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Digital Simulation of Asymmetrical PWM Full-Bridge Converter using Simulink

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ABSTRACT

The main aim of this project is Digital simulation of Asymmetrical pulse width modulated (APWM) full-bridge converter. The APWM full-bridge converter uses soft switching, which means Zero Voltage Switching (ZVS) and Zero Current Switching (ZCS) .To achieve ZVS turn-on of power switches of primary side and to minimize circulating current loss, APWM full-bridge converter uses full-bridge topology and asymmetric control scheme. Zero Current Switching (ZCS) turn-off is achieved by forming resonant circuit, which consists of leakage inductance of the transformer and blocking capacitor, Thus reverse recovery problem of output diode is eliminated. In addition, voltage stresses of the power switches are clamped to the input voltage. These characteristics of APWM full-bridge converter plays vital role to minimize power losses.
Keywords : APWM, ZVS, ZCS, full-bridge converter.

I. INTRODUCTION

In the wake of over consumption of conventional energy resources and environmentally damaging retrieval techniques involved in their production, the need for generating eco friendly energy from obtainable sources has gained importance. The renewable energy sources like photovoltaic and fuel cells generate low-voltage energy [1]-[2]. Of these, photovoltaic cells which rely on climatic conditions generate low-voltage with fluctuations. So a front-end converter between the low voltage source and load operating at high voltage is the need of the hour. A sample system for renewable energy conservation is shown in Figure 1.

In general the capacity of such front-end converters would be below 250W. With the advancement of cell technology, the need for higher capacities of front-end converter has been increased. The higher power capacity results in reduction of the cost per watt as well. For achieving required power capacity, common topologies considered are forward/flyback converters that use an active-clamp with voltage doubler, LLC converters, and phase-shift full-bridge (PSFB) converters.

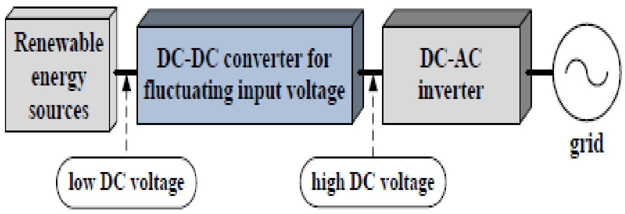


Figure 1. Renewable energy conversion.

An active-clamp circuit is known for its zero-voltage switching (ZVS) functionality. The circuit uses leakage inductance, magnetizing inductance, and parasitic capacitance to realize ZVS for power switches [3]. Especially, forward/flyback converters that use the active-clamp with voltage doubler provide the zero-current switching (ZCS) of the diodes of the transformer secondary side due to the resonant-current formed with the leakage inductance and the resonant capacitor. As the voltage across primary switches of the transformer of forward/flyback converters is higher than input voltage, the MOSFET with low on resistance R_{DS} (on) cannot be used.

A converter that made to operate in resonant mode, yields improved efficiency. The LLC converter can be operated at resonance, with formal input voltage, and is able to operate at no load. Moreover it can also be designed to operate over a wide input voltage. Zero voltage and zero current switching are attainable over the complete operating range. But to achieve enough voltage gain controllability, the frequency has to be increased very high because of wide bandwidth. Especially, conventional LLC resonant topology as the front-end converter of the micro-inverter is hardly implemented because it is difficult to maintain high efficiency over fluctuating input voltage with different load conditions.

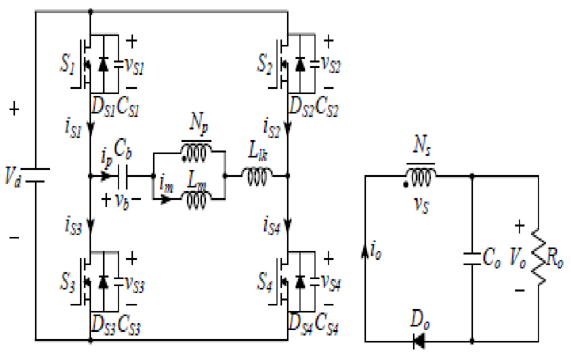


Figure 2. Circuit diagram of APWM full-bridge converter.

The phase-shift full-bridge (PSFB) converters are used for DC-DC conversion in ample applications [5]. However, under the fluctuating input voltage, the full-bridge converter with the phase-shift control scheme is not appropriate because its control scheme has some serious disadvantages such as a narrow ZVS range of the lagging leg switches, duty cycle loss, large circulating current loss, and voltage spikes across the output diodes. In particular, the large voltage spike is very serious problem in the applications which require high voltage. To overcome the problem of the narrow ZVS range under the fluctuating input voltage, the freewheeling period is more required.

This project describes the implementation of a full-bridge converter with APWM control [4]. In this converter resonance phenomenon is used for achieving ZVS turn-on of the switches and ZCS turn-off of the output diode. ZCS turn off helps in eliminating voltage stresses across the power switches. As there is no freewheeling period at the primary side of the transformer, the circulating current loss can be cut out as well.

II. OPERATION OF APWM FULL-BRIDGE CONVERTER

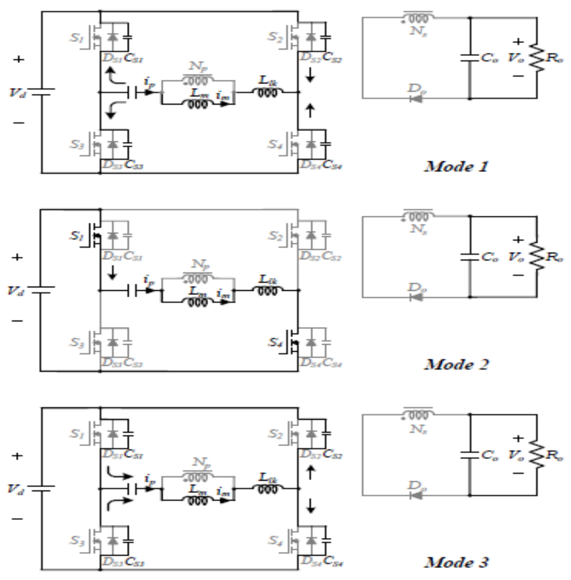
A circuit configuration of APWM full-bridge converter is shown in Figure 2.For analysis of steady state operation of APWM full-bridge converter the following assumptions are made.

1) The transformer is considered as an ideal transformer having primary winding turns N_p, the secondary winding turns N_s, the magnetizing inductance L_m, and the leakage inductance L_{lk}.

2) The switches S_1,S_2,S_3,S_4 are taken as ideal switches instead of their body diodes and output capacitors(C_{s1}=C_{s2}=C_{S3}=C_{S4}=C_{oss}).

3) The output capacitor C_o ,and dc blocking capacitor C_b are taken as larger values to remove voltage ripples, So the voltage across C_b and C_0 are constant.

The two switches S_1,S_4 will be on for a duty ratio D, then the other switches i.e S_2,S_3 will be off for a duty ratio 1-D and vice versa. The switches S_1(S_4) and S_2(S_3) are operated asymmetrically. The APWM full-bridge converter has no freewheeling period, So the circulating current loss at the primary side of



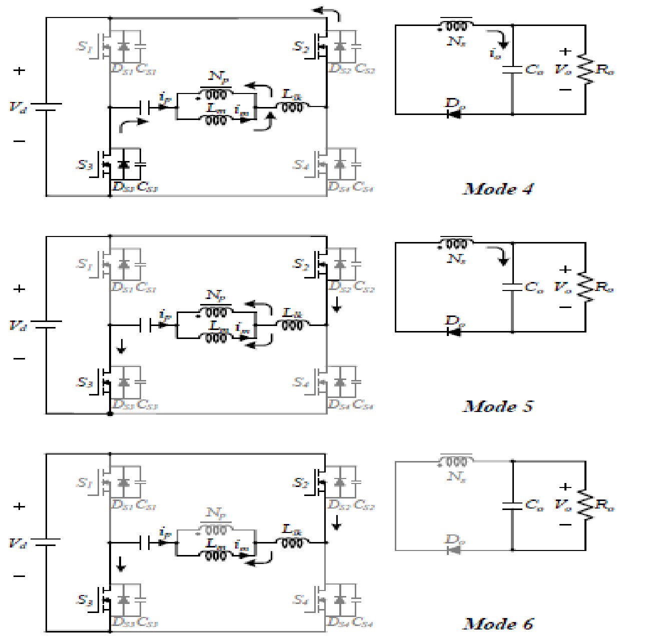


Figure 3. Operating modes of APWM full-bridge converter.

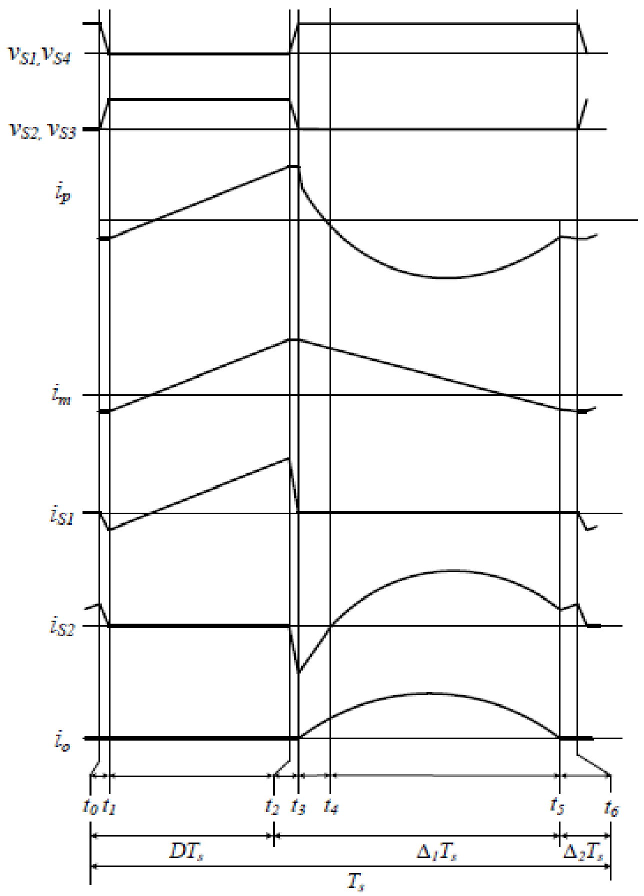


Figure 4. Theoretical waveforms of APWM full-bridge converter the transformer can be eliminated.

Figure 3. represents operating modes and Figure 4. represents the theoretical waveforms of APWM full-bridge converter. Operation of APWM full-bridge converter is divided into six modes in a switching period T_s.

Mode 1[t_0 t_1]: In this mode the switches S_2 and S_3 become off at t_0. The primary current i_p is to discharge output capacitances C_{s1} and C_{s4} which are across switches S_1 and S_4 ,and also to charge output capacitances C_{s2} and C_{s3}which are across switches S_2 and S_3.The duration of mode1 is very small because of output capacitances which are across switches are chosen to be very small value. So the primary current i_p, and magnetizing current i_m is constant for that short duration.

Mode 2[t_1 t_2]: The voltages across switches S_1 and S_4 are V_{s1} and V_{s4} respectively.V_{s1} and V_{s4} become zero at t_1,then the negative current flows through their body diodes D_{s1} and D_{s4} of switches before S_1 and S_4 become on., which means Zero Voltage Switching occurred by making switches S_1 and S_4 on, and resonance forms between dc blocking capacitor and magnetizing inductance, leakage inductance i.e primary inductance of the transformer L_m+L_{lk}. Eventhough effect of resonance can not appear because switching period T_s is much lesser than resonant period .The difference between voltage of dc blocking capacitor C_b and input voltage V_d changes direction of primary current i_p i.e i_p starts increasing linearly from constant as follows.

$$i_P(t) = i_p(t_1) + \frac{V_d - V_b}{L_m + L_k}(t-t_1)$$

where V_d =input voltage, and V_b= average voltage across dc blocking capacitor C_b.

Mode 3[t_2 t_3]: In this mode the switches S_1 and S_4 become off at t_2. The primary current i_p is to charge output capacitances C_{s1} and C_{s4} which are across switches S_1 and S_4 ,and also to discharge output capacitances C_{s2} and C_{s3}which are across switches S_2 and S_3. Mode 3 operation is same as that of mode1,the primary current i_p, and magnetizing current i_m is constant for that short duration.

Mode 4[t_3 t_4]: Mode 4 is same as that of mode 2, For switches S_2 and S_3 Zero Voltage Switching turn-on occurred in this mode. The stored energy of magnetizing inductance is transferred from magnetizing inductance to the secondary side of the transformer. The transformer leakage inductance L_{lk}, dc blocking capacitor forms resonance .The magnetizing current i_m decreased and follows as

$$i_m(t) = i_p(t_3) - \frac{V_o}{nL_m}(t-t_3)$$

where n = turns ratio.

.Mode 5[t_4 t_5]: The primary current i_p appears to be zero at t_4, and the direction of primary current i_p changes at t_4.During this mode direction of magnetizing current i_m also changes, by the end of this mode primary current i_o becomes zero having resonant characteristics. Mode 5 ends whenever output current i_o reaches zero.

Mode 6[t_5 t_6]: The output current i_o approaches zero at t_5 , Because of resonance occurred in mode 4 is ended. The output diode D_o is managed to be on upto the switches S_2 and S_3 become off. The primary current i_p, and magnetizing current i_m are equal in this mode. Thus the output diode D_o Zero Current Switching turn-off occurs.

III. DESIGN CONSIDERATIONS

The APWM full-bridge converter is to design output voltage V_o=350V and output power P_o=400W,So $R_{o,min}$=306Ω.The Transformer turns ratio is considered as n=8.

a. ZVS condition of power switches

For switches S_1 and S_4 to achieve ZVS turn-on the primary current $i_p(t_1)$ should be negative before S_1 and S_4 are turned on,From [1] the condition for Zero Voltage Switching can be given as

$$nI_0 - \frac{(1-D)T_s}{nL_m} V_o < 0$$

For switches S_1 and S_4 maximum duty ratio at minimum input voltage $V_{d,min}$ From [1] can be given as follows.

$$D_{max} = \frac{Vo}{2nV_{d,min}}$$

To satisfy condition of ZVS the magnetizing inductance L_m, can be given From [1] as follows

$$L_m < \left(1- \frac{V_o}{2nV_{d,min}}\right) T_s. \frac{R_{o,min}}{n^2}$$

The magnetizing inductance L_m, takes care of minimization conduction loss of APWM full-bridge converter by maintaining magnetizing current $i_m(t_1)$ to be small negative value.

b. ZCS condition of output diode

The critical angular frequency ω_{rc}, must be smaller than resonant angular frequency ω_r to achieve condition of ZCS turn-off.The condition to achieve ZCS of output diode From [1] can be given as

$$\left(\frac{n^2L_m}{R_{o,min}} + t_{s2,min}\right) - \frac{1}{\omega_{rc}}\sin\omega_{rc}\, t_{s2,min} - \left(\frac{n^2L_m}{R_{o,min}} + t_{s2,min}\right) = 0$$

Where $t_{s2,min}$ is the minimum turn-on duration of switches S_2 and S_3.

The critical angular frequency ω_{rc}, can be given From [1] as follows

$$\omega_{rc} \approx \frac{\Pi+1.462}{t_{s2,min}} \approx \frac{\Pi+1.462}{(1-D_{max})T_S}$$

The condition that the dc blocking capacitor C_b should satisfy can be given From[1] as follows.

$$C_b \leq \frac{1}{\omega_{rc}^2 L_{lk}}$$

IV. Comparison Of Boost converter and APWM Full-bridge converter

In general to achieve high voltage from low input voltage boost converter can be used, but boost converter has its limitations like Duty cycle, Power losses, Ripple voltage and Ripple current. To get high output voltage duty cycle should be closer to 1,as it ranges from 0 to 1. AS duty cycle is more means ,Mosfet conduction time is more, Which causes more conduction losses.

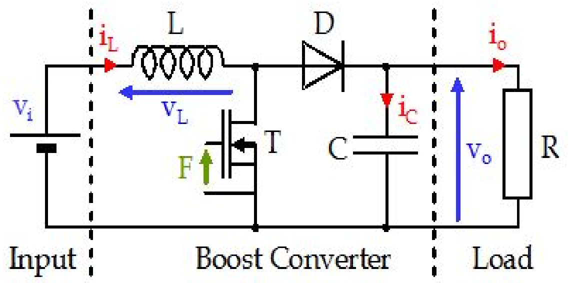


Figure 5. Circuit diagram of Boost converter

Ripple voltage (ΔV_c) in a boost converter can be given as

$$\Delta V_c = \frac{DI_o}{Cf_s}$$

Where D=Duty cycle, I_o=output current, f_s= Switching frequency.

Ripple current (ΔI_L) in a boost converter can be given as

$$\Delta I_L = \frac{DV_{in}}{Lf_s}$$

Where V_{in} = input voltage.

As Ripple voltage and Ripple current in a boost converter are linearly proportional to duty cycle, So Ripple voltage and Ripple current increases as duty cycle increases, which is not acceptable. These limitations causes to choose APWM Full-bridge converter for boosting purpose.

APWM Full-bridge converter uses soft switching techniques such as ZVS (Zero Voltage Switching) and , ZCS (Zero Current Switching). ZVS is achieved by Power switches and ZCS is achieved by output diode, So switching losses can be reduced and output of APWM Full-bridge converter can be boosted to more voltage when compared to boost converter.

V. SIMULATION RESULTS

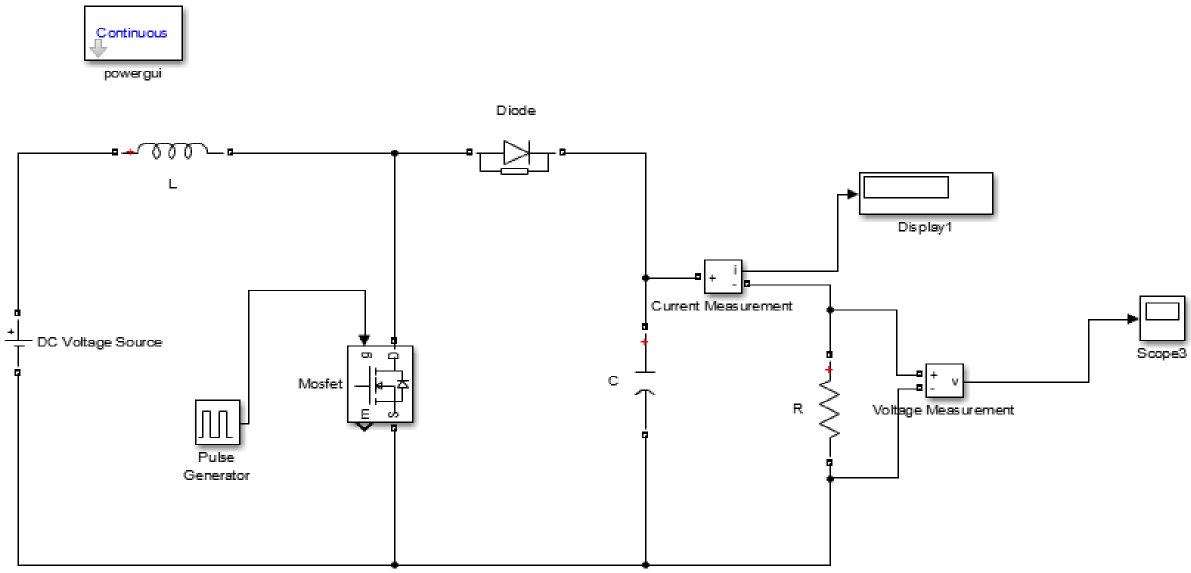


Figure 6. Matlab/Simulink model of Boost converter

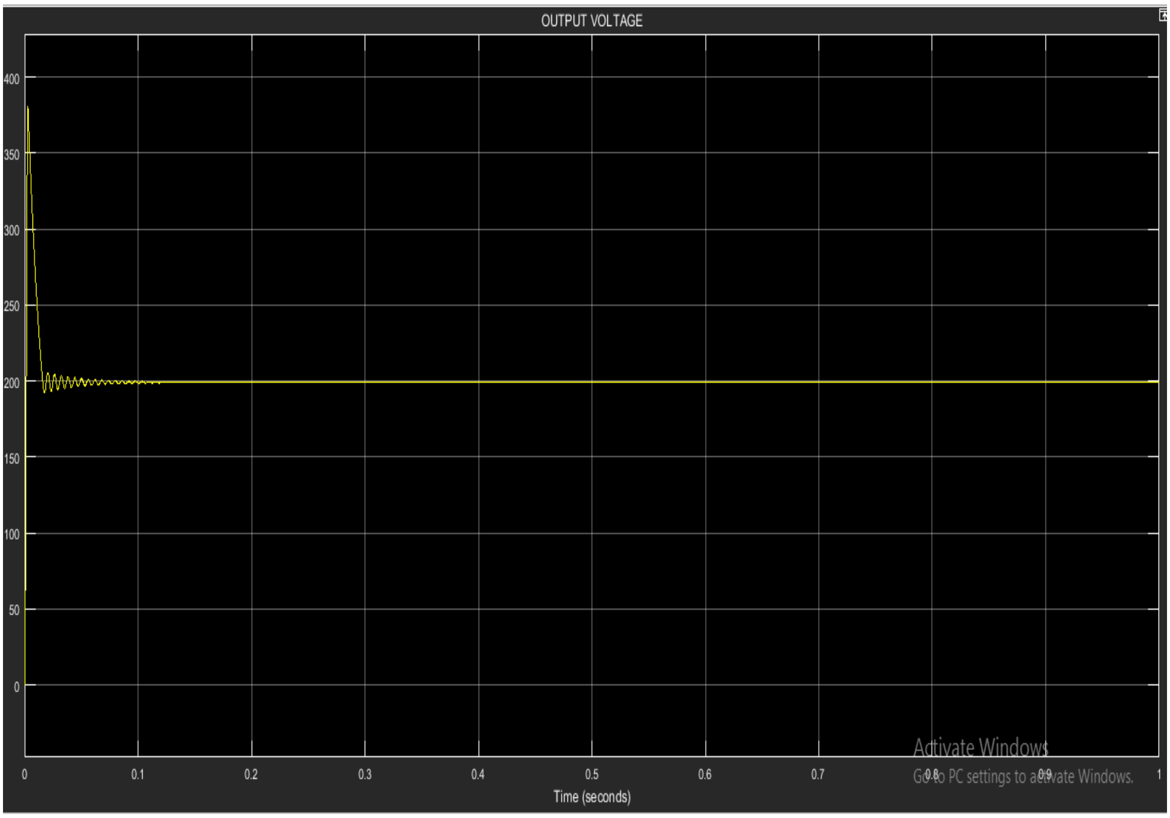


Figure 7. Output voltage of boost converter for V_{in}=40V and Duty cycle D=0.8

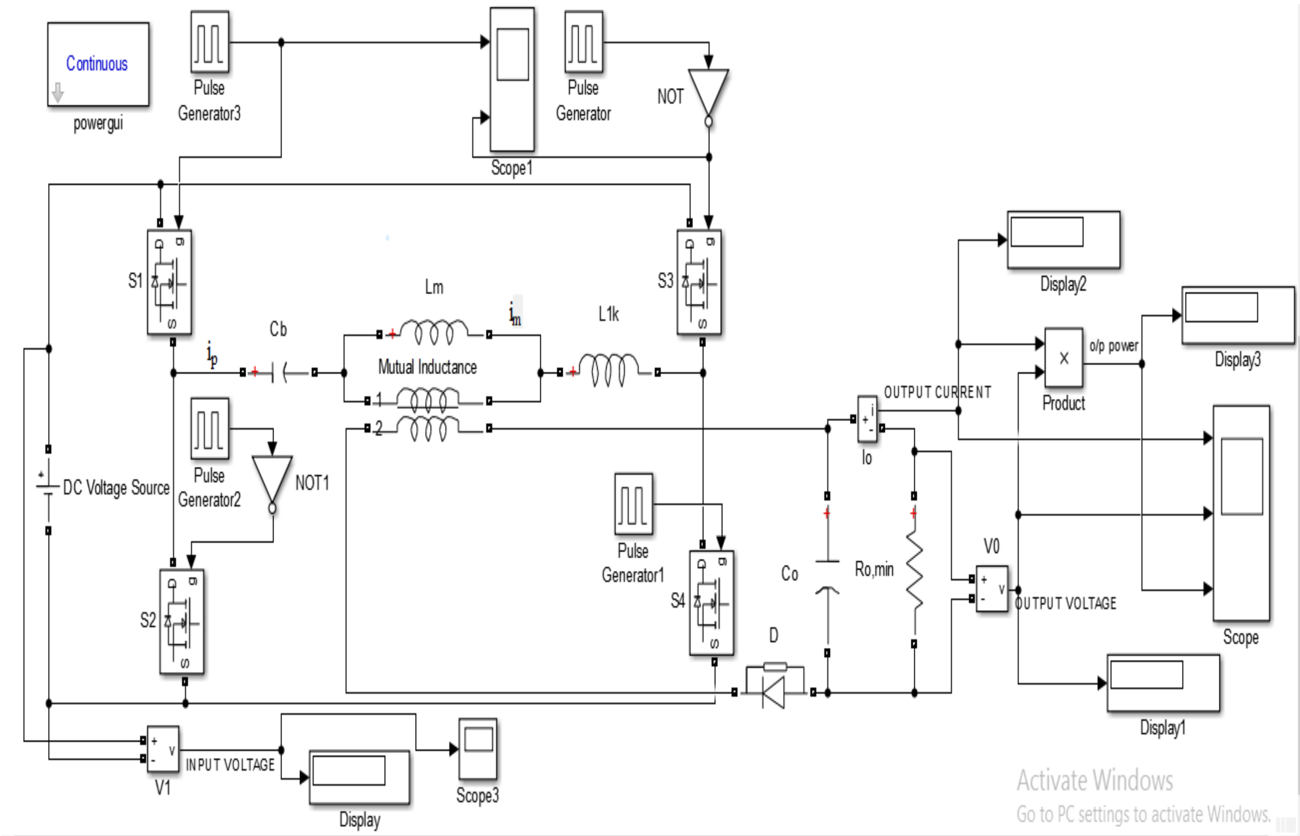


Figure 8. Matlab/Simulink model of APWM full-bridge converter

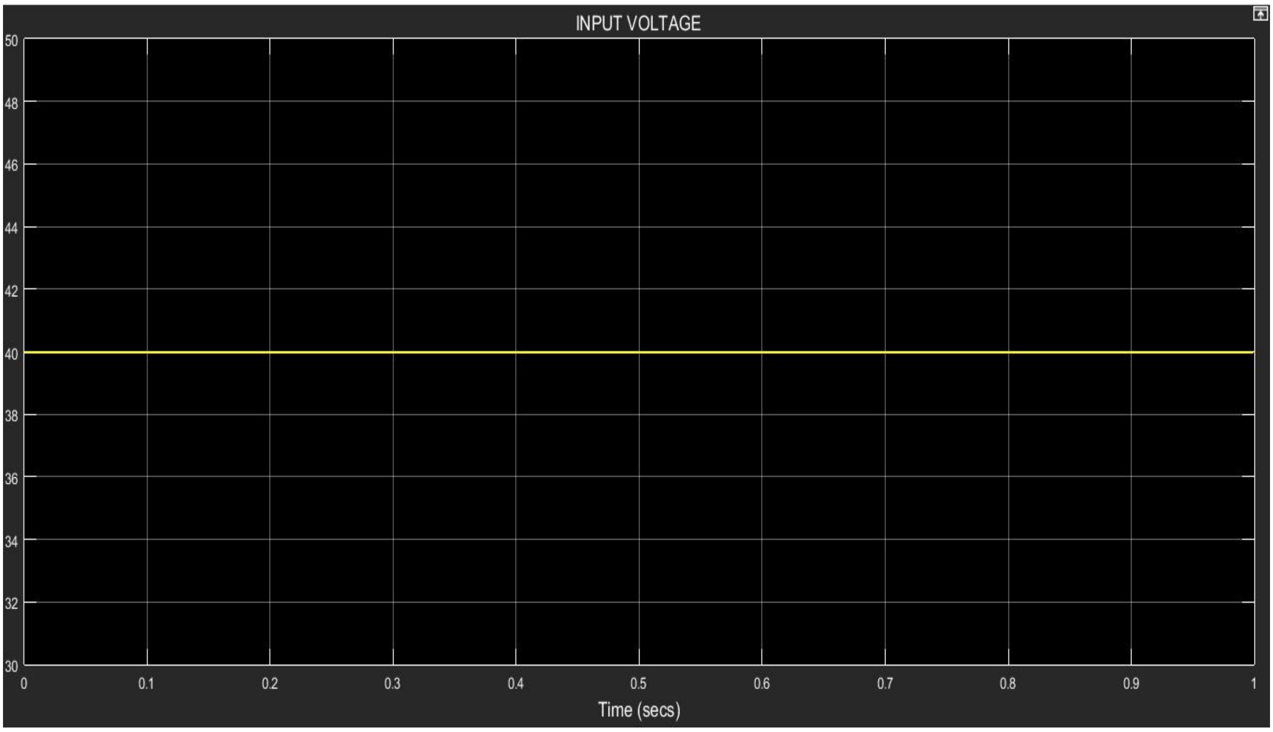


Figure 9. Input voltage to APWM Full-bridge converter

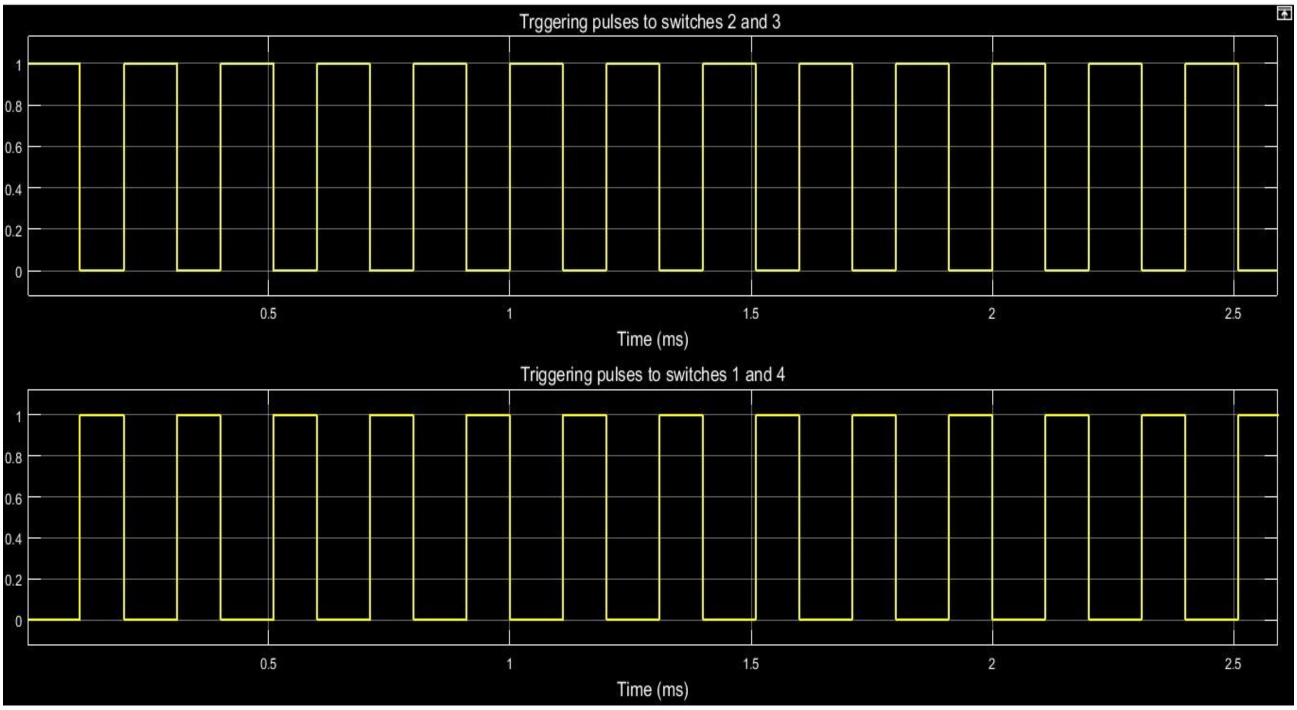


Figure 10. Triggering pulses to switches

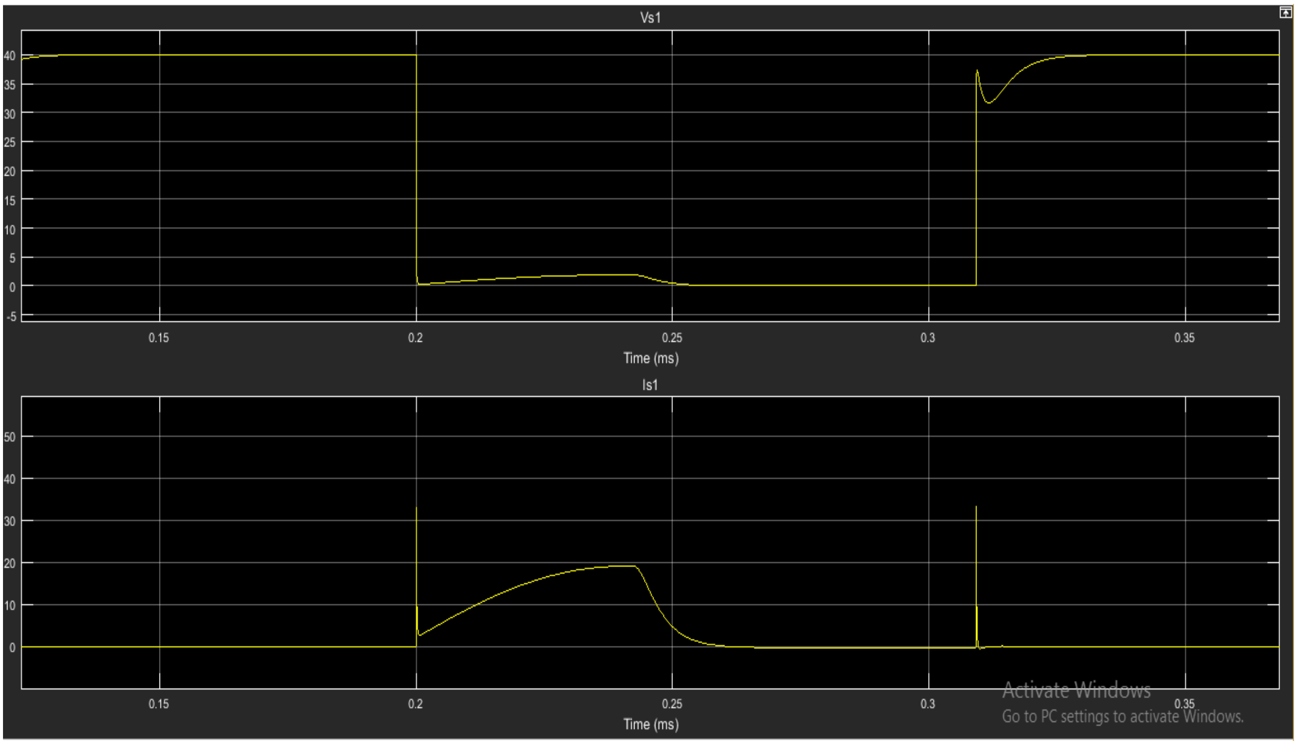


Figure 11. ZVS turn-on of switch S_1.

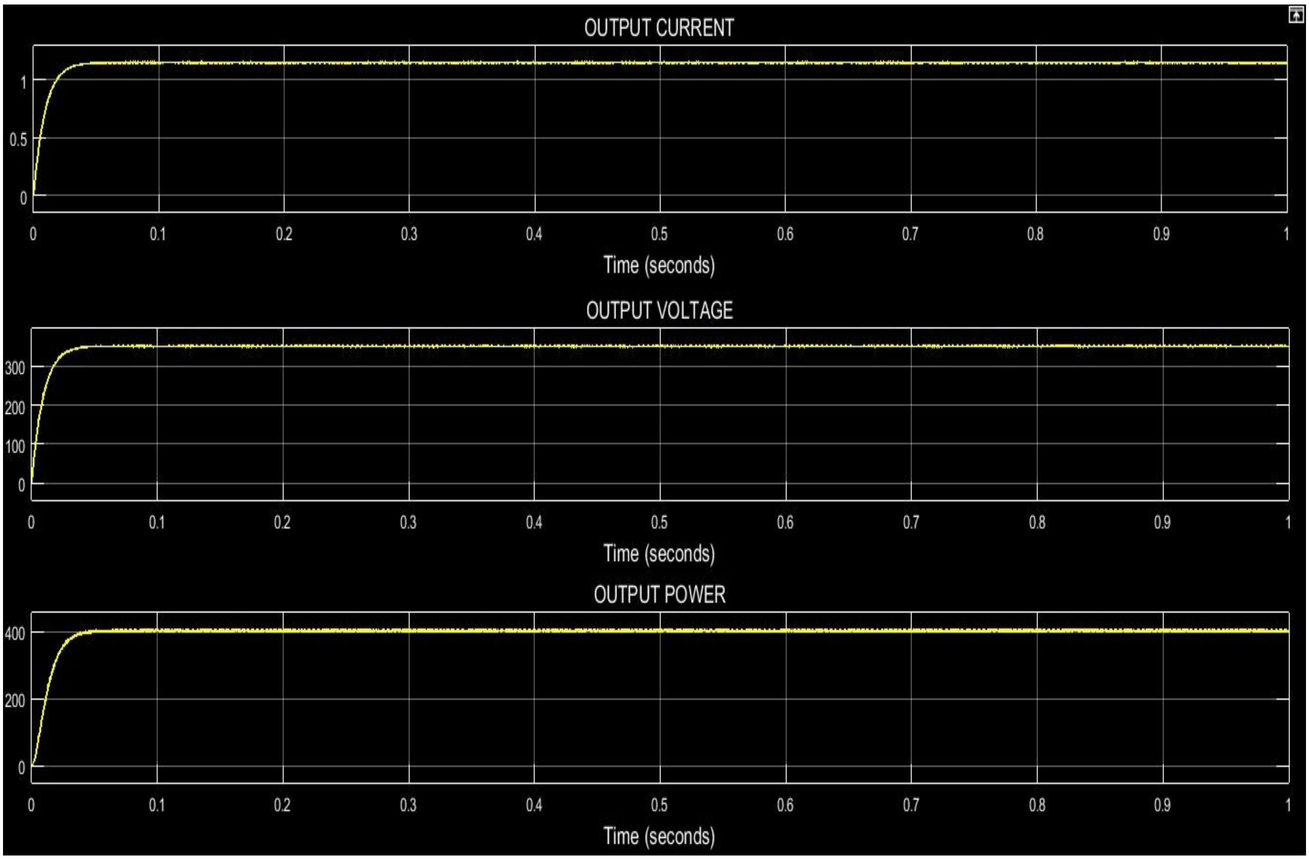


Figure 12. Output of APWM full-bridge converter for V_{in}= 40V.

VI. CONCLUSION

In this project Asymmetrical Pulse Width Modulated Full-bridge Converter is analysed and Simulated. Zero Voltage Switching of all power switches and Zero Current Switching of output diode is achieved without extra components. The converter is able to provide an output voltage of 350V and output power of 400Wfor an input voltage 40V.

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