EE605 Simulation Laboratory

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in

Electrical and Electronic Engineering

Submitted by

Raj Naik Dhulapkar (20EEE1023)

Under the Supervision of
Dr. C.Vyjayanthi
Associate Professor

Department of Electrical and Electronics Engineering
National Institute of Technology Goa

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National Institute of Technology Goa

Farmagudi, Ponda, Goa 403401

Department of Electrical and Electronics Engineering

CERTIFICATE

This is to certify that Mr. Sanket Bhat bearing Roll. No. 20EEE1027, has submitted the **Laboratory Report** as a part of the Laboratory Course, "**Basic Electrical Science Lab (EE152)**" in the academic year 2020-2021 at the Institution of **National Institute of Technology Goa**.

(Course Instructor)
Department of EEE
NIT Goa

MARKSHEET

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Experiment 1

Half Wave Rectifier

1.1 Aim

Single Phase Half Wave Uncontrolled and Controlled Rectifier

1.2 Software Used

MATLAB R2020a

1.3 Theory

In a half wave rectifier circuit, the diode is placed in series with the load. When the AC voltage is positive, the diode is forward biased and conducts, allowing the current to flow through the load in the forward direction. During the negative half cycle, the diode becomes reverse biased and blocks the current flow. As a result, the load receives pulsating DC voltage with only one polarity. The output voltage of the half wave rectifier is not continuous and has a large amount of ripple. This circuit is used in low-power applications where cost and simplicity are important factors.

1.4 Theoretical Calculations

The theoretical calculations for a half-wave rectifier with an R load are given by the formulas:

$$V_{o,avg} = V_{phase}\sqrt{2(1 + cos\alpha)2\pi} = V_m(1 + cos\alpha)2\pi$$

$$I_{o,avg} = V_o R$$

In uncontrolled rectifiers, $\alpha = 0$, and the thyristor is replaced with a diode. For a single-phase half-wave uncontrolled rectifier with an RMS voltage of 230V and a resistive load of 10Ω, the output voltage is 103.53V, and the output current is 10.53A.

For a single-phase half-wave controlled rectifier with an RMS voltage of 230V and a resistive load of 10Ω and a firing angle of $\alpha = 30$∘, the output voltage is 96.6V, and the output current is 9.66A.

1.5 Single Phase Half Wave Uncontrolled Rectifier with R load

1.5.1 Circuit used for simulation

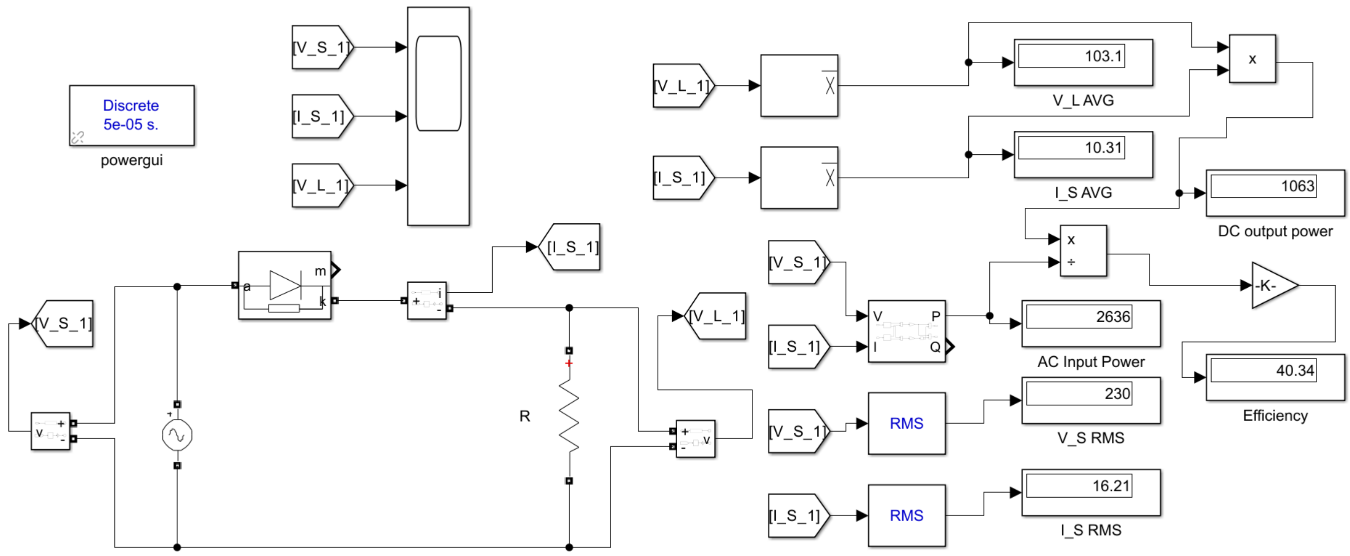


Figure 1.1: Circuit for Single Phase Half Wave Uncontrolled Rectifier with R load

1.5.2 Components Required

Sr. No	Parameters	Ratings	Quantity
1	AC Single Phase Voltage Source	230V (V_{rms})	1
2	Resistor	10Ω	1
3	Diode	-	1
4	Voltmeter	-	2
5	Ammeter	-	1

Table 1.1: Components for Single Phase Half Wave Uncontrolled Rectifier with R load

1.5.3 Observations

The simulated values closely match the theoretical values, indicating that the circuit is functioning correctly. Since the load is resistive, the output current is in phase with the output voltage. The output voltage and current waveforms indicate that the diode is forward-biased during the positive half-cycle of the AC source.

we obtain an efficiency of 40.34%

Parameters	Theoretical Values	Simulation Values
AC Input Voltage ($V_{in,rms}$)	230V	230V
Output Average Voltage ($V_{o,avg}$)	103.53V	103.1V
Output Average Current ($I_{o,avg}$)	10.35A	10.31A
AC Input Power (P_{AC})	2389.5 W	2636 W
DC Input Power (P_{DC})	1071.53 W	1063 W
Efficiency (%)	44.84	40.34

Table 1.2: Observations for Single Phase Half Wave Uncontrolled Rectifier with R load

1.5.4 Resultant Waveforms

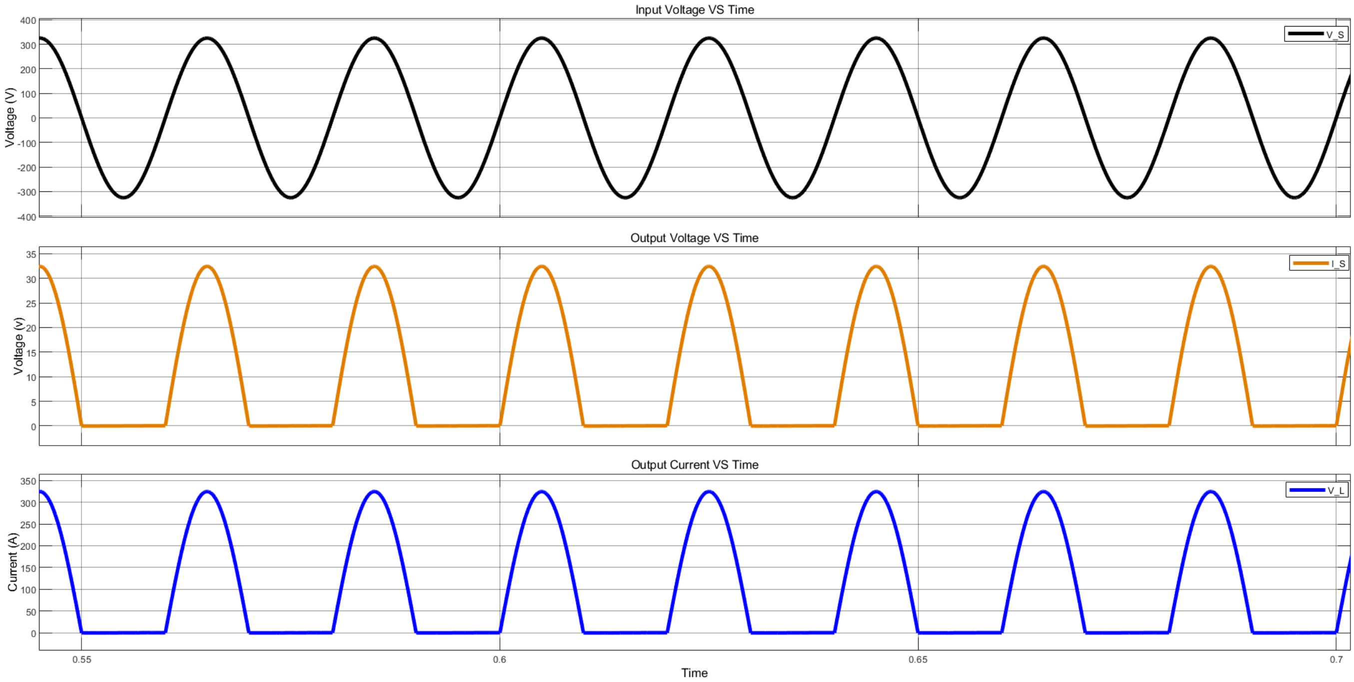


Figure 1.2: Scope Waveforms for Single Phase Half Wave Uncontrolled Rectifier with R load waveforms

1.6 Single Phase Half Wave Uncontrolled Rectifier with RL load

1.6.1 Circuit used for simulation

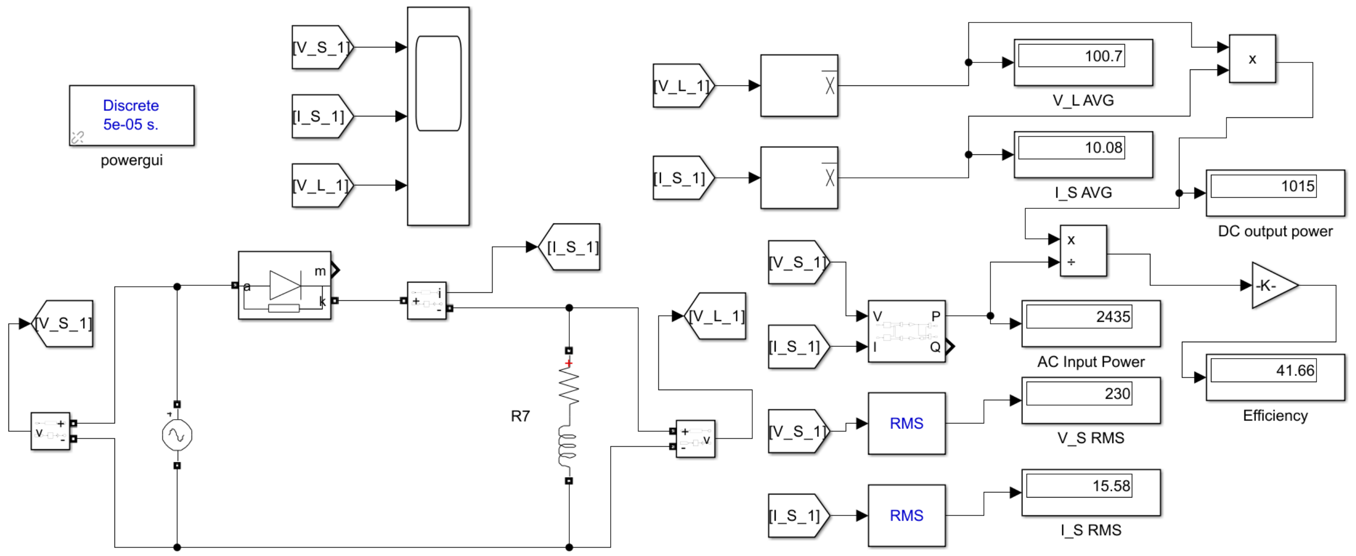


Figure 1.3: Circuit for Single Phase Half Wave Uncontrolled Rectifier with RL load

1.6.2 Components Required

Sr. No	Parameters	Ratings	Quantity
1	AC Single Phase Voltage Source	230V (V_{rms})	1
2	Resistor	10Ω	1
3	Inductor	10mH	1
4	Diode	-	1
5	Voltmeter	-	2
6	Ammeter	-	1

Table 1.3: Components for Single Phase Half Wave Uncontrolled Rectifier with RL load

1.6.3 Observations

The simulated values closely match the theoretical values, which is a positive sign. However, because the load in the circuit has an inductive component, the output current lags behind the output voltage. This lag causes the diode to conduct until the output current reaches zero, which results in the output voltage becoming negative during this period. Once the output current reaches zero, the diode stops conducting, and the output voltage returns to zero. The efficiency of uncontrolled rectifier with RL load is 41.66%.

Parameters	Theoretical Values	Simulation Values
AC Input Voltage ($V_{in,rms}$)	230V	230V
Output Average Voltage ($V_{o,avg}$)	103.53V	100.7V
Output Average Current ($I_{o,avg}$)	10.35A	10.08A
AC Input Power (P_{AC})	2389.5 (W)	2435 (W)
DC Input Power (P_{DC})	1071.53 (W)	1015 (W)
Efficiency (%)	44.84	41.66

Table 1.4: Observations for Single Phase Half Wave Uncontrolled Rectifier with RL load

1.6.4 Resultant Waveforms

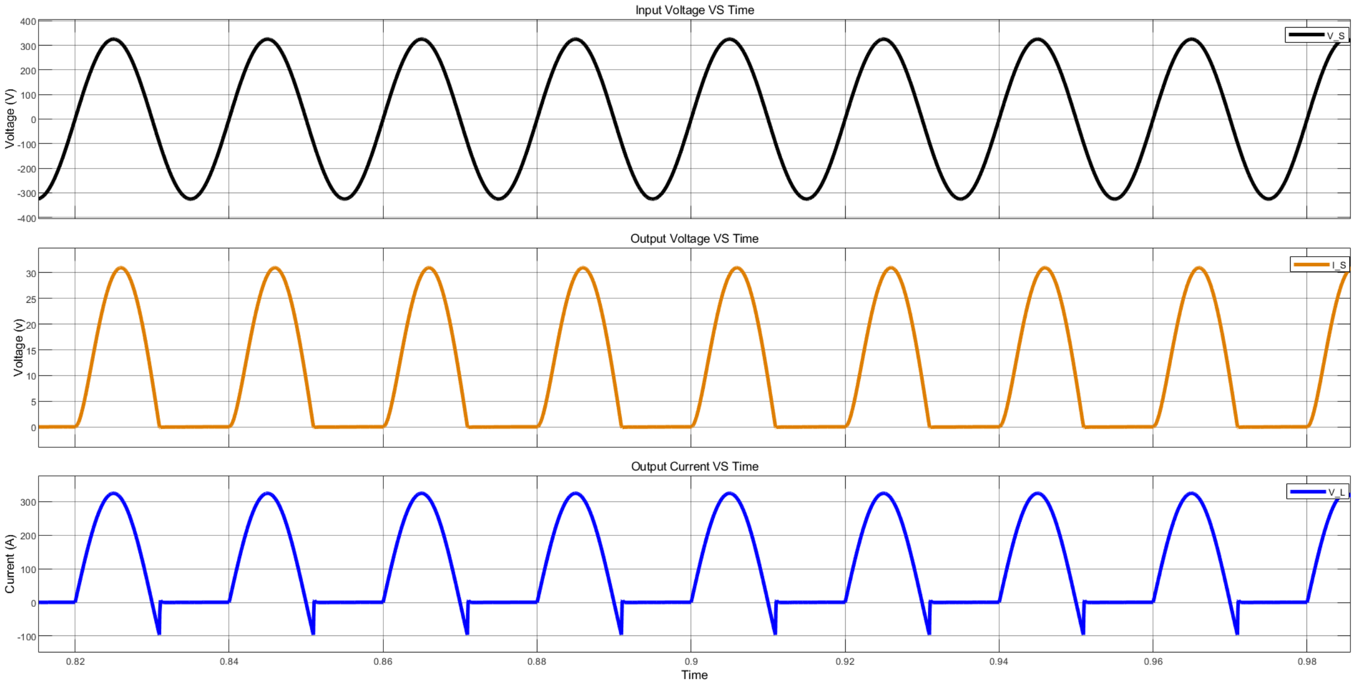


Figure 1.4: Scope Waveforms for Single Phase Half Wave Uncontrolled Rectifier with RL load

1.7 Single Phase Half Wave Uncontrolled Rectifier with RL load and Freewheeling Diode

1.7.1 Circuit used for simulation

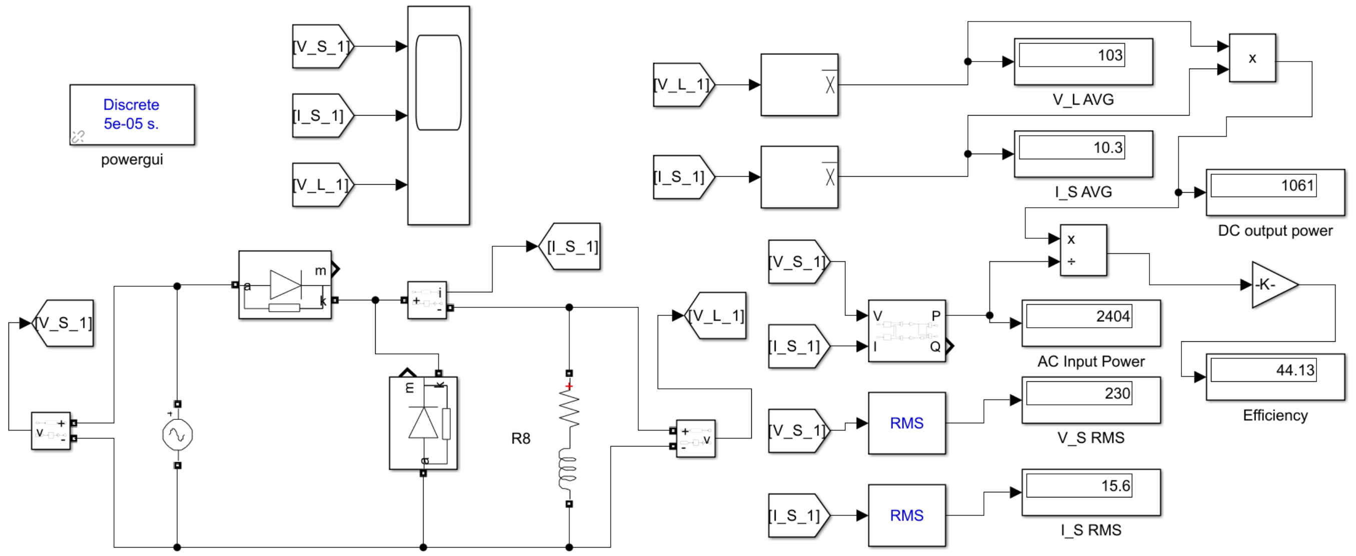


Figure 1.5: Circuit for Single Phase Half Wave Uncontrolled Rectifier with RL load and Freewheeling Diode

1.7.2 Components Required

Sr. No	Parameters	Ratings	Quantity
1	AC Single Phase Voltage Source	230V (V_{rms})	1
2	Resistor	10Ω	1
3	Inductor	10mH	1
4	Diode	-	1
5	Voltmeter	-	2
6	Ammeter	-	1

Table 1.5: Components for Single Phase Half Wave Uncontrolled Rectifier with RL load and Freewheeling Diode

1.7.3 Observations

Upon observation, it can be noted that the simulated output voltage is closer to the calculated voltage, whereas the simulated output current deviates further from the calculated current. Additionally, the inclusion of the freewheeling diode results in an abrupt cutoff of output current in the rectifier circuit as the AC source supply reaches zero volts, as the lagging current begins to flow through the freewheeling diode instead of the rectifier circuit. The efficiency of uncontrolled rectifier with RL load with freewheeling diode is 44.13%.

Parameters	Theoretical Values	Simulation Values
AC Input Voltage ($V_{in,rms}$)	230V	230V
Output Average Voltage ($V_{o,avg}$)	103.53V	103V
Output Average Current ($I_{o,avg}$)	10.35A	10.3A
AC Input Power (P_{AC})	2389.5 (W)	2404 (W)
DC Input Power (P_{DC})	1071.53 (W)	1061 (W)
Efficiency (%)	44.84	44.13

Table 1.6: Observations for Single Phase Half Wave Uncontrolled Rectifier with RL load and Freewheeling Diode

1.7.4 Resultant Waveforms

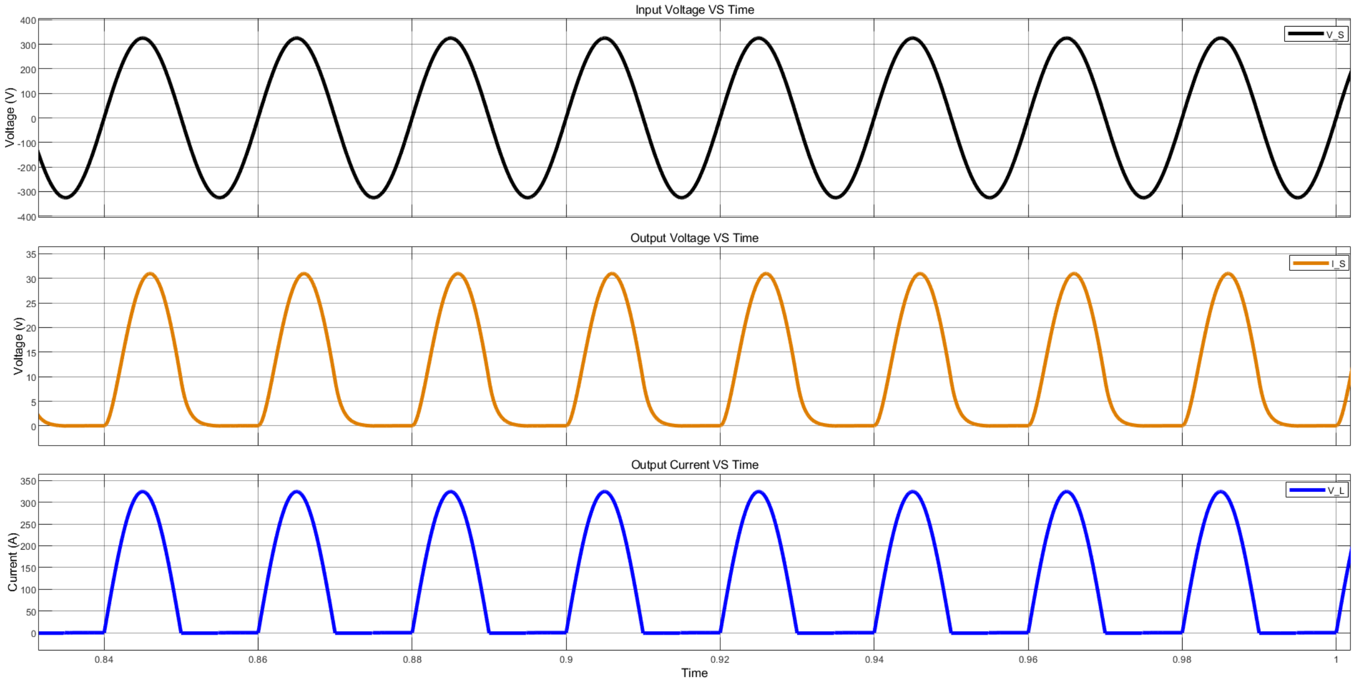


Figure 1.6: Scope Waveforms for Single Phase Half Wave Uncontrolled Rectifier with RL load and Freewheeling Diode

1.8 Single Phase Half Wave Uncontrolled Rectifier with RLE load

1.8.1 Circuit used for simulation

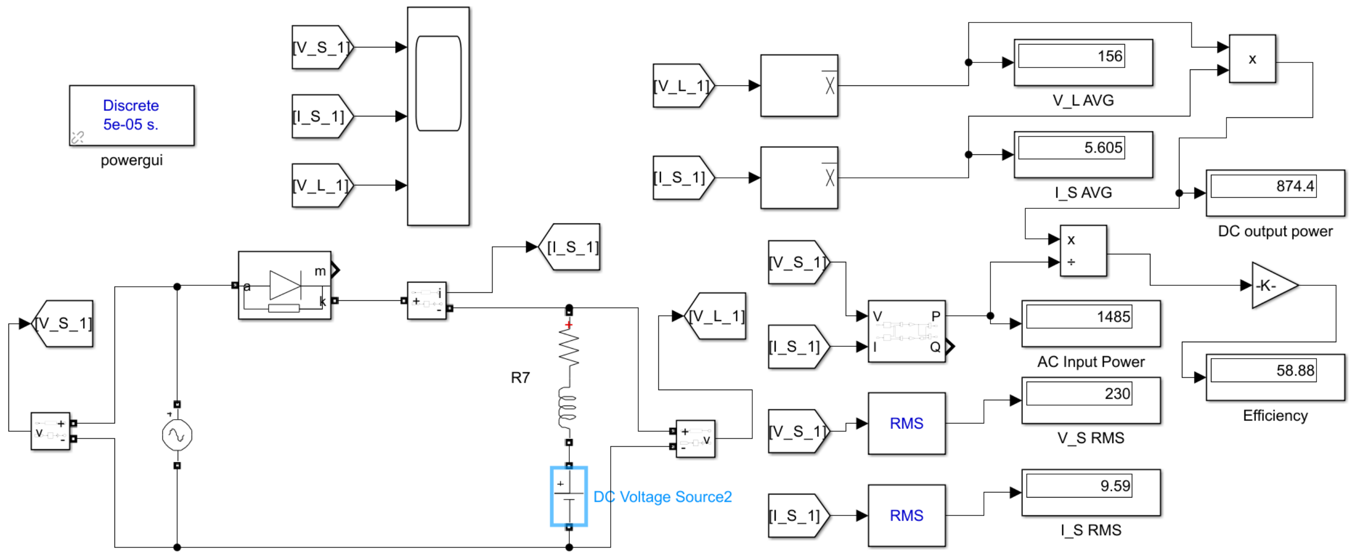


Figure 1.7: Circuit for Single Phase Half Wave Uncontrolled Rectifier with RLE load

1.8.2 Components Required

Sr. No	Parameters	Ratings	Quantity
1	AC Single Phase Voltage Source	230V (V_{rms})	1
2	Resistor	10Ω	1
3	Inductor	10mH	1
4	Diode	-	1
5	DC Source	100V	1
6	Voltmeter	-	2
7	Ammeter	-	1

Table 1.7: Components for Single Phase Half Wave Uncontrolled Rectifier with RLE load

1.8.3 Observations

The output voltage waveform for the RL load is sinusoidal, and the rectifier's output voltage waveform is also sinusoidal but with a positive DC offset. The difference in the output waveform is due to the rectifier's ability to convert the negative half cycle of the input waveform into a positive voltage. When the output current falls to zero, the diode stops conducting, and the output voltage remains at a constant level of 100V, which is equal to the peak value of the input AC voltage. The efficiency of uncontrolled rectifier with RLE load is 58.88%.

Parameters	Theoretical Values	Simulation Values
AC Input Voltage ($V_{in,rms}$)	230V	230V
Output Average Voltage ($V_{o,avg}$)	149V	156V
Output Average Current ($I_{o,avg}$)	5.8A	5.605A
AC Input Power (P_{AC})	2389.5 (W)	1485 (W)
DC Input Power (P_{DC})	1071.53 (W)	874.4 (W)
Efficiency (%)	44.84	58.88

Table 1.8: Observations for Single Phase Half Wave Uncontrolled Rectifier with RLE load

1.8.4 Resultant Waveforms

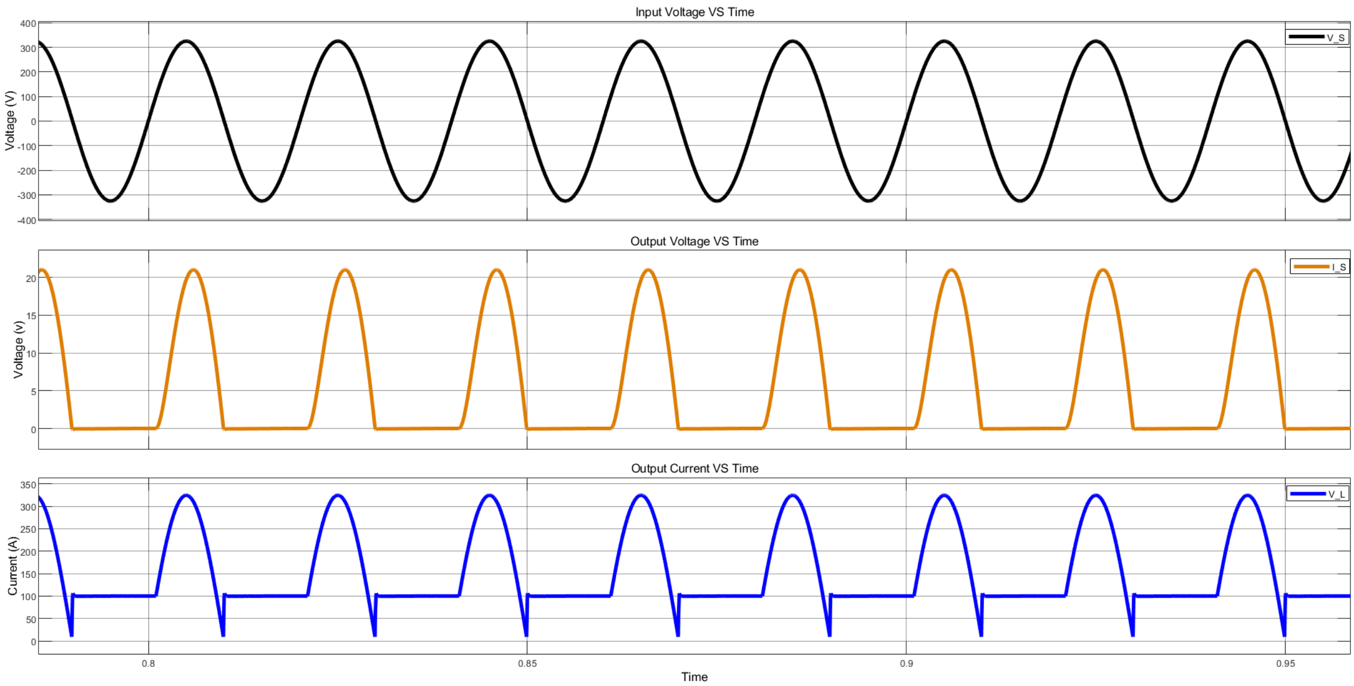


Figure 1.8: Scope Waveforms for Single Phase Half Wave Uncontrolled Rectifier with RLE load waveforms

1.9 Single Phase Half Wave Controlled Rectifier with R load

1.9.1 Circuit used for simulation

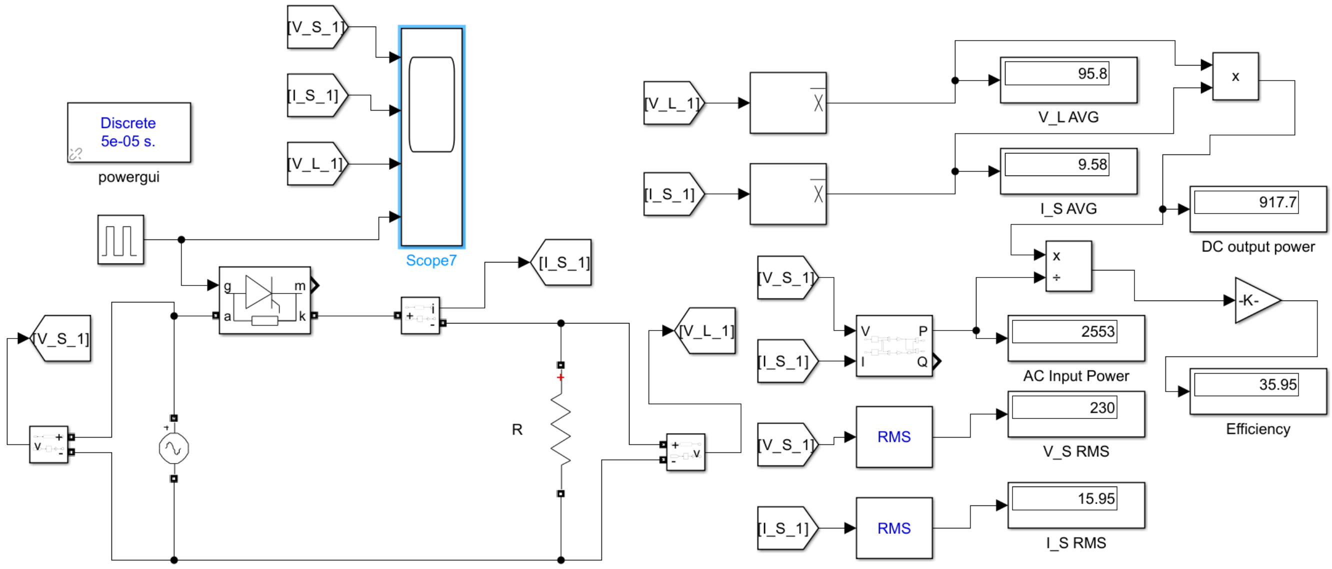


Figure 1.9: Circuit for Single Phase Half Wave Controlled Rectifier with R load (Firing Angle = 30°)

1.9.2 Components Required

Sr. No	Parameters	Ratings	Quantity
1	AC Single Phase Voltage Source	230V (V_{rms})	1
2	Resistor	10Ω	1
3	Inductor	10mH	1
4	Diode	-	1
5	Voltmeter	-	2
6	Ammeter	-	1
7	Thyristor	-	1

Table 1.9: Components for Single Phase Half Wave Controlled Rectifier with R load

1.9.3 Observations

The simulated values match the theoretical values accurately, indicating that the rectifier is functioning as expected. As the load is purely resistive, the output current is in phase with the output voltage. The rectifier circuit is uncontrolled, and the output voltage follows the shape of the input voltage, except that it is always positive.

The efficiency of controlled rectifier with R load is 35.95%.

Parameters	Theoretical Values	Simulation Values
AC Input Voltage ($V_{in,rms}$)	230V	230V
Output Average Voltage ($V_{o,avg}$)	96.6V	95.8V
Output Average Current ($I_{o,avg}$)	9.66A	9.58A
AC Input Power (P_{AC})	2214.44 (W)	25534 (W)
DC Input Power (P_{DC})	926.98 (W)	917.7 (W)
Efficiency (%)	41.86	35.95

Table 1.10: Observations for Single Phase Half Wave Controlled Rectifier with R load

1.9.4 Resultant Waveforms

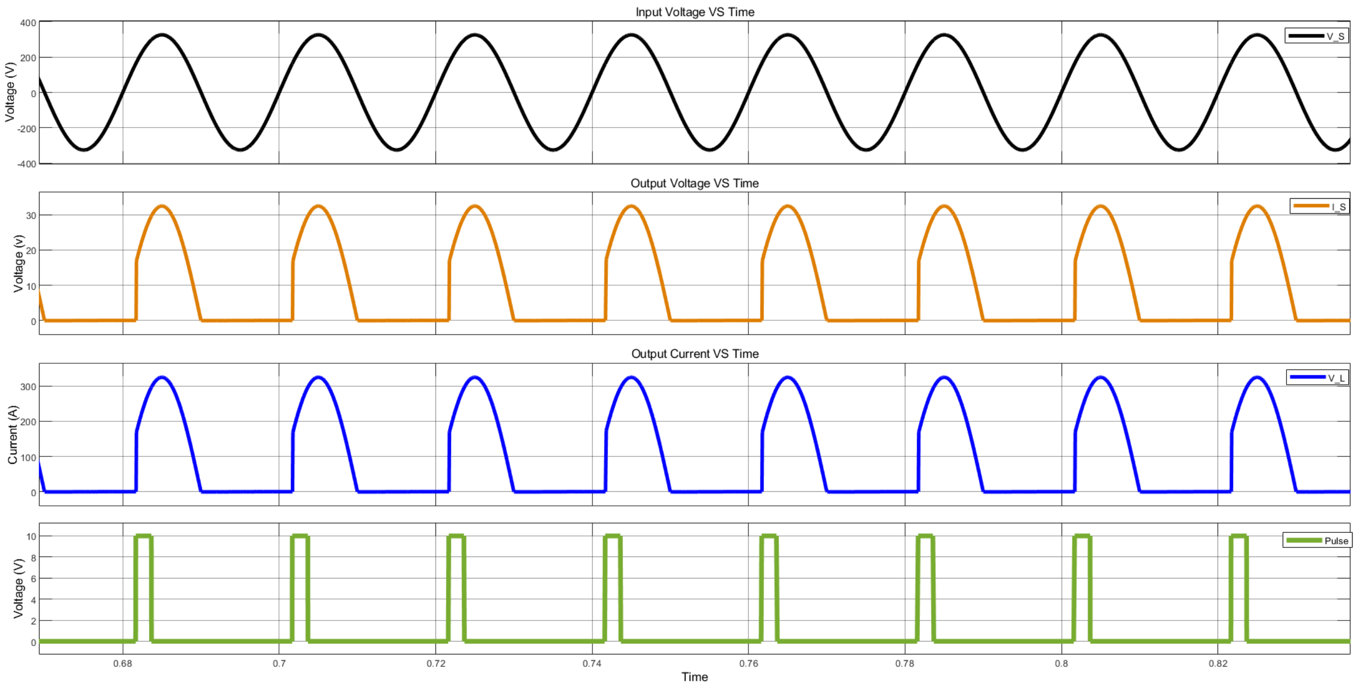


Figure 1.10: Scope Waveforms for Single Phase Half Wave Controlled Rectifier with R load

1.10 Single Phase Half Wave Controlled Rectifier with RL load

1.10.1 Circuit used for simulation

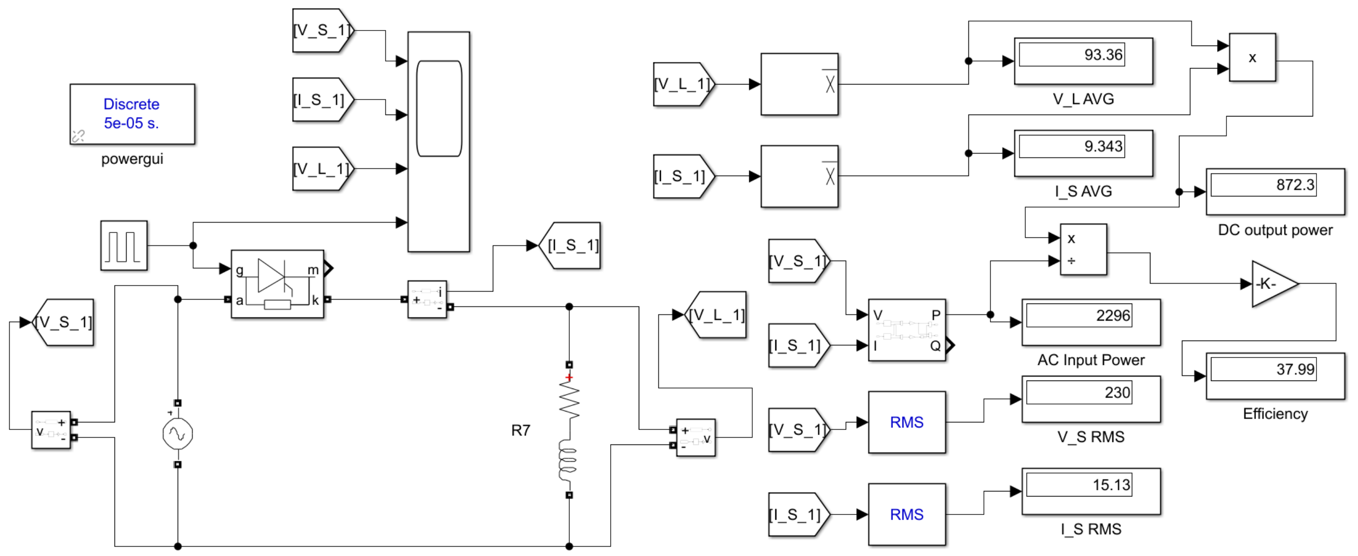


Figure 1.11: Circuit for Single Phase Half Wave Controlled Rectifier with RL load (Firing Angle = 30°)

1.10.2 Components Required

Sr. No	Parameters	Ratings	Quantity
1	AC Single Phase Voltage Source	230V (V_{rms})	1
2	Resistor	10Ω	1
3	Inductor	10mH	1
4	Diode	-	1
5	Voltmeter	-	2
6	Ammeter	-	1
7	Thyristor	-	1

Table 1.11: Components for Single Phase Half Wave Controlled Rectifier with RL load

1.10.3 Observations

Upon giving a firing gate pulse to the thyristor, the circuit starts conducting. As the load has an inductive component, the output current lags the output voltage. This causes the diode to conduct until the output current reaches zero, which results in the output voltage becoming negative during this time period. Once the output current becomes zero, the thyristor stops conducting and the output voltage also returns to zero. This operation is known as a half-wave uncontrolled rectifier. The efficiency of controlled rectifier with RL load is 37.99%.

1.10.4 Resultant Waveforms

Parameters	Theoretical Values	Simulation Values
AC Input Voltage ($V_{in,rms}$)	230V	230V
Output Average Voltage ($V_{o,avg}$)	96.6V	93.36V
Output Average Current ($I_{o,avg}$)	9.66A	9.343A
AC Input Power (P_{AC})	2214.44 (W)	2296 (W)
DC Input Power (P_{DC})	926.98 (W)	872.3 (W)
Efficiency (%)	41.86	37.99

Table 1.12: Observations for Single Phase Half Wave Controlled Rectifier with RL load

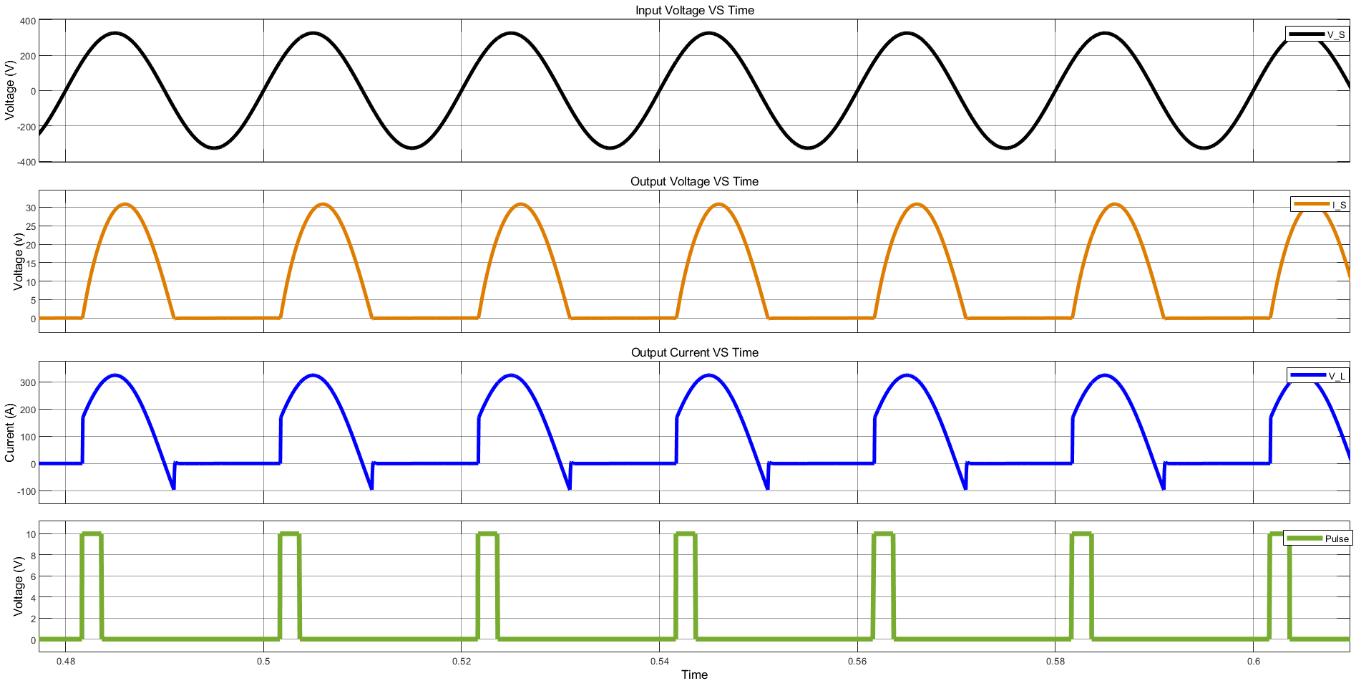


Figure 1.12: Scope Waveforms for Single Phase Half Wave Controlled Rectifier with RL load

1.11 Single Phase Half Wave Controlled Rectifier with RLE load

1.11.1 Circuit used for simulation

1.11.2 Components Required

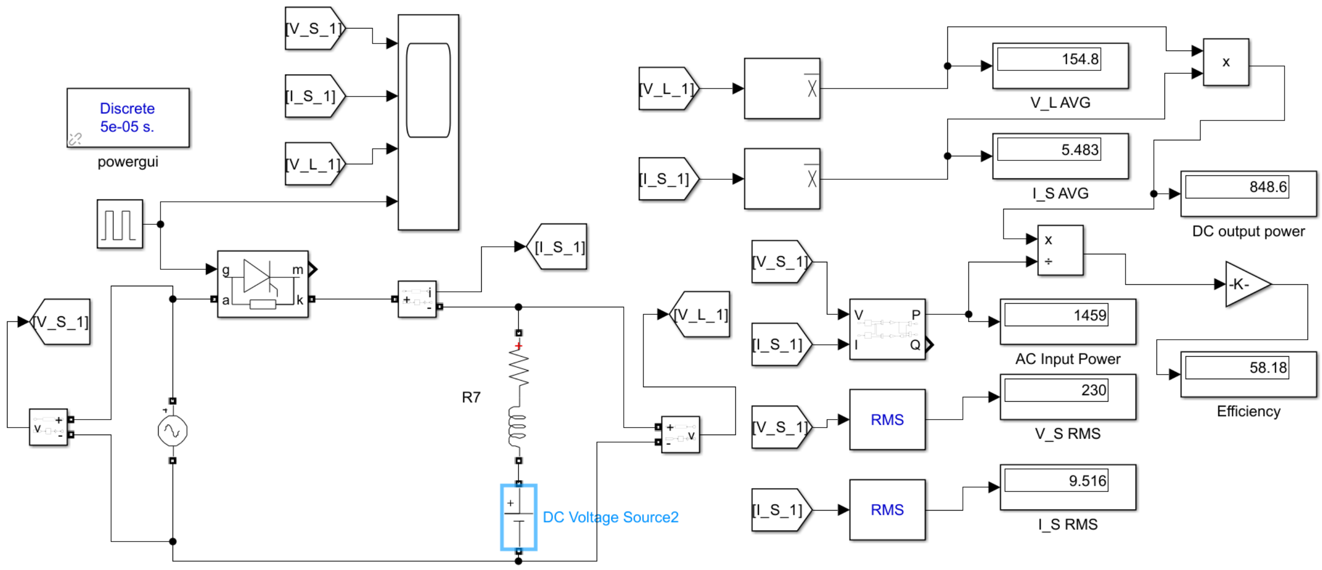


Figure 1.13: Circuit for Single Phase Half Wave Controlled Rectifier with RLE load (Firing Angle = 30°)

Sr. No	Parameters	Ratings	Quantity
1	AC Single Phase Voltage Source	230V (V_{rms})	1
2	Resistor	10Ω	1
3	Inductor	10mH	1
4	Diode	-	1
5	Voltmeter	-	2
6	Ammeter	-	1
7	Thyristor	-	1
8	DC Source	100V	1

Table 1.13: Components for Single Phase Half Wave Controlled Rectifier with RLE load

1.11.3 Observations

It is observed that the circuit starts conducting only after a firing gate pulse is given to the thyristor. Upon triggering, the circuit mimics the characteristics of an uncontrolled half wave rectifier with RLE load. The output voltage waveform follows the same waveform shape as the RLE load, and the output current lags the output voltage due to the inductive component of the load. The efficiency of controlled rectifier with RL load is 58.18%.

1.11.4 Resultant Waveforms

Parameters	Theoretical Values	Simulation Values
AC Input Voltage ($V_{in,rms}$)	230V	230V
Output Average Voltage ($V_{o,avg}$)	96.66V	154.8V
Output Average Current ($I_{o,avg}$)	9.66A	5.483A
AC Input Power (P_{AC})	2214.44 (W)	1459 (W)
DC Input Power (P_{DC})	926.98 (W)	848.6 (W)
Efficiency (%)	41.86	58.18

Table 1.14: Observations for Single Phase Half Wave Controlled Rectifier with RLE load

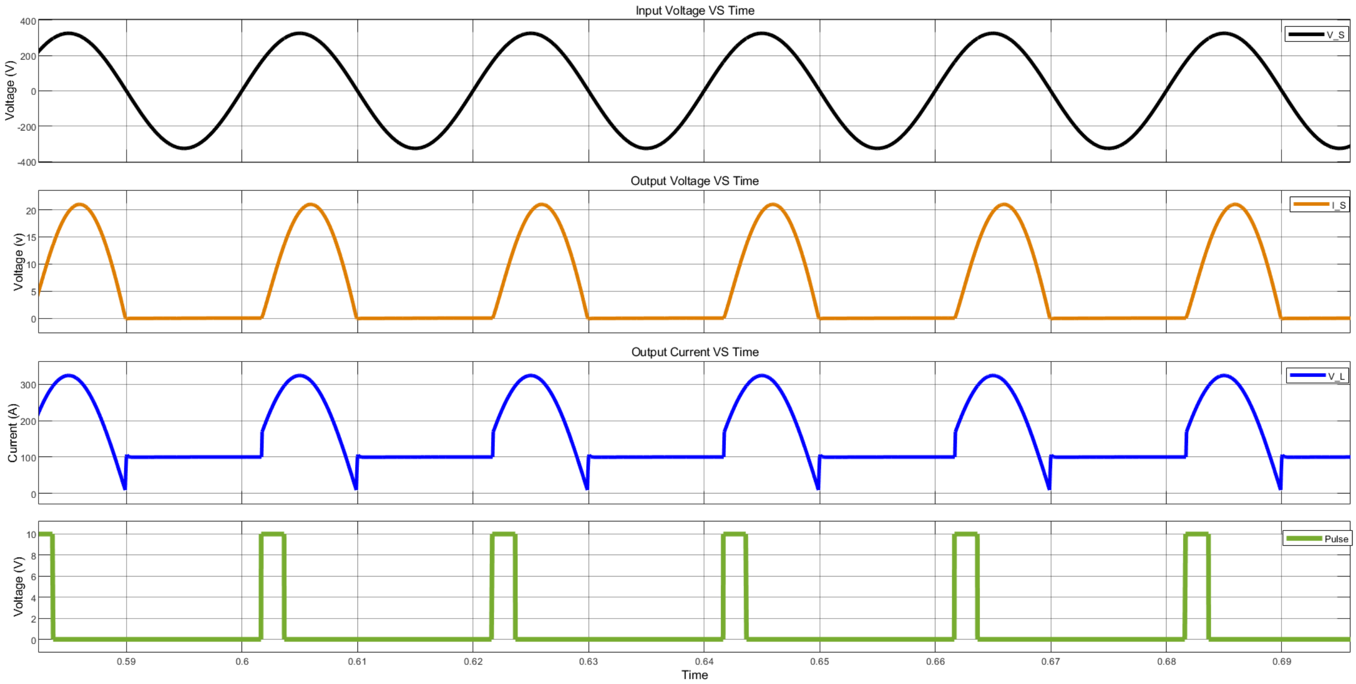


Figure 1.14: Scope Waveforms for Single Phase Half Wave Controlled Rectifier with RLE load

1.12 Conclusion

In this experiment, the implementation of single-phase half-wave rectifiers, both controlled and uncontrolled, with resistive, inductive, resistive-inductive and resistive-inductive with freewheeling diode loads were successfully accomplished using MATLAB's Simulink. The output waveforms for voltage and current were obtained in each case, and a comparative analysis between theoretically calculated and simulated output parameters was also performed.

Efficiency measurements were conducted on the half-wave uncontrolled rectifiers with R load, RL load, RL load with freewheeling diode, and RLE load, yielding efficiency values of 40.34%, 41.66%, 44.13%, and 58.88%, respectively. Thus, it can be concluded that the half-wave uncontrolled rectifier with RLE load has the maximum efficiency of 58.88%. Similarly, the efficiency values of half-wave controlled rectifiers with R load, RL load, and RLE load were measured as 35.95%, 37.99% and 58.18% respectively. Thus, the half-wave controlled rectifier with RLE load has the maximum efficiency of 58.18%.

Overall, the simulation results provided a clear indication of the efficiency of each type of rectifier with different loads. These results can be used as a guide to select the appropriate type of rectifier for a specific load in real-world applications. The implementation of these rectifiers has great practical significance in power electronics and can be used in a variety of applications, such as power supplies, motor drives, and lighting systems.

Experiment 2

Full Wave Rectifier

2.1 Aim

To design and implement Single Phase Full Wave Uncontrolled and Controlled rectifiers, and simulate them with R and RL loads.

2.2 Software Used

MATLAB R2020a

2.3 Theory

A full-wave rectifier is an electronic circuit that converts an alternating current (AC) input signal into a unidirectional pulsating direct current (DC) output signal. It is a rectifier that uses both halves of the input sinusoidal waveform. It is essentially two half-wave rectifiers connected together to feed the load. The rectification is done by passing the positive half of the waveform while inverting the negative half of the sine wave. This results in a pulsating DC output. However, the output does not reverse direction, as it uses the full 100

The full-wave rectifier is a more efficient rectifier compared to the half-wave rectifier because it produces a smoother DC output. Additionally, it has a higher output voltage and lower output ripple than a half-wave rectifier.

In a single-phase full-wave rectifier, four diodes are used in a bridge configuration to rectify the AC input signal. The input AC voltage is applied across the two AC input terminals of the rectifier, and the output voltage is taken from the two DC output terminals. The four diodes are connected in such a way that the input voltage is rectified, producing a DC output voltage across the output terminals.

The four diodes used in the bridge rectifier are arranged in a way such that when the AC input voltage is positive, diodes D1 and D3 are forward-biased and conduct, while diodes D2 and D4 are reverse-biased and do not conduct. Conversely, when the AC input voltage is negative, diodes D2 and D4 are forward-biased and conduct, while diodes D1 and D3 are reverse-biased and do not conduct. This process of rectification occurs for each half-cycle of the AC input voltage, producing a unidirectional DC output signal.

2.4 Theoretical Calculations

In the theory of full-wave rectifiers, the average output voltage and current for controlled full-wave rectifiers with resistive (R) load can be calculated using the following equations:

$$V_0 = \frac{V_{phase}}{\sqrt{2}} \frac{(1 + \cos\alpha)}{\pi} \tag{2.1}$$

$$V_0 = \frac{V_m(1 + \cos\alpha)}{2\pi} \tag{2.2}$$

$$I_0 = \frac{V_0}{R} \tag{2.3}$$

where α is the thyristor's firing angle. It should be noted that in uncontrolled rectifiers, the thyristor is switched out for a diode and α is equal to 0.

For a single-phase full-wave uncontrolled rectifier, the average output voltage and current can be calculated as follows:

$$V_0 = 2\sqrt{2}V_{rms} \tag{2.4}$$

$$I_0 = 2I_{rms} \tag{2.5}$$

where V_{rms} is the root mean square value of the input voltage and I_{rms} is the root mean square value of the input current.

For a single-phase full-wave controlled rectifier, the average output voltage and current can be calculated as follows:

$$V_0 = \frac{2\sqrt{2}V_{rms}(1-\cos\alpha)}{\pi} \tag{2.6}$$

$$I_0 = \frac{2I_{rms}(1-\cos\alpha)}{\pi} \tag{2.7}$$

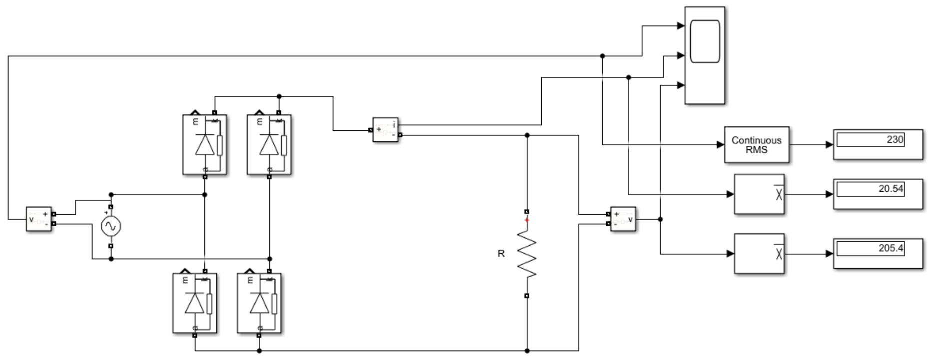
Consider an AC source with an RMS voltage of 230V and a resistive load of 10Ω. The output voltage and current for a single phase full-wave uncontrolled rectifier are given by:

$$V_0 = 207.07\text{V} \tag{2.8}$$

$$I_0 = 20.70\text{A} \tag{2.9}$$

2.5 Single Phase Full Wave Uncontrolled Rectifier with R load

2.5.1 Circuit used for simulation



Single Phase Full Wave Uncontrolled Rectifier with R load

Figure 2.1: Circuit used for simulation

2.5.2 Components Required

Sr. No	Parameters	Ratings	Quantity
1	AC Single Phase Voltage Source	230V (V_{rms})	1
2	Resistor	10Ω	1
3	Diode	-	1
4	Voltmeter	-	2
5	Ammeter	-	1

Table 2.1: Components for Single Phase Full Wave Uncontrolled Rectifier with R load

2.5.3 Observations

Parameters	Theoretical Values	Simulation Values
AC Input Voltage ($V_{in,rms}$)	230V	230V
Output Average Voltage ($V_{o,avg}$)	207.07V	205.4V
Output Average Current ($I_{o,avg}$)	20.70A	20.54V
DC Input Power (P_{DC})	4218.916W	4173W
Efficiency (%)	79.73	79.73

Table 2.2: Observations for Single Phase Full Wave Uncontrolled Rectifier with R load

Upon careful observation, it can be inferred that the simulated values exhibit a close resemblance to their theoretical counterparts. Given that the load is resistive, the output current waveform is found to be in phase with the output voltage waveform. Moreover, it is worth noting that as a result of full-wave rectification of the input AC signal, the output DC signal is characterized by a frequency that is double that of the input signal.

2.5.4 Resultant Waveforms

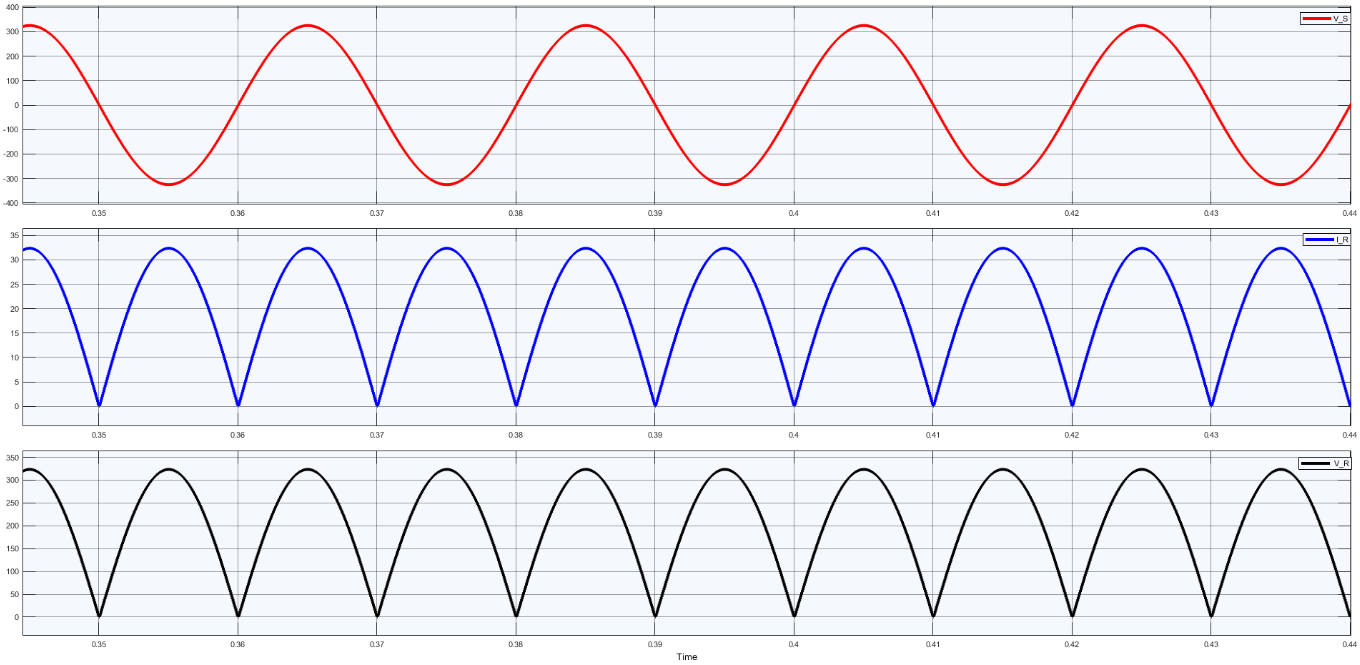
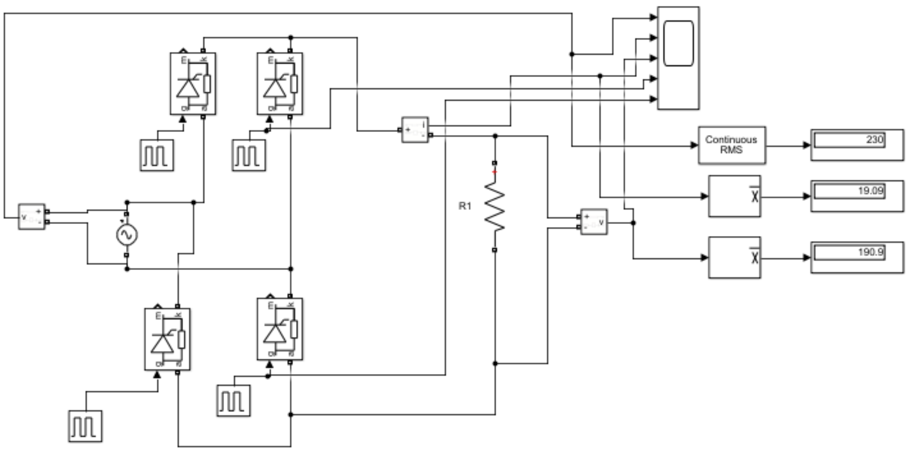


Figure 2.2: Scope Waveforms for Single Phase Full Wave Uncontrolled Rectifier with R load waveforms

2.6 Single Phase Full Wave Controlled Rectifier with R load

2.6.1 Circuit used for simulation



Single Phase Half Wave Uncontrolled Rectifier with RL load

Figure 2.3: Circuit used for simulation

2.6.2 Components Required

Sr. No	Parameters	Ratings	Quantity
1	AC Single Phase Voltage Source	230V (V_{rms})	1
2	Resistor	10Ω	1
3	Inductor	10mH	1
4	Diode	-	1
5	Voltmeter	-	2
6	Ammeter	-	1

Table 2.3: Components for Single Phase Half Wave Uncontrolled Rectifier with RL load

2.6.3 Observations

Upon observation, it is noted that the simulated values exhibit a level of conformity with the theoretical values. Due to the presence of an inductive component in the load, the output current lags behind the output voltage, resulting in a period during which the output voltage becomes negative while the diode conducts until the output current attains a value of zero. The diode then ceases to conduct, and both the output voltage and current return to zero. The efficiency of uncontrolled rectifier with RL load is 44.84%.

Parameters	Theoretical Values	Simulation Values
AC Input Voltage ($V_{in,rms}$)	230V	230V
Output Average Voltage ($V_{o,avg}$)	193.2V	190.9V
Output Average Current ($I_{o,avg}$)	19.32A	19.09A
AC Input Power (P_{AC})	2389.5 (W)	2318 (W)
DC Input Power (P_{DC})	1071.53 (W)	1017 (W)
Efficiency (%)	44.84	43.84

Table 2.4: Observations for Single Phase Half Wave Uncontrolled Rectifier with RL load

2.6.4 Resultant Waveforms

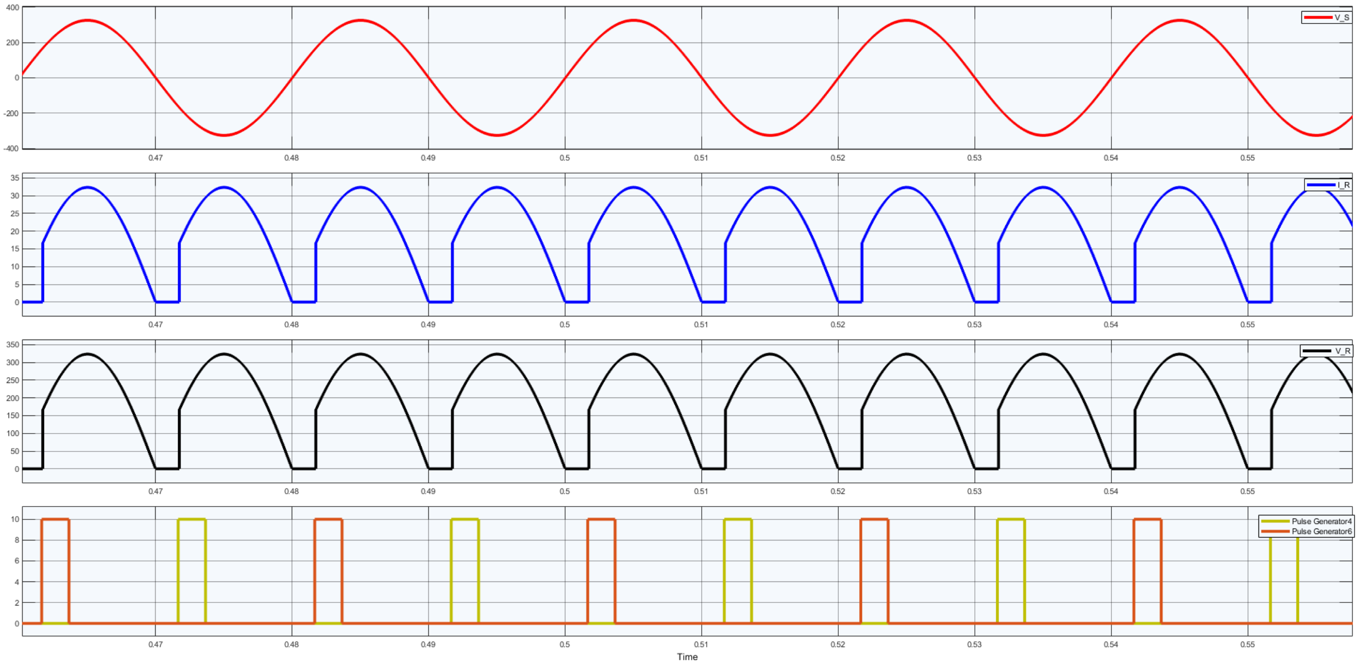


Figure 2.4: Scope Waveforms for Single Phase Half Wave Uncontrolled Rectifier with RL load

2.7 Single Phase Full Wave Controlled Rectifier with RL load

2.7.1 Circuit used for simulation

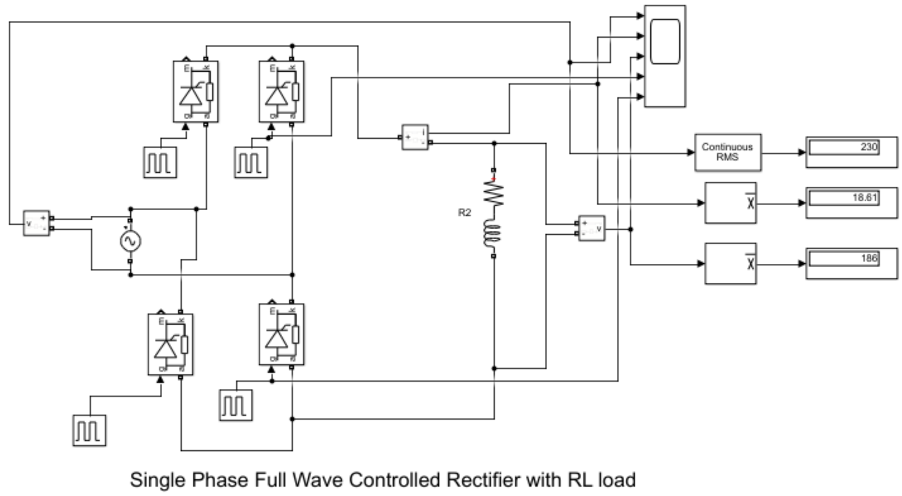


Figure 2.5: Circuit used for simulation

2.7.2 Components Required

Sr. No	Parameters	Ratings	Quantity
1	AC Single Phase Voltage Source	230V (V_{rms})	1
2	Resistor	10Ω	1
3	Inductor	10mH	1
4	Diode	-	1
5	Voltmeter	-	2
6	Ammeter	-	1

Table 2.5: Components for Single Phase Half Wave Uncontrolled Rectifier with RL load and Freewheeling Diode

2.7.3 Observations

Upon analysis, it has been observed that the simulated output voltage closely approximates the calculated voltage, whereas the simulated output current significantly deviates from the calculated current. The incorporation of the freewheeling diode results in a sudden cessation of output current in the rectifier circuit when the AC supply source drops to zero volts, as the lagging current shifts to flow through the freewheeling diode rather than the rectifier circuit. The efficiency of uncontrolled rectifier with RL load with freewheeling diode is 44.8%.

Parameters	Theoretical Values	Simulation Values
AC Input Voltage ($V_{in,rms}$)	230V	230V
Output Average Voltage ($V_{o,avg}$)	103.53V	103V
Output Average Current ($I_{o,avg}$)	10.35A	10.3A
AC Input Power (P_{AC})	2389.5 (W)	2266 (W)
DC Input Power (P_{DC})	1071.53 (W)	1015 (W)
Efficiency (%)	44.84	44.8

Table 2.6: Observations for Single Phase Half Wave Uncontrolled Rectifier with RL load and Freewheeling Diode

2.7.4 Resultant Waveforms

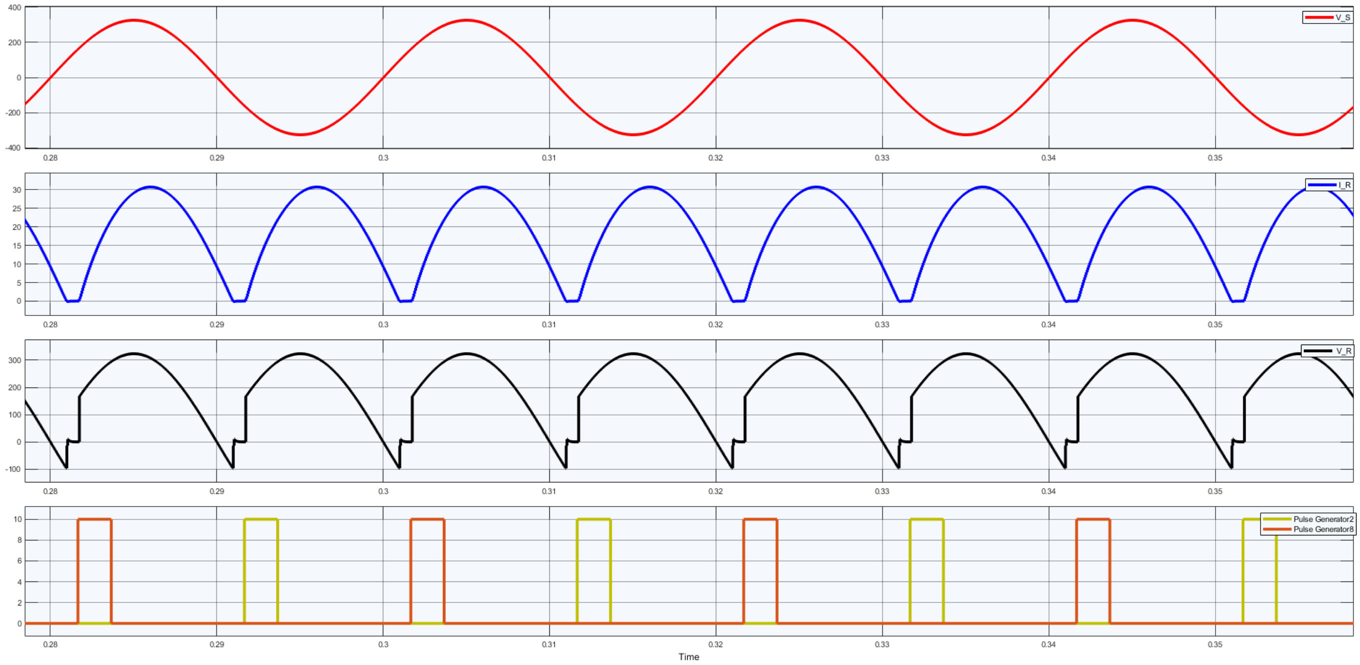


Figure 2.6: Scope Waveforms for Single Phase Half Wave Uncontrolled Rectifier with RL load and Freewheeling Diode

2.8 Conclusion

Utilizing the MATLAB Simulink platform, the design of single phase full wave rectifiers with both controlled and uncontrolled R and RL loads was carried out with remarkable success. Voltage and current output waveforms were attained and output parameter values, both theoretically calculated and simulated, were juxtaposed. The full-wave uncontrolled rectifier's efficiencies with R and RL load are measured to be 89.32%. Furthermore, the full-wave controlled rectifier's efficiencies with R and RL load were measured to be 83.41% and 81.33%, respectively.

In conclusion, the full-wave rectifier is a more efficient and practical alternative to the half-wave rectifier because it produces a smoother DC output, has a higher output voltage and lower output ripple. The four diodes used in a bridge configuration ensure that the input AC voltage is rectified, producing a DC output voltage across the output terminals. This process of rectification produces a unidirectional DC output signal that can be used for various applications. The average output voltage and current for full-wave rectifiers with R load can be calculated using the above equations. It is important to note that these calculations are based on idealized conditions and practical circuits may have additional factors that affect their performance.