Switching Schemes

1. Construction of Simulink Model:

The model shown below is a 3ϕ, 6-pulse, IGBT based rectifier with the following characteristics.

- Supply voltage: 3ϕ, 460 V, 60 Hz
- The load is resistive with R_L = 60Ω

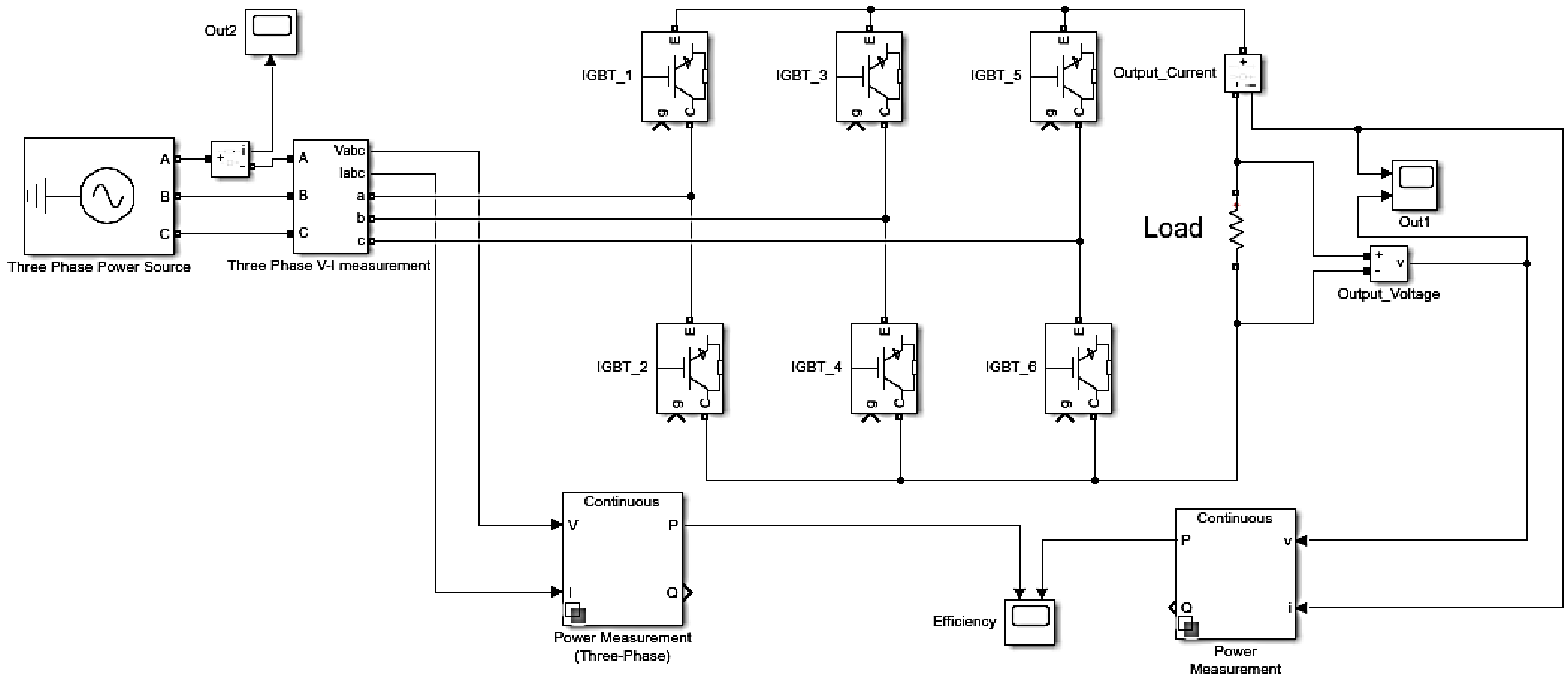

Fig.1: 3-Phase Rectifier Model

In this model, the Current measurement and Scope named "Out2" is used to measure the Total Harmonic Distortion through the PowerGUI block with the continuous mode of operation. Similarly, Three-Phase Power measurement and V-I measurement blocks are used to measure the Input Power on the Power Source side and Single-Phase Power and V-I measurement blocks are used to measure the Output Power and Output Voltage at the Load side. These Power measurements are utilized to calculate the Efficiency of the Power Electronic converter for various switching techniques. Furthermore, the switching techniques such as Sinusoidal Pulse Width Modulation, Hysteresis Band Current Control and Space Vector Modulation are used to generate the gate pulses for the switching operations of IGBTs in the model. Also, the following parameters are analyzed.

- Output DC voltage.
- THD_I for input current.
- Efficiency

2. Sinusoidal Pulse Width Modulation

In this switching technique, the Sinusoidal Reference wave of amplitude 0.85 and frequency 60Hz is compared with the carrier wave of amplitude 1V and switching frequency 1740 Hz to attain the modulation index of 0.85. The PWM generator block is connected as shown in the below figure to generate the gate pulses for the IGBTS.

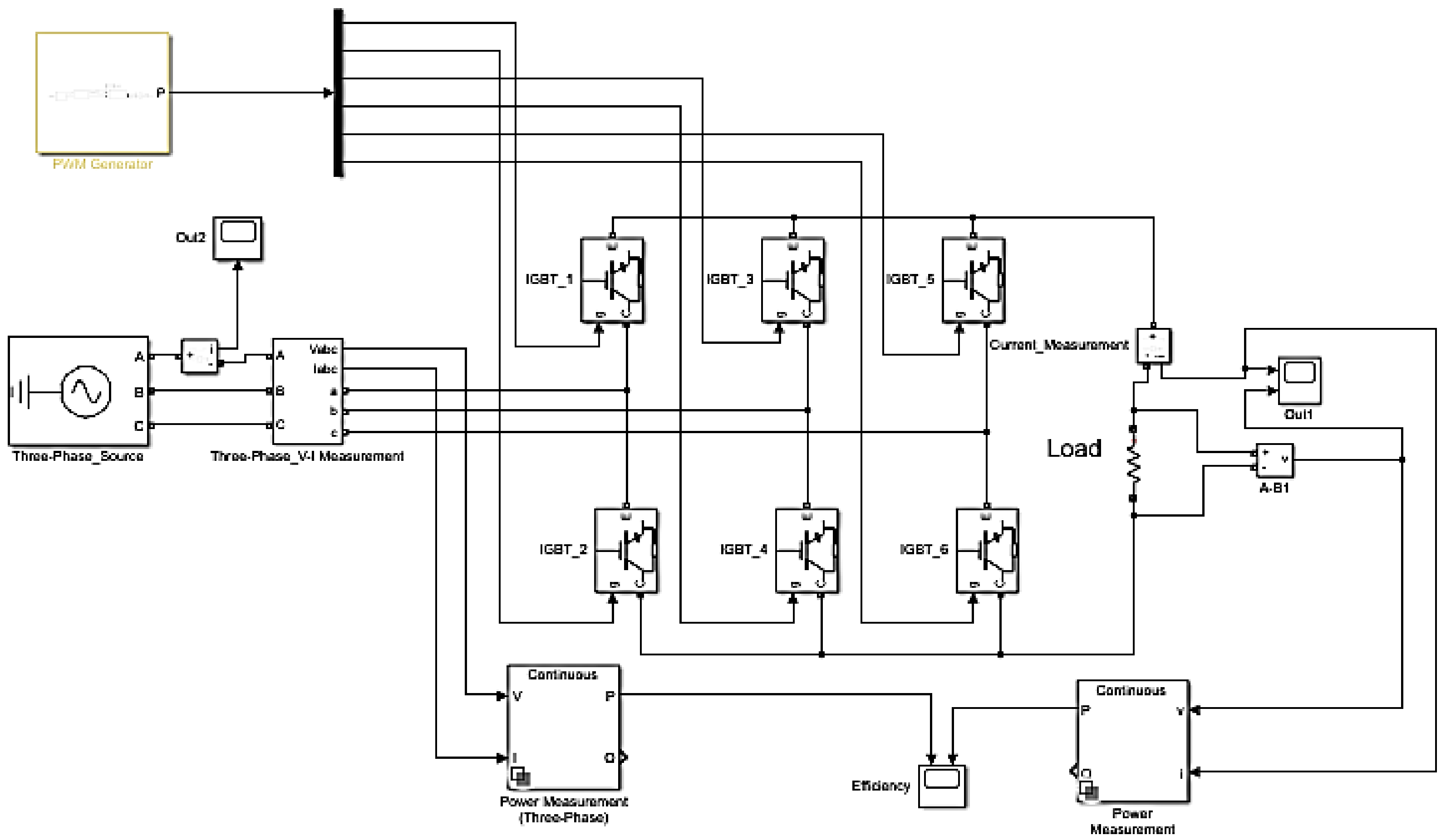

Fig.2: Sinusoidal Pulse Width Modulation Model

3. Hysteresis Band Current Control Method

In this switching technique, the Fixed Hysteresis Band of ±5A is created in the model shown below. The Output current is fed-back to the current controller and processed through the comparators to develop a hysteresis band, consequently, the gate pulses are developed to operate the IGBTS.

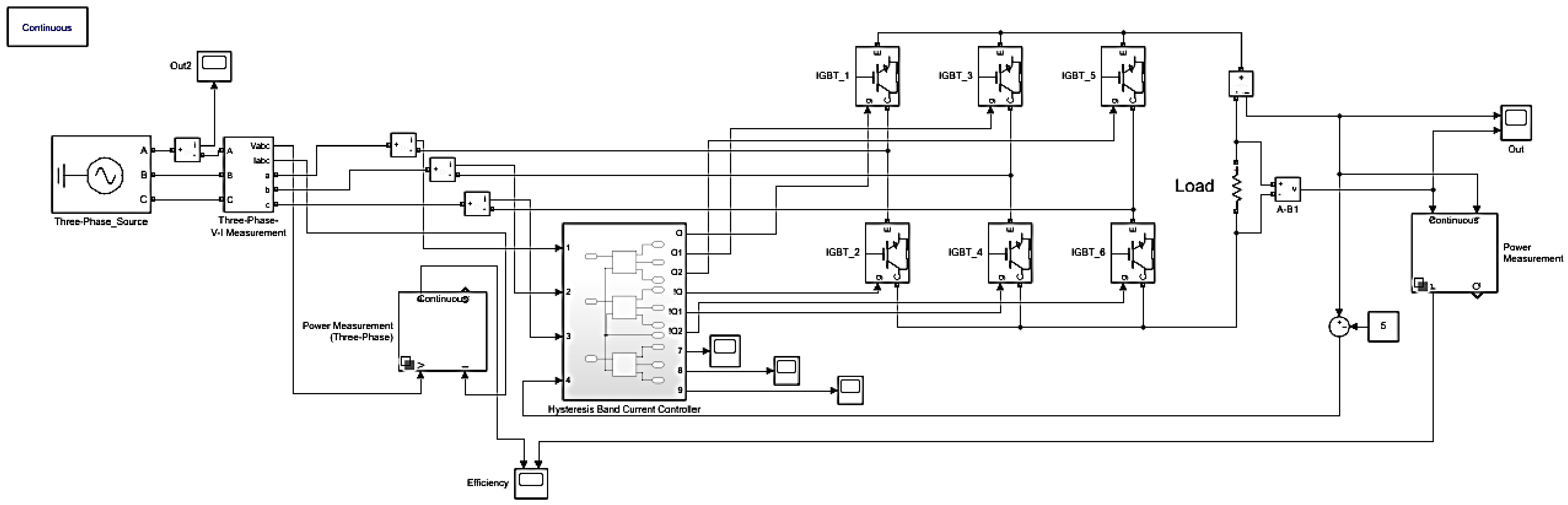

Fig.3: Hysteresis Band Current Controller Model

The Sub-system of Hysteresis Band Current Controller Block is shown below. The input currents and output current are connected to the HBCC blocks and appropriate gate pulse for the IGBTs are generated.

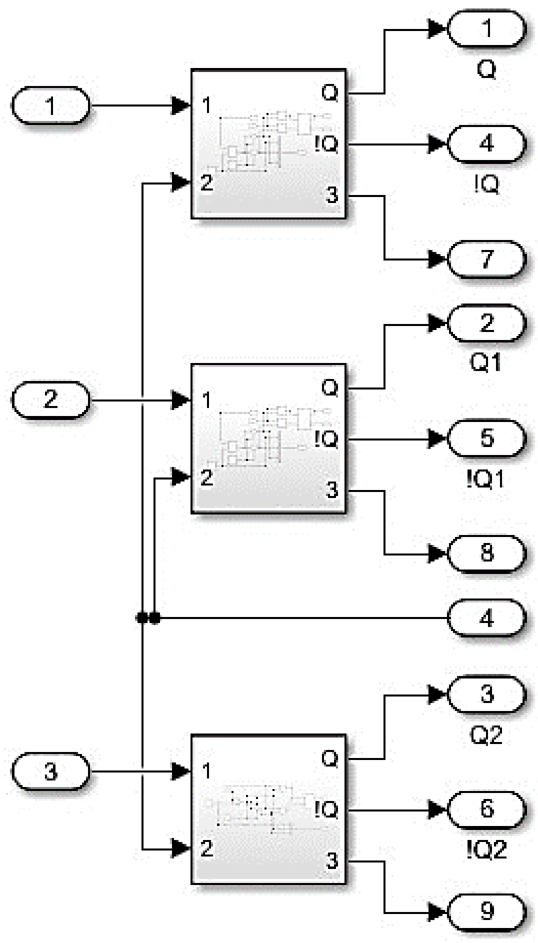

Fig.4: Single HBCC Block

The Sub-system of the Single Controller Leg Block is shown below. The input current and output current are processed in the Single Leg block along with the reference wave signal through various comparators and flip-flop to generate the gate pulses.

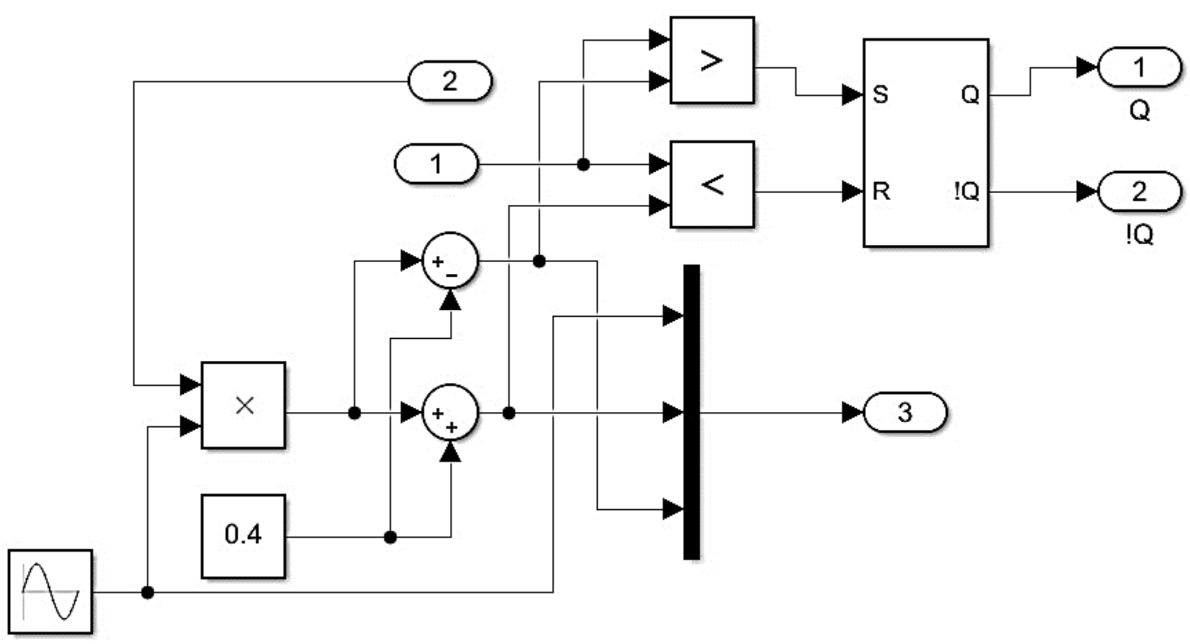

Fig.5: Single HBCC Leg

4. Space Vector Modulation

In this switching technique, ON switching pulses are centered, for each leg of Converter, within each half carrier signal cycle. The Space Vector Modulation Block is configured with the fundamental frequency of 60Hz, Chopping Frequency of 2000Hz, and Modulation Index of 0.85. The Space Vector Modulation generator block is connected as shown in the below figure to generate the gate pulses for the IGBTS.

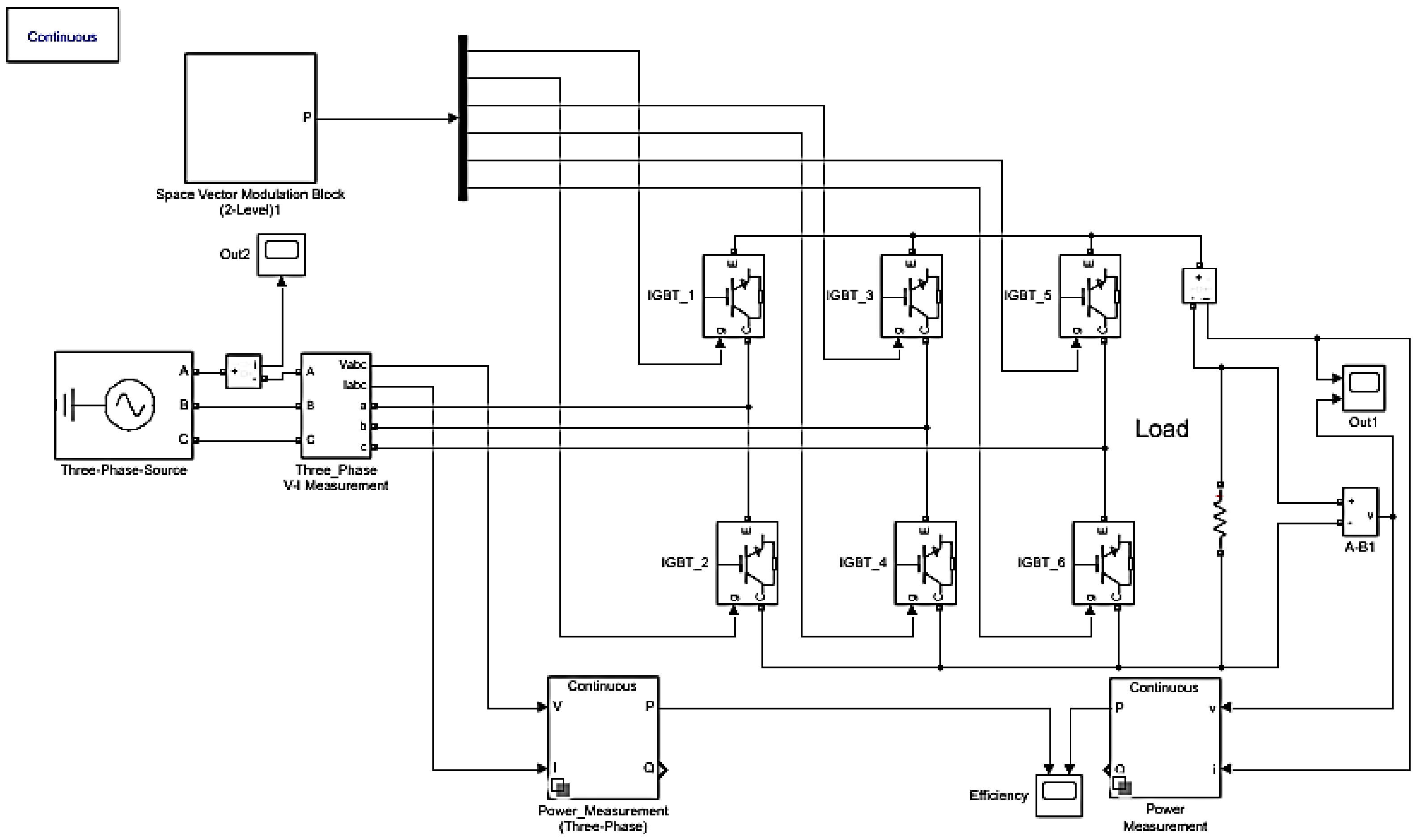

Fig.6: Space Vector Modulation

5. Results and Discussion

i. Output DC Voltages

The Peak DC output Voltage of Sinusoidal Pulse Width Modulation is 375V.

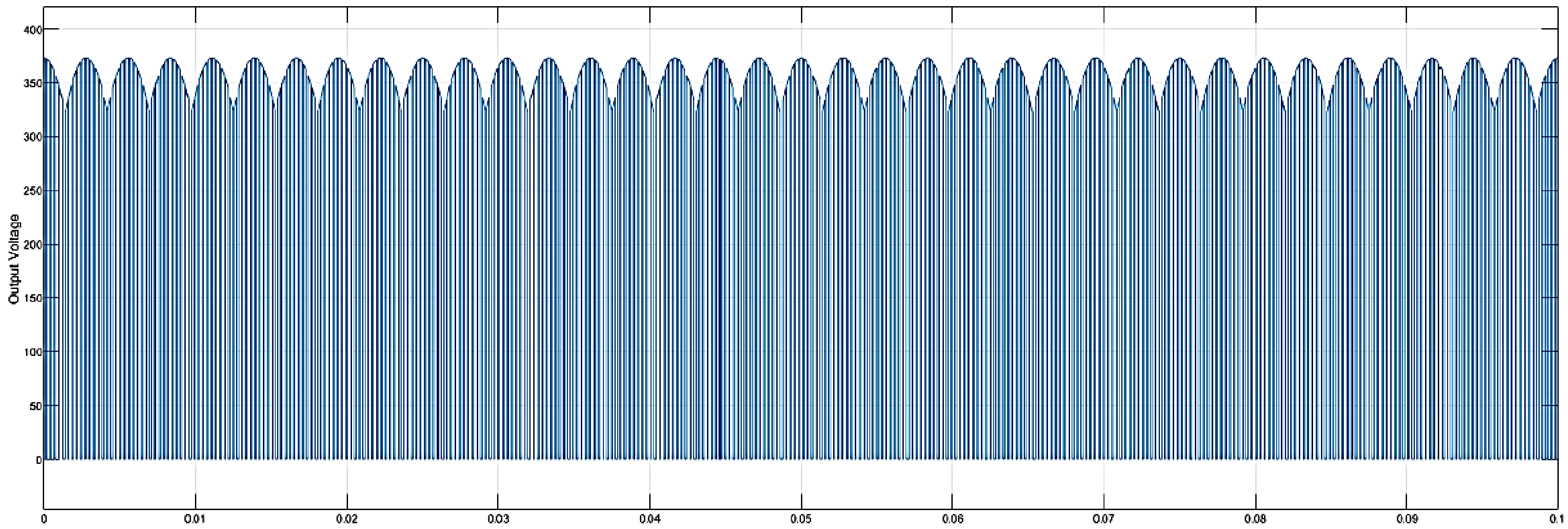

Fig.7: Output Voltage of Sinusoidal Pulse Width Modulation

The Peak DC output Voltage of Hysteresis Band Current Control is 375V.

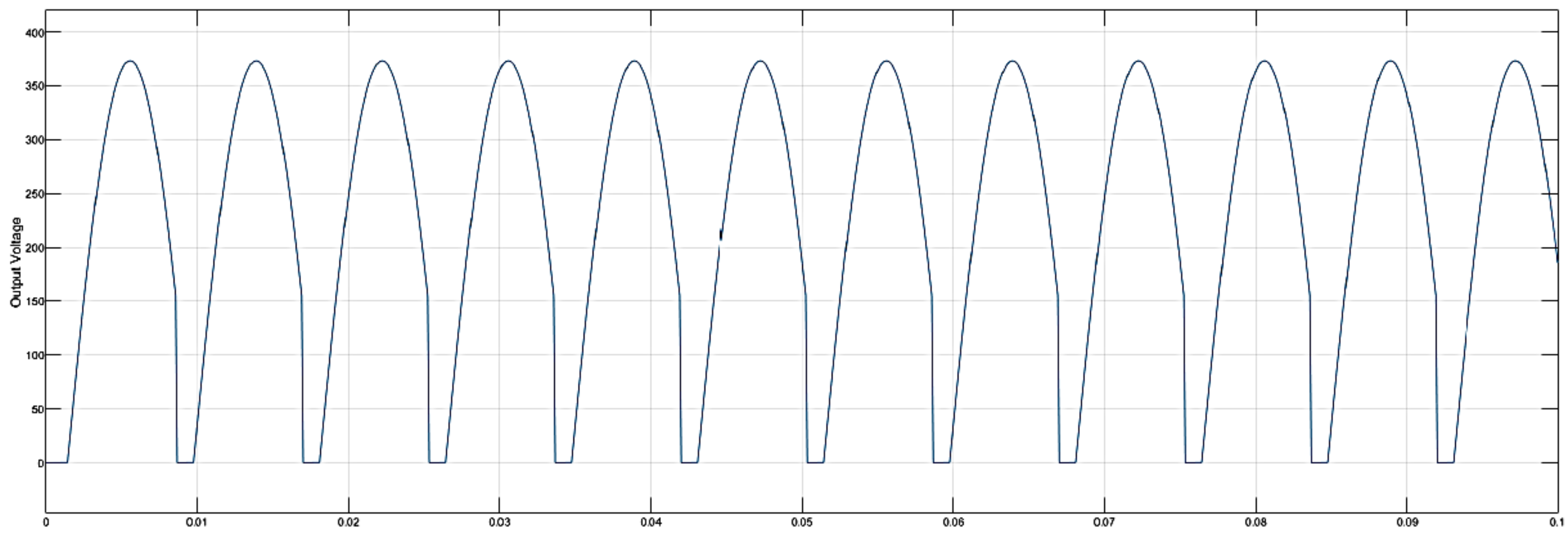

Fig.8: Output Voltage of Hysteresis Band Current control

The Peak DC output Voltage of Space Vector Modulation is 375V.

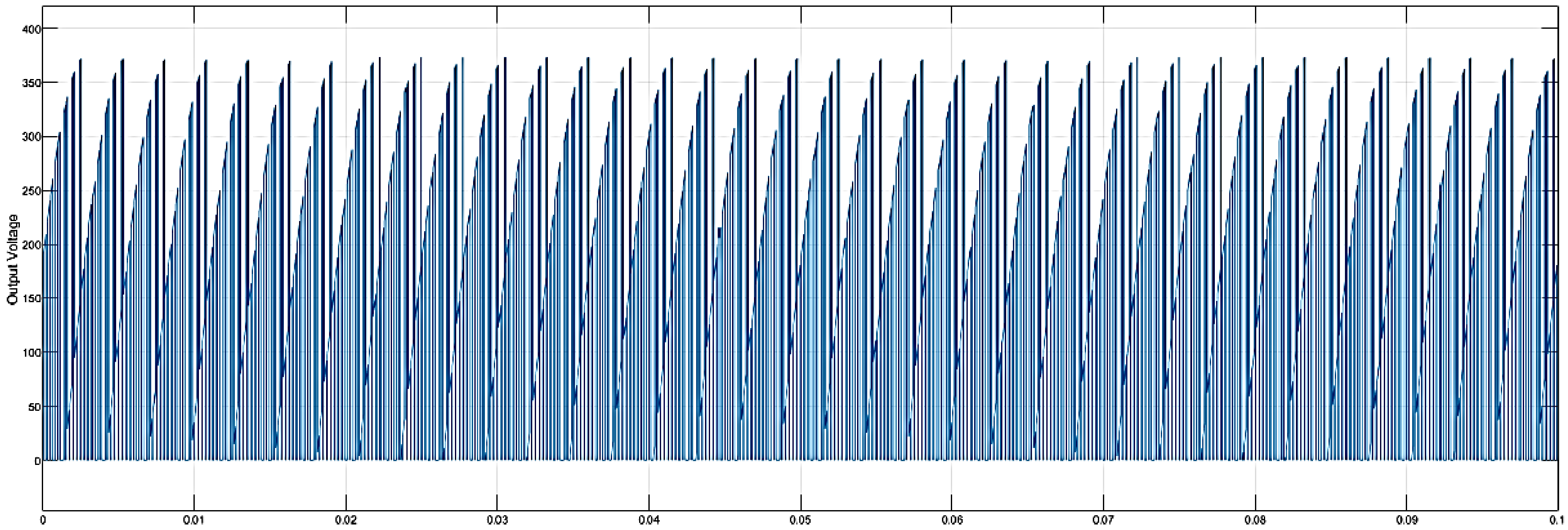

Fig.9: Output Voltage of Space Vector Modulation

ii. Total Harmonic Distortion of Input Current

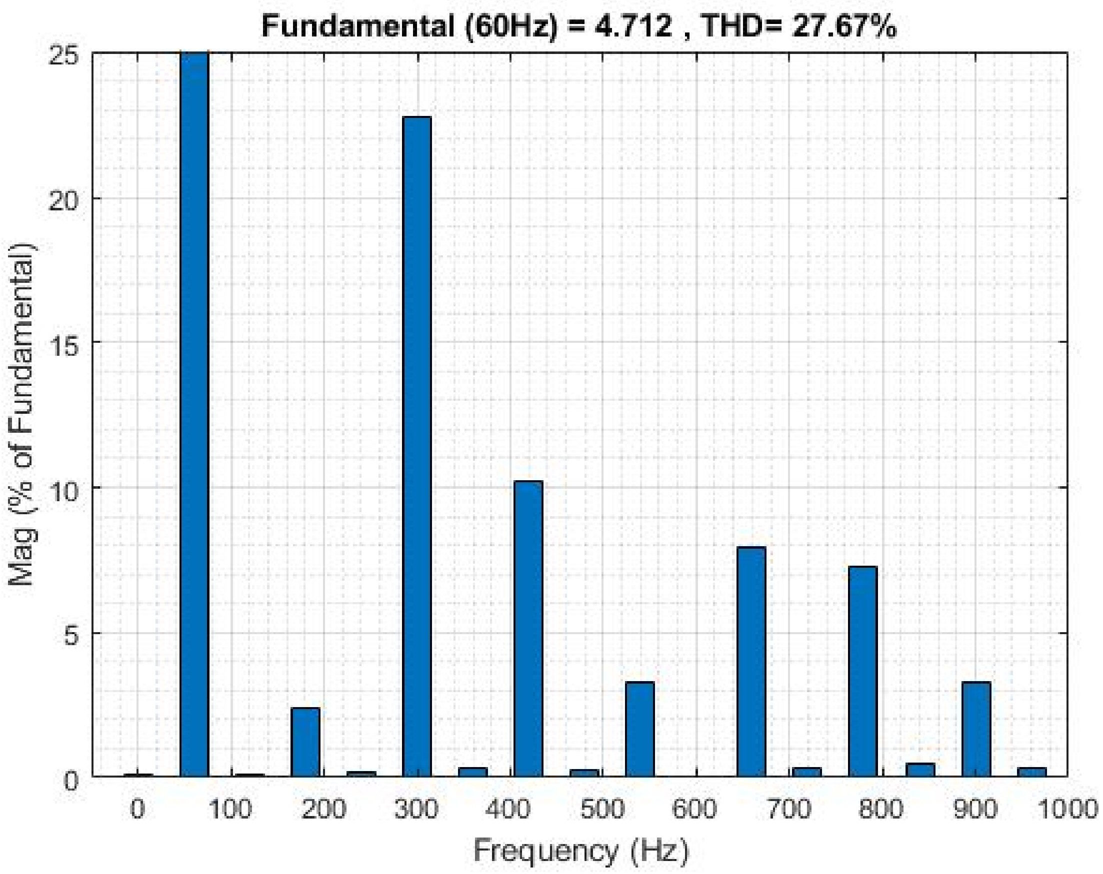

Fig.10: Total Harmonic Distortion of Sinusoidal Pulse Width Modulation

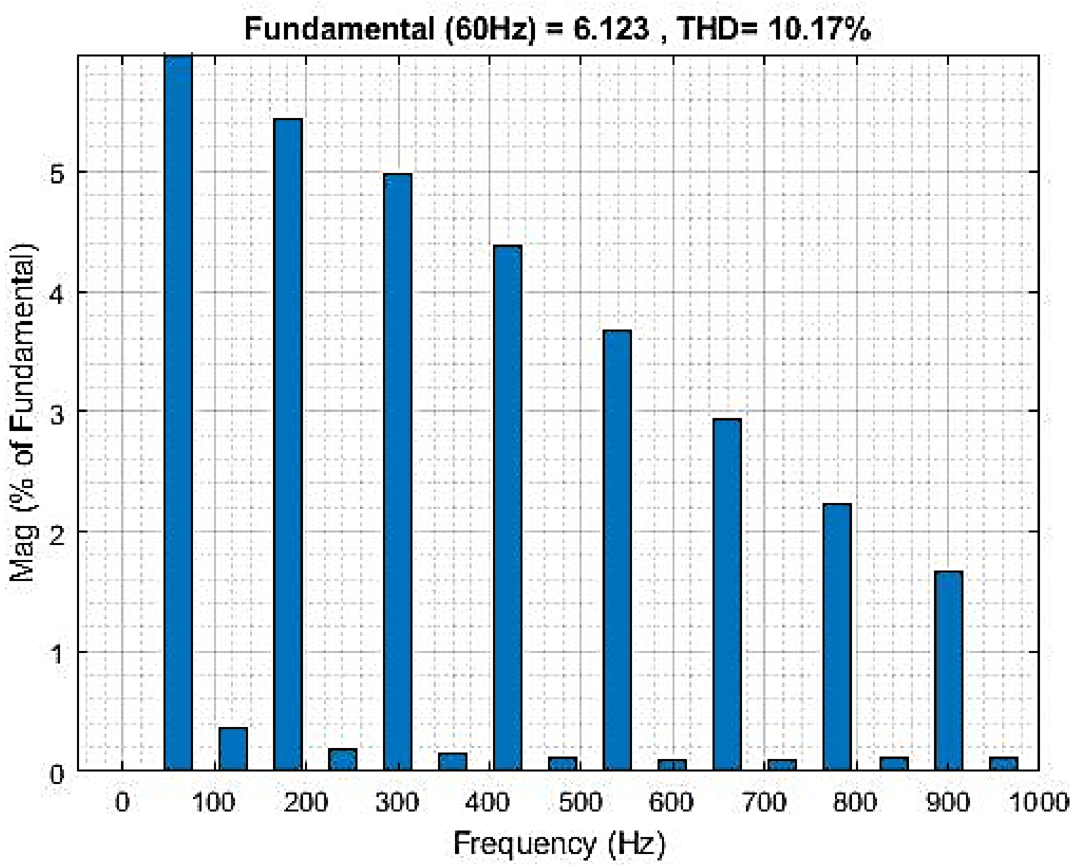

Fig.11: Total Harmonic Distortion of Hysteresis Band Current Control

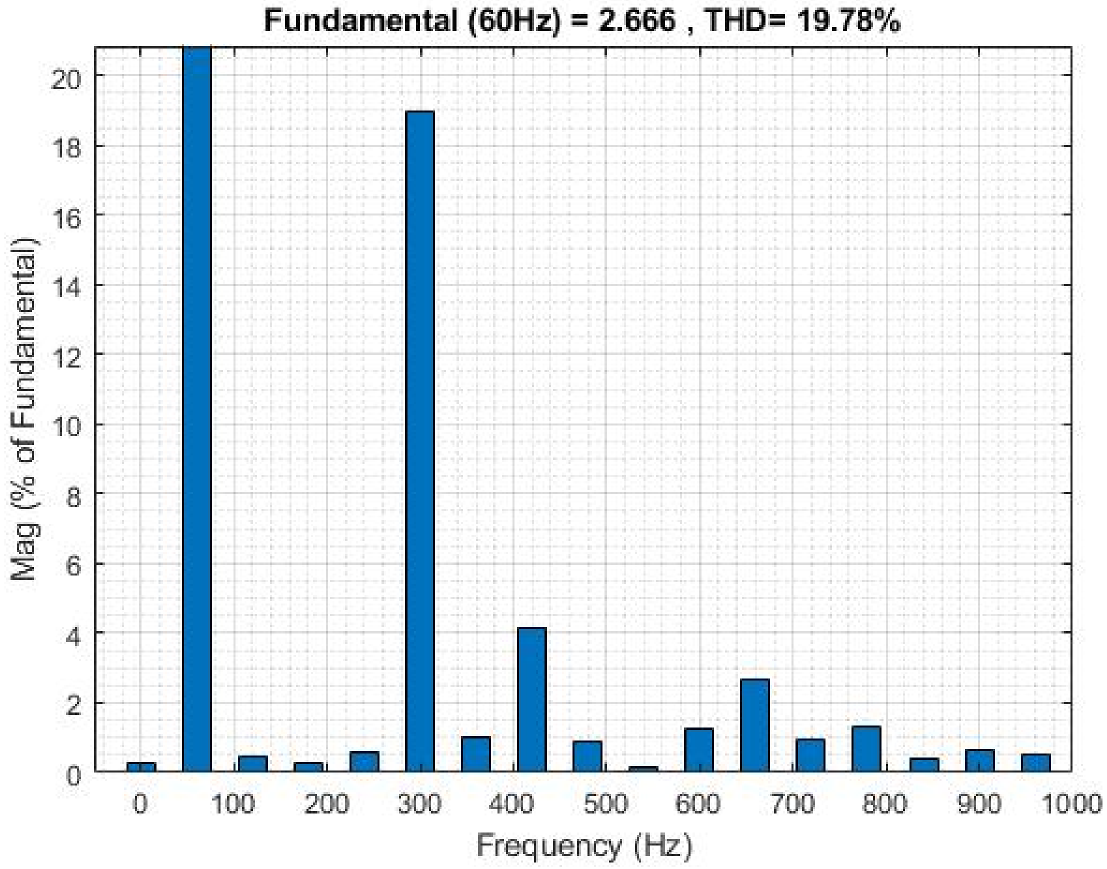

Fig.12: Total Harmonic Distortion of Space Vector Modulation

iii. Efficiency

The Efficiency of the converter is calculated as shown below through the simulation of Output and Input power. Power measurements of Sinusoidal Pulse Width Modulation are shown below. Input Power is 1500 Watts and Output Power is 1050 Watts, therefore the efficiency is 70%.

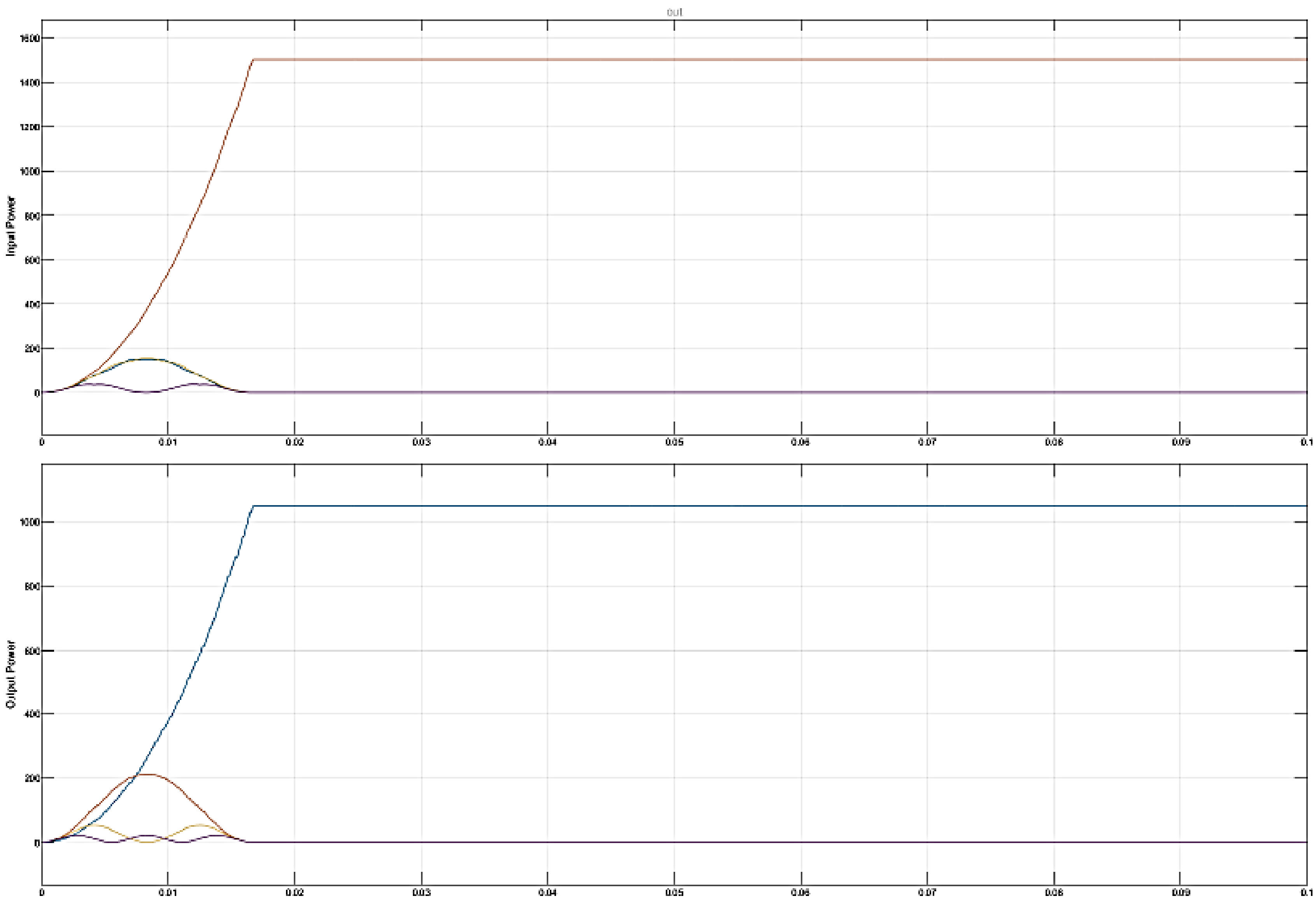

Fig.13 Power Measurements of Sinusoidal Pulse Width Modulation

Power measurements of the Hysteresis Band Current Control method are shown below. From the Simulation, Input Power is 1150 Watts and Output Power is 860 Watts, therefore the efficiency is 74.78%.

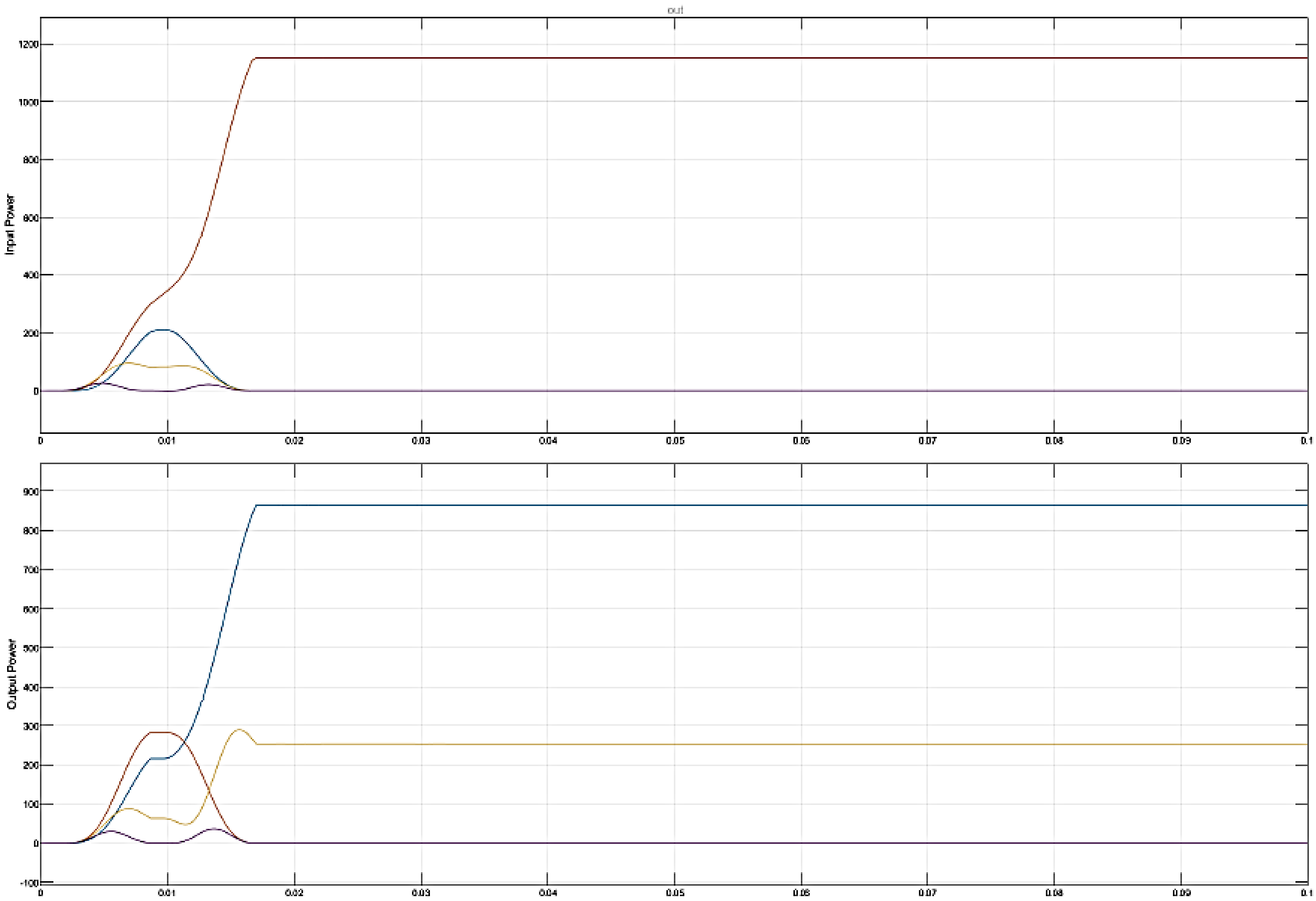

Fig.14: Power Measurements of Hysteresis Band Current Control

Power measurements of the Space Vector Modulation method are shown below. From the Simulation, Input Power is 625 Watts and Output Power is 360 Watts, therefore the efficiency is 57.6%.

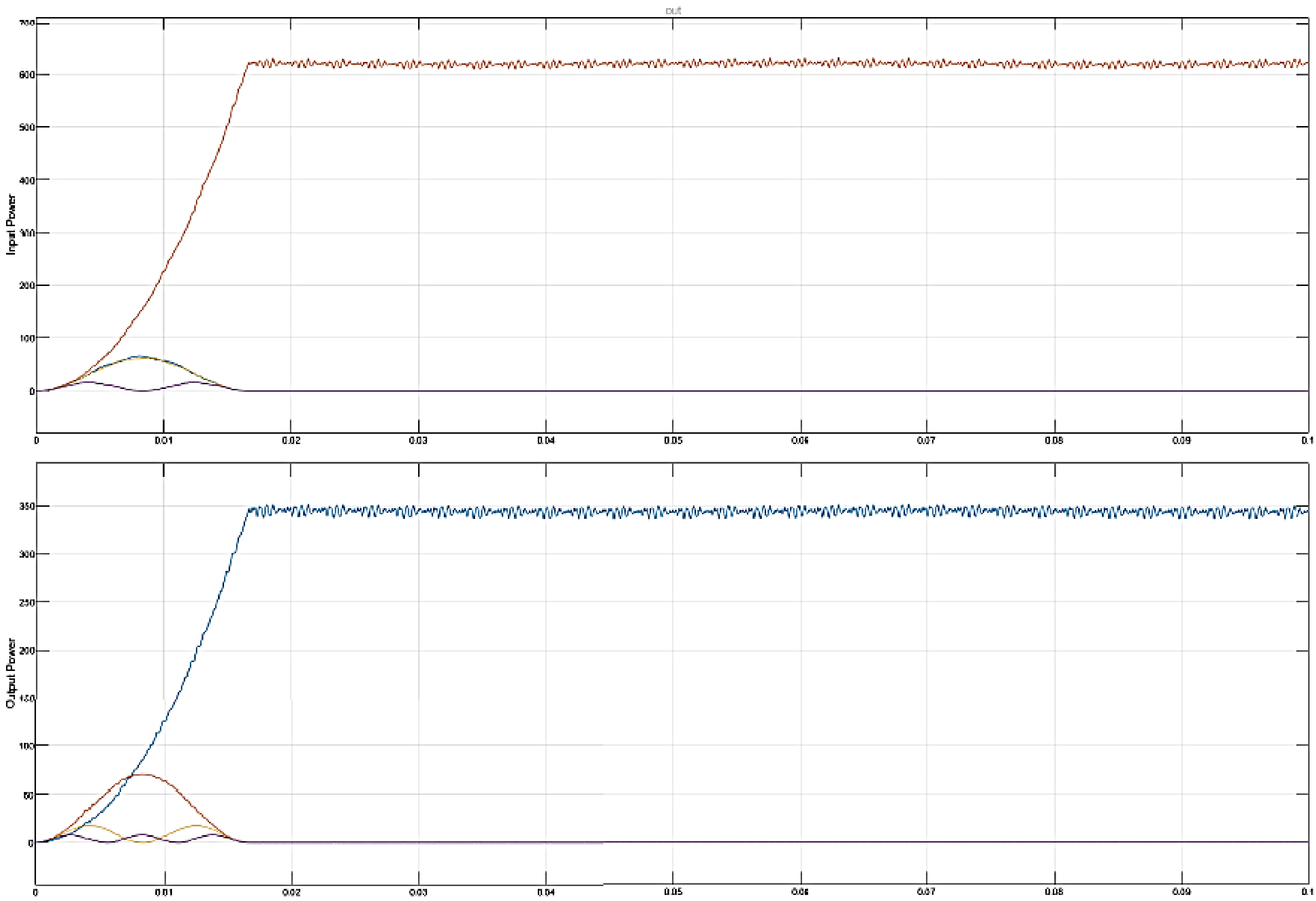

Fig.15: Power Measurements of Space Vector Modulation

iv. Results Summary

S. No	Switching Technique	Output DC Voltage (V)	THD of Input Current (%)	Efficiency (%)
1	Sinusoidal Pulse Width Modulation	350	27.67	70
2	Hysteresis Band Current Control	375	10.17	74.78
3	Space Vector Modulation	375	19.78	57.6

As shown in the Simulink Platform results, HBCC based three-phase rectifier has high efficiency of 74.78% and low Total Harmonic Distortion of 10.17%. Despite the complex construction of Space Vector Modulation switching technique, this switching method has less efficiency in the Simulink environment, whereas the Sinusoidal Pulse Width Modulation has high efficiency of 74.78%. These switching techniques have got real-time industrial applications. In this project, the result of different switching techniques has been analysed for same 3 phase rectifier Simulink model. The inference of the comparison is listed below.

i. The output DC voltages are almost the same among all the switching techniques, but the waveforms differ because of different switching patterns.

ii. The Total Harmonic Distortion is high in Space Vector Modulation and Sinusoidal Pulse Width Modulation techniques rather than Hysteresis Band Current Control due to the impact of first and fifth-order harmonics.

iii. However, the Hysteresis Band Current Control method has the highest efficiency among the three switching techniques, whereas the Space Vector Modulation remains as the low efficient switching technique.

6. Conclusion

In this Project, a Simulink model of a Three-phase Rectifier has been operated with various switching techniques such as Sinusoidal Pulse Width Modulation, Hysteresis Band Current Controller and Space Vector Modulation. Furthermore, the performance of the Simulink model with various switching techniques is analysed in terms of Output DC Voltage, Total Harmonic Distortion of Input Current and Efficiency of the Converter. The operation of the Model is simulated, and various waveform patterns are observed and documented in this project. Moreover, the simulation results are discussed and compared among the various switching techniques. Ultimately, the Hysteresis Band Current Controller is identified as a most reliable switching technique after considering the aspects of Output DC Voltage, Total Harmonic Distortion of Input Current and Efficiency.