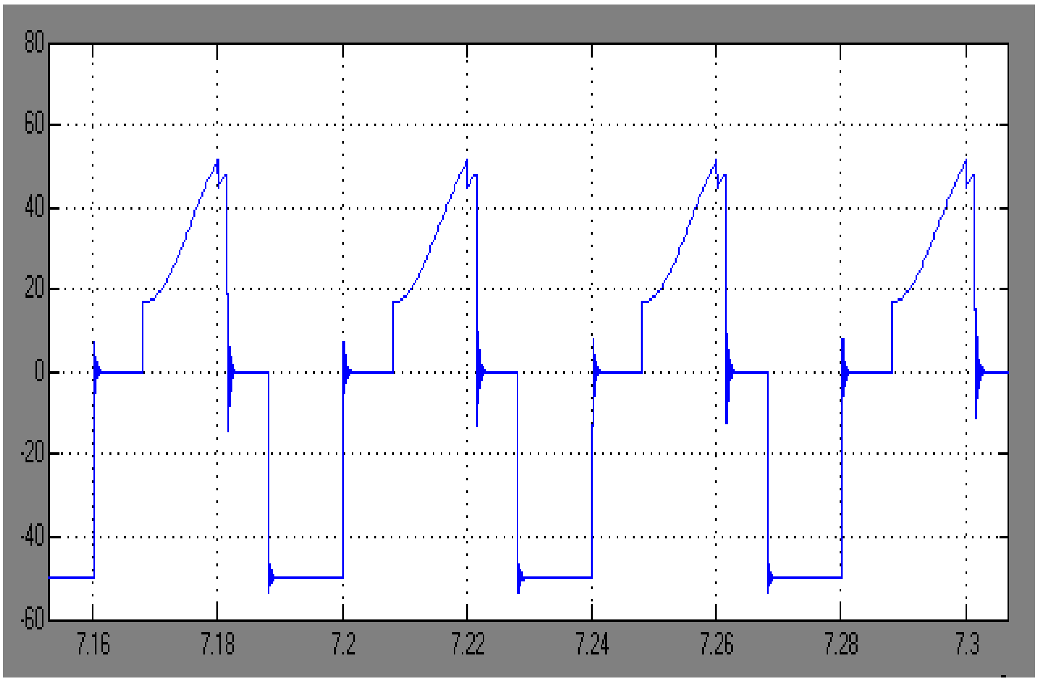

Figure A16.Transformer secondary side voltage

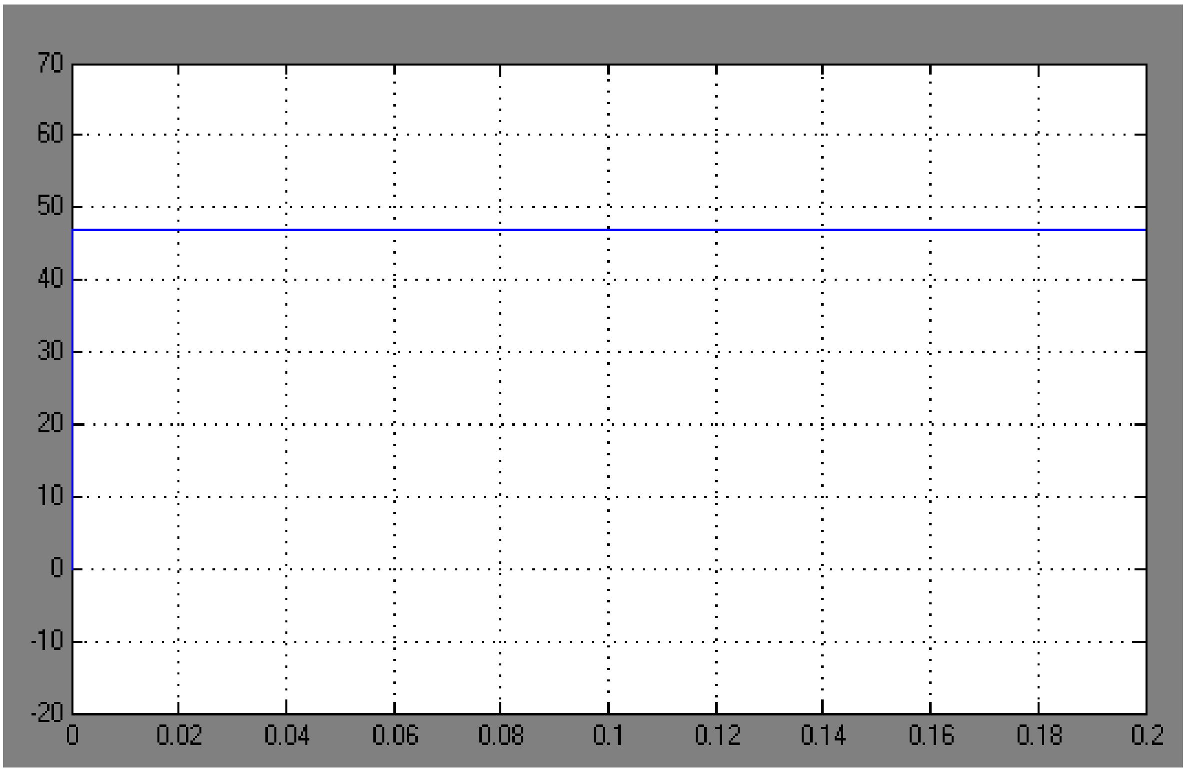

Figure A17.Output voltage for buckmode