Birzeit University
Faculty of Engineering & Techonology
Department of Electrical & Computer Engineering
ENEE4105

“Three Phase Controlled Rectidiers”

Student :Mohamad Bornat

Instructor:Dr.Hakam Shehadeh

March,2018

Abstract

This experiment aimed to examine and study the parameters of different three–phase converter topologies such as half-wave, semi-converter, and full-wave converters. Different load conditions were tested and some factors and parameters describing the circuits were calculated to verify the theoretical aspects. The effect of firing angle (delay angle) on rms and average values of output voltage and current was investigated. Results obtained agree with the theory and calculated parameters. It's shown that half-wave converter can operate in two-quadrants depending on the type of connected load. Moreover, the output voltage and current in a semi-converter are never fall to negative values due to the diodes existing in the topology. Furthermore, the time constant of the R-L load determines the continuous flow of output current through the legs of the full-wave and semi-converter circuits.

Contents

List of Figures

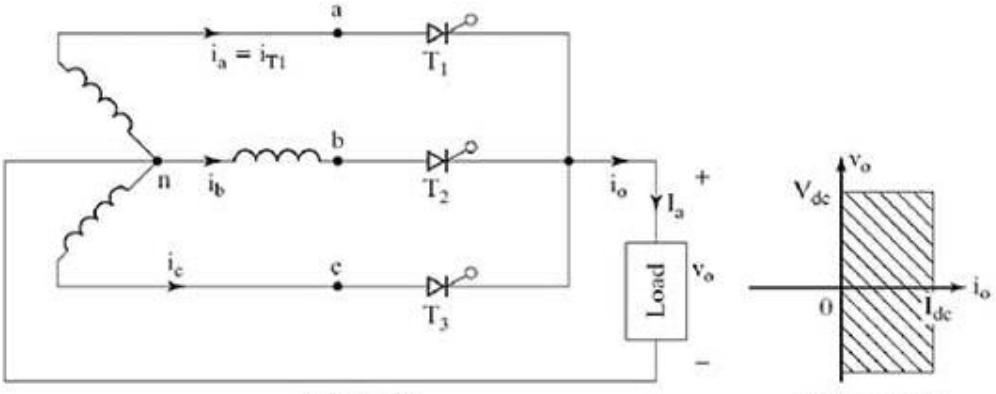
Chapter 1

Introduction

Three-phase controlled rectifiers have a wide range of applications, from small rectifiers to large High Voltage Direct Current (HVDC) transmission systems. They are used for electro-chemical process, many kinds of motor drives, traction equipment, controlled power supplies, and many other applications. From the point of view of the commutation process, they can be classified in two important categories: *Line Commutated Controlled Rectifiers (Thyristor Rectifiers)*, and *Force Commutated PWM Rectifiers*.

➢ Three-phase half-wave rectifier

Three **single phase half-wave converters** are connected together to form a **three phase half-wave converter** as shown in the figure.



(a) Circuit (b) Quadrant

Fig. 1.1: Half Wave Converter Circuit Diagram

The **3-PHASE HALF WAVE CONVERTER** combines three **single phase half wave controlled rectifiers** in one single circuit feeding a common load. The thyristor T_1 in series with one of the supply phase windings *'a-n'* acts as one half wave controlled rectifier. The second thyristor T_2 in series with the supply phase winding *'b-n'* acts as the second half wave controlled rectifier. The third thyristor T_3 in series with the supply phase winding acts as the third half wave controlled rectifier.

The 3-phase input supply is applied through the star connected supply transformer as shown in the figure. The common neutral point of the supply is connected to one end of the load while the other end of the load connected to the common cathode point.

When the thyristor T_1 is triggered at $\omega t=(\prod/6 + \alpha)=(30° + \alpha)$, the phase voltage V_{an} appears across the load when T_1conducts. The load current flows through the supply phase winding *'a-n'* and through thyristor T_1 as long as T_1 conducts.

When thyristor T_2 is triggered at $\omega t=(5\prod/6\alpha)$, T_1 becomes reverse biased and turns-off. The load current flows through the thyristor and through the supply phase winding *'b-n'* . When T_2 conducts the phase voltage v_{bn} appears across the load until the thyristor T_3 is triggered .

When the thyristor T_3 is triggered at $\omega t=(3\prod/2 + \alpha)=(270°+\alpha)$, T_2 is reversed biased and hence T_2 turns-off. The phase voltage V_{an} appears across the load when T_3 conducts.

When T_1 is triggered again at the beginning of the next input cycle the thyristor T_3 turns off as it is reverse biased naturally as soon as T_1 is triggered. The figure shows the 3-phase input supply voltages, the output voltage which appears across the load, and the load current assuming a constant and ripple free load current for a highly inductive load and the current through the thyristor T_1.

For a purely resistive load where the load inductance 'L = 0' and the trigger angle $\alpha >(\prod/6)$, the load current appears as discontinuous load current and each thyristor is naturally commutated when the polarity of the corresponding phase supply voltage reverses. The frequency of output ripple frequency for a **3-PHASE HALF WAVE CONVERTER** is f_s, where f_s is the input supply frequency.

➢ Three-phase Full and Semi Converters

three phase full converter is a fully controlled bridge controlled rectifier using six thyristors connected in the form of a full wave bridge configuration. All the six thyristors are controlled switches which are turned on at a appropriate times by applying suitable gate trigger signals.
The**three phase full converter** is extensively used in industrial power applications upto about 120kW output power level, where two quadrant operations is required. The figure shows a **three phase full converter** with highly inductive load. This circuit is also known as three phase full wave bridge or as a six pulse converter.
The thyristors are triggered at an interval of $(\prod/3)$ radians (i.e. at an interval of 30°). The frequency of output ripple voltage is $6f_s$ and the filtering requirement is less than that of **three phase semi and half wave converters**.

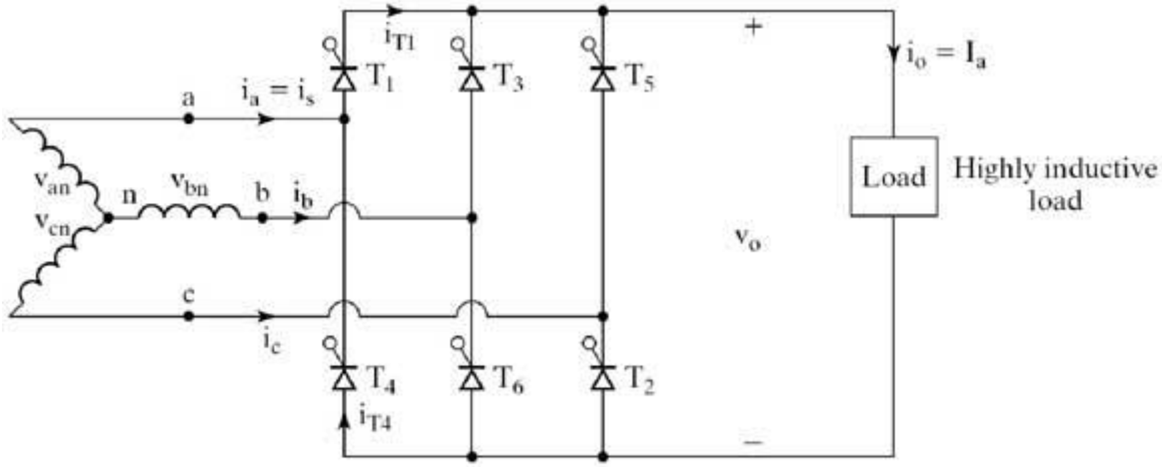


Fig. 1.2: Full Wave Converter Circuit Diagram

At $\omega t=(\prod/6 +\alpha)$, thyristor is already conducting when the thyristor is turned on by applying the gating signal to the gate of . During the time period $\omega t=(\prod/6 +\alpha)$ to $(\prod/2 +\alpha)$, thyristors and conduct together and the line to line supply voltage appears across the load.

At $\omega t=(\prod/2 +\alpha)$, the thyristor T_2 is triggered and T_6 is reverse biased immediately and T_6 turns off due to natural commutation. During the time period $\omega t=(\prod/ +\alpha)$ *to* $(5\prod/6 +\alpha)$, thyristor T_1 and T_2 conduct together and the line to line supply voltage appears across the load.

The thyristors are numbered in the circuit diagram corresponding to the order in which they are triggered. The trigger sequence (firing sequence) of the thyristors is 12, 23, 34, 45, 56, 61, 12, 23, and so on. The figure shows the waveforms of three phase input supply voltages, output voltage, the thyristor current through T_1 and T_4, the supply current through the line ‘a’.

Chapter 2

Procedure and Discussion

2.1 Three Phase Half Wave Controlled Rectifiers

This section is concerned with studying the behaviour of single-phase have-wave converter circuits for three types of loads; resistive, and resistive-inductive loads.

2.1.1 Three Phase Half Wave Converter with Resistive Load

A resistive load of 33.3 Ω was connected to a half-wave single –phase converter circuit, the converter was fed with a phase-to-neutral voltage of 45V via a transformer. The converter was driven at a firing angle of 45^o and then at 90^o. CASSY software was utilized to plot the measured quantities which included the input and output voltages and currents and SCR Voltage .

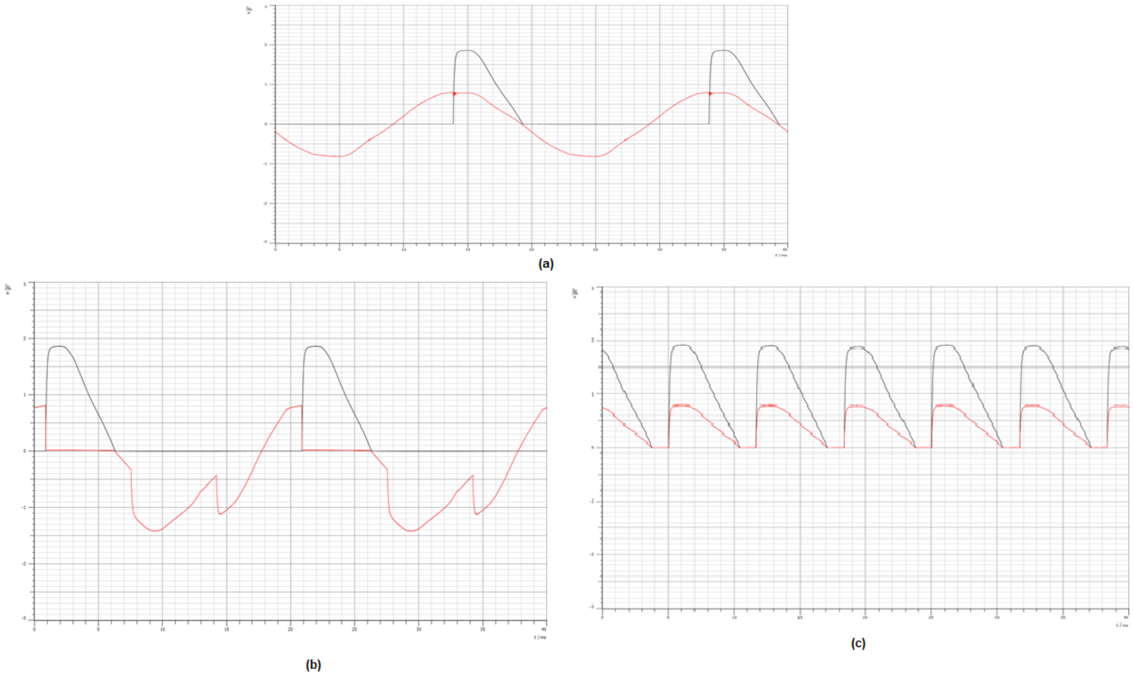


Fig. 2.1: Half Wave Converter with Resistive load at firing angle of 45^o (a) : input Voltage & input Current (b) SCR Voltage & input Current (c) Output Voltage & Output Current

The rms and average values of input and output voltages and currents were measured as summarized in table 1:

Table 1: RMS and average values of input and output voltages and currents of a single phase half-wave converter

Quantity	*Average [V]*	*RMS*	*Firing angle [deg]*
Input voltage [V]	-	47.7	45
Input current [A]	0.698	0.324	45
Output voltage [V]	37.5	42	45
Output current [A]	0.98	1.22	45

Peak-to-peak voltage ripple at 45deg is 128.8V as appears in figure 2.1.
The frequency of the output voltage is =151Hz (1/6.6ms) .

- **Calculations of FF, RF, and TUF at 45deg**

$$FF = \frac{Vrms}{Vdc} = \frac{42}{37.5} = \mathbf{1.12}$$

$$RF = \sqrt{(FF^2 - 1)} = \mathbf{0.504}$$

$$TUF = \frac{Pdc}{3 * VsIs} = \frac{0.98 * 37.5}{3 * 0.324 * 47.7} = \mathbf{0.77}$$

- **Theoretical Calculations**

$$V_{dc} = \frac{3\sqrt{3}Vm}{2\pi}(cos\alpha) = 39.2V$$

The same steps were repeated but for firing angle = 90^o

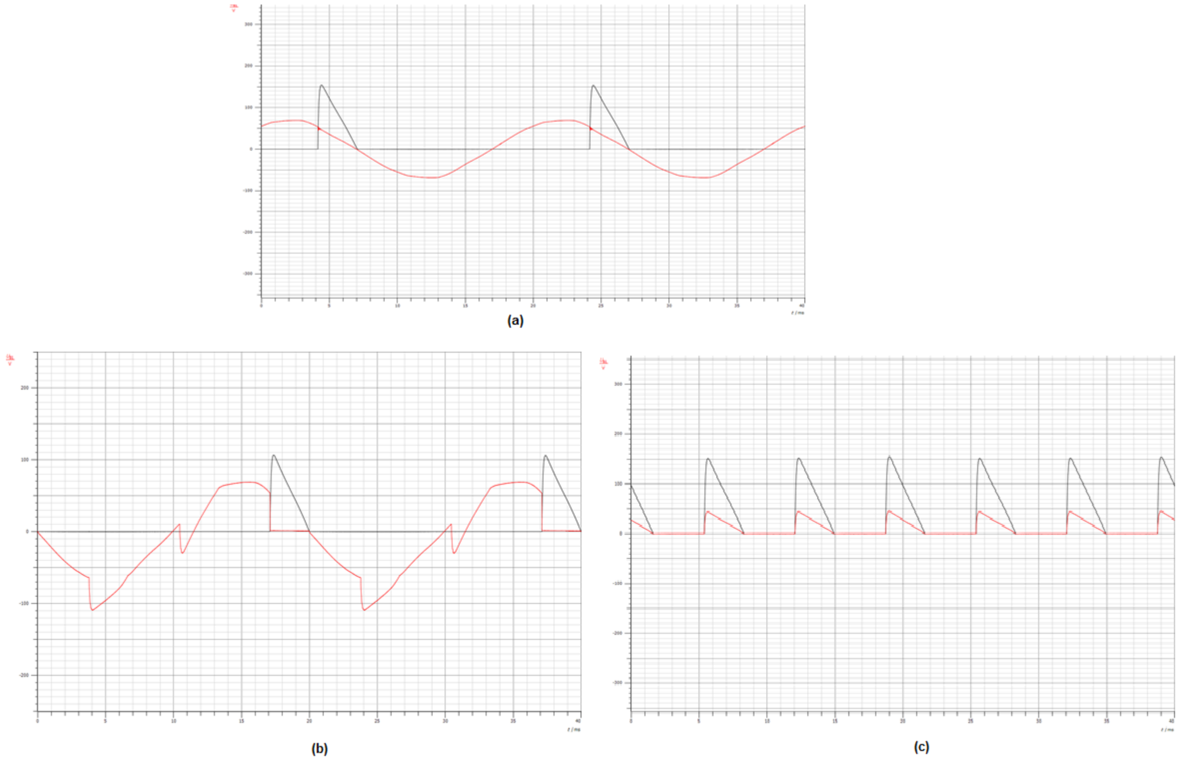


Fig. 2.2: Half Wave Converter with Resistive load at firing angle of 90^o (a) : input Voltage & input Current (b) SCR Voltage & input Current (c) Output Voltage & Output Current

The rms and average values of input and output voltages and currents were measured as summarized in table 2:

Quantity	*Average [V]*	*RMS*	*Firing angle [deg]*
Input voltage [V]	-	51.7	90
Input current [A]	0.097	0.3	90
Output voltage [V]	10.4	18.2	90
Output current [A]	0.29	0.54	90

Table 2: RMS and average values of input and output voltages and currents of a single phase half-wave converter

- **Calculations of FF, RF, and TUF at 90deg**

$$FF = \frac{Vrms}{Vdc} = \frac{18.2}{10.4} = \mathbf{1.75}$$

$$RF = \sqrt{(FF^2 - 1)} = \mathbf{1.43}$$

$$TUF = \frac{Pdc}{VsIs} = \frac{10.4 * 0.29}{18.2 * 0.54} = 0.3$$

- **Theoritical Calculations**

$$V_{dc} = \frac{3Vm}{2\pi}\left(1 + (\frac{\pi}{6} + cos\alpha)\right) = 14.5V$$

The firing angle was set to 0^o and then increased gradually in steps of 30^o up to 150^o. Table 3 summarizes the measured and calculated values of average output voltage and current.

Table 3: Effect of delay angle on average value of output voltage and current of half-wave converter

Delay angle [deg]	0	30	60	90	120	150
Average output voltage [V]	52.2	41.5	25.6	10.4	1.8	0
Average output current [A]	1.53	1.22	0.75	0.303	0.05	0
Normalized average output voltage	**1**	**0.79**	**0.49**	**0.19**	**0.03**	**0**
Normalized average output current	1	0.79	0.49	0.2	0.03	0
Theoretical average output voltage [V] Vdc/Vm	53	45	27	015	4	0
Normalized theoretical output voltage	**1**	**0.87**	**0.5**	**0.24**	**0.063**	**0**

Plot of the normalized output voltages for theoretical and experimental data is shown in the following figure:

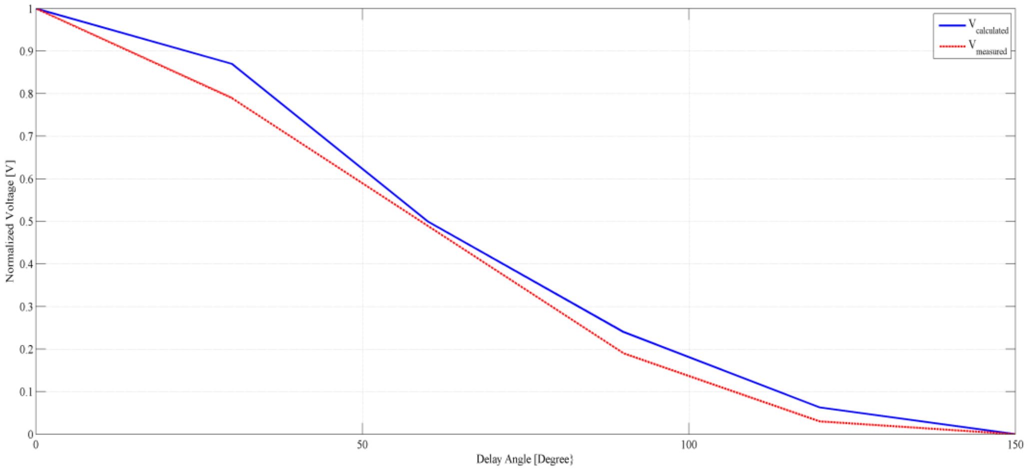


Fig. 2.3: The normalized measured and calculated output voltage as a function of delay angle for semi converter with resistive load.

- The obtained waveforms of the SCR voltage is clearly shown to be the difference between the input voltage and the output voltage; that explains why the SCR voltage is dropped to zero when the SCR is triggered at 45 deg and 90 deg and takes the shape of the input signal when it turns off.
- The output current and voltage have the same shape and polarity which means this converter is only able to operate in first quadrant
- Operating at high firing angle degrades the operation of the converter and it becomes worse
- This converter is not good to be used since the ripple factor is too high and the transformer gives too small ratio of its capacity as suggested by TUF value for this type of converters

2.1.2 Three Phase Half Wave Converter with Resistive – inductive Load

A resistive-inductive load of 33.3 Ω in series with 50mH was connected to the half-wave converter output. The converter was fed with a phase-to-neutral voltage of 45V via a transformer. The converter was driven at a firing angle of 45^{o} and then at 90^{o}. CASSY software was utilized to plot the measured quantities which included the input and output voltages and currents as well as the SCR voltage and current as shown in the following figure:

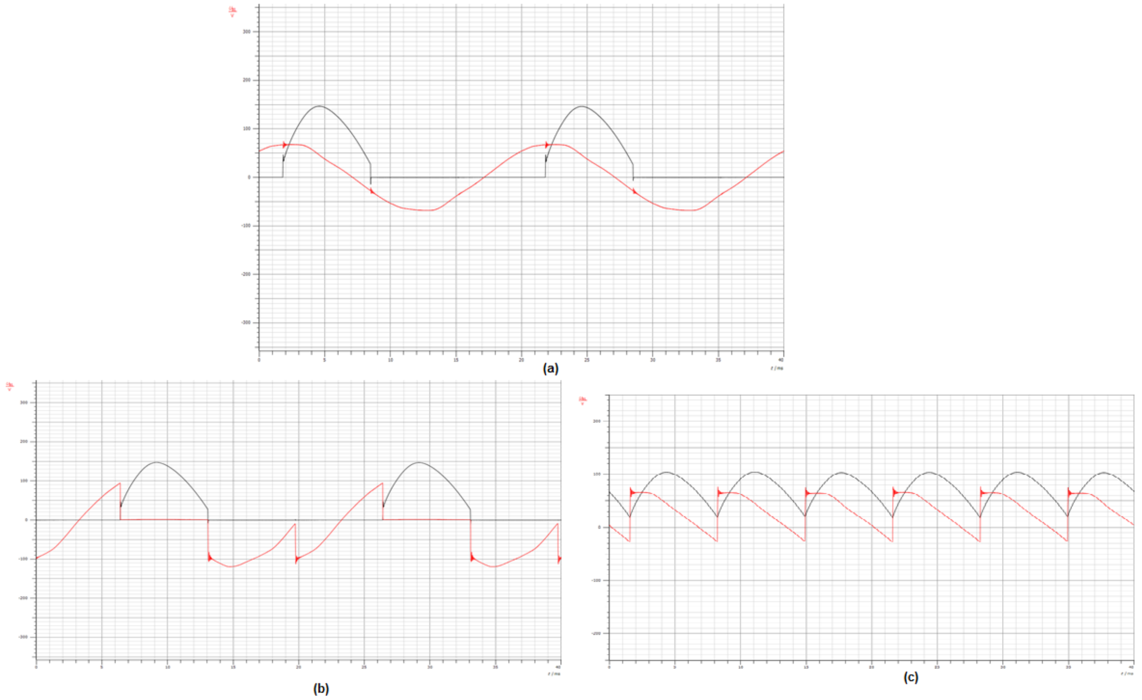


Fig. 2.4: Half Wave Converter with Resistive-Inductive load at firing angle of 45^{o} (a) : input Voltage & input Current (b) SCR Voltage & input Current (c) Output Voltage & Output Current

The rms and average values of input and output voltages and currents were measured as summarized in table 4:

Table 4: RMS and average values of input and output voltages and currents of R-L half—wave converter

Quantity	*Average [V]*	*RMS*	*Firing angle [deg]*
Input voltage [V]	-	47.7	45
Input current [A]	0	0.698	45
Output voltage [V]	30.8	43.3	45
Output current [A]	0.87	0.9	45

The same steps were repeated but for firing angle = 90°

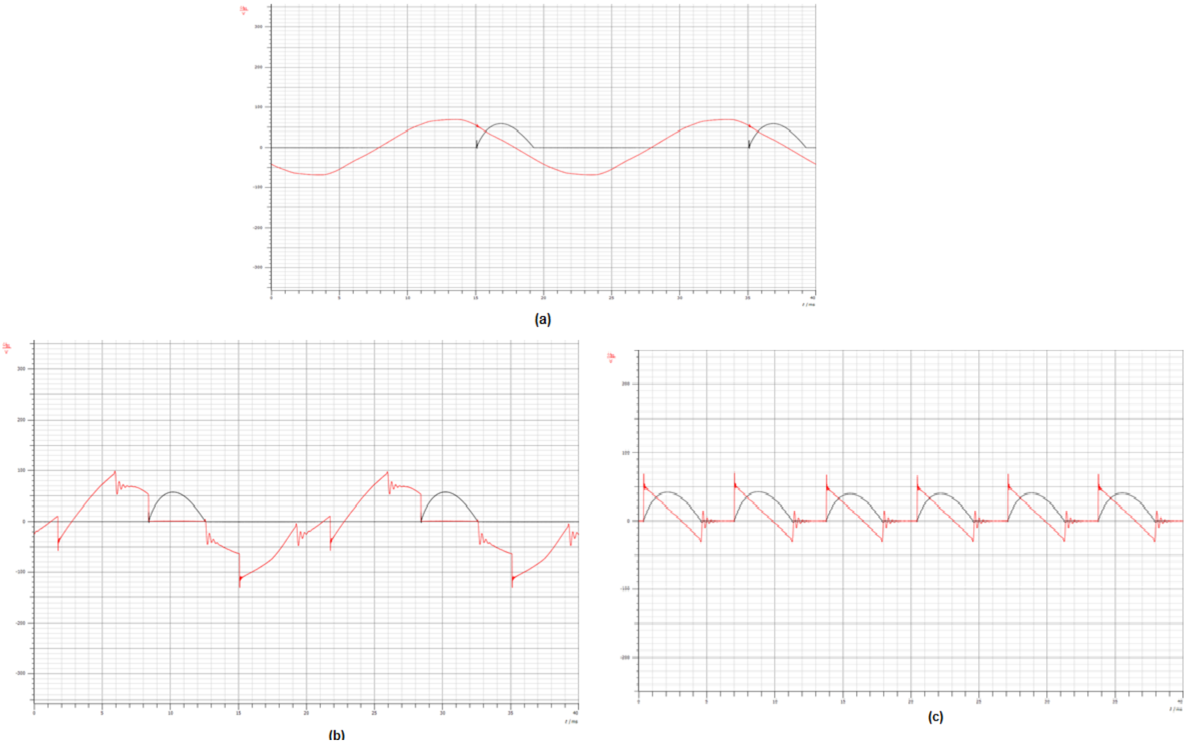


Fig. 2.5: Half Wave Converter with Resistive-Inductive load at firing angle of 90° (a) : input Voltage & input Current (b) SCR Voltage & input Current (c) Output Voltage & Output Current

The rms and average values of input and output voltages and currents were measured as summarized in table 5:

Table 5: RMS and average values of input and output voltages and currents of R-L half—wave converter

Quantity	*Average [V]*	*RMS*	*Firing angle [deg]*
Input voltage [V]	-	51.7	90
Input current [A]	0.097	0.3	90
Output voltage [V]	10.4	20.5	90
Output current [A]	0.2	0.28	90

- **Calculations of FF, RF, and TUF at 45 deg based on measured average and rms values :**

$$FF = \frac{Vrms}{Vdc} = \frac{31.2}{14.2} = \mathbf{2.197}$$

$$RF = \sqrt{(FF^2 - 1)} = \mathbf{1.95}$$

$$TUF = \frac{Pdc}{VsIs} = \frac{0.402 * 14.2}{0.665 * 31.2} = \mathbf{0.275}$$

- **Calculations of FF, RF, and TUF at 90 deg based on measured average and rms values :**

$$FF = \frac{Vrms}{Vdc} = \frac{22.2}{7} = \mathbf{3.17}$$

$$RF = \sqrt{(FF^2 - 1)} = \mathbf{3.00}$$

$$TUF = \frac{Pdc}{VsIs} = \frac{0.197 * 7}{0.388 * 22.2} = \mathbf{0.160}$$

- The lower value of the form factor indicates that the shape of the output voltage is better at the triggering and turn off instants due to the resistance which absorbs the energy at the sudden changes of current and thus reduces oscillations.
- The increase of firing angle makes the output voltage to decrease in terms of average and rms values, which offers the ability to control the speed of motors or other applications.
- Notice that the R-L load keeps the current so that the SCR does not turn off when the input voltage is negative since the current is never below the holding current I_H.

2.2 Three Phase Semi-Converter

This section is concerned with studying the behaviour of three-phase semi-converter circuits for two types of loads; resistive and resistive-inductive loads. Circuits connected are shown in figure .

2.2.1 Three Phase Semi Converter with Resistive Load

A resistive load of 300 Ω was connected to the three phase semi- converter circuit in figure ; the converter was fed with a phase-to-neutral voltage of 45V via a transformer. The converter was driven at a firing angle of 45° and then at 90°.

CASSY software was utilized to plot the measured quantities which included the input and output voltages and currents as shown in figure 2.6:

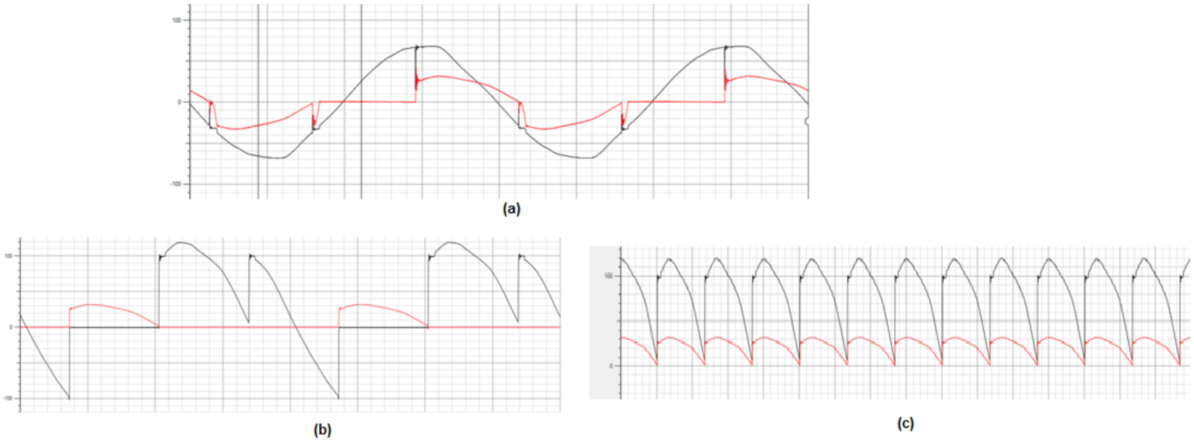


Fig. 2.6: Semi Converter with Resistive at firing angle of 45° (a) : input Voltage & input Current (b) SCR Voltage & input Current (c) Output Voltage & Output Current

Table 6: RMS and average values of input and output voltages and currents of R Semi converter for $\alpha = 45°$

Quantity	*Average [V]*	*RMS*	*Firing angle [deg]*
Input voltage [V]	-	51	90
Input current [A]	-	0.238	90
Output voltage [V]	45	62.1	90
Output current [A]	0.139	0.21	90

The same steps were repeated but for firing angle = 90º

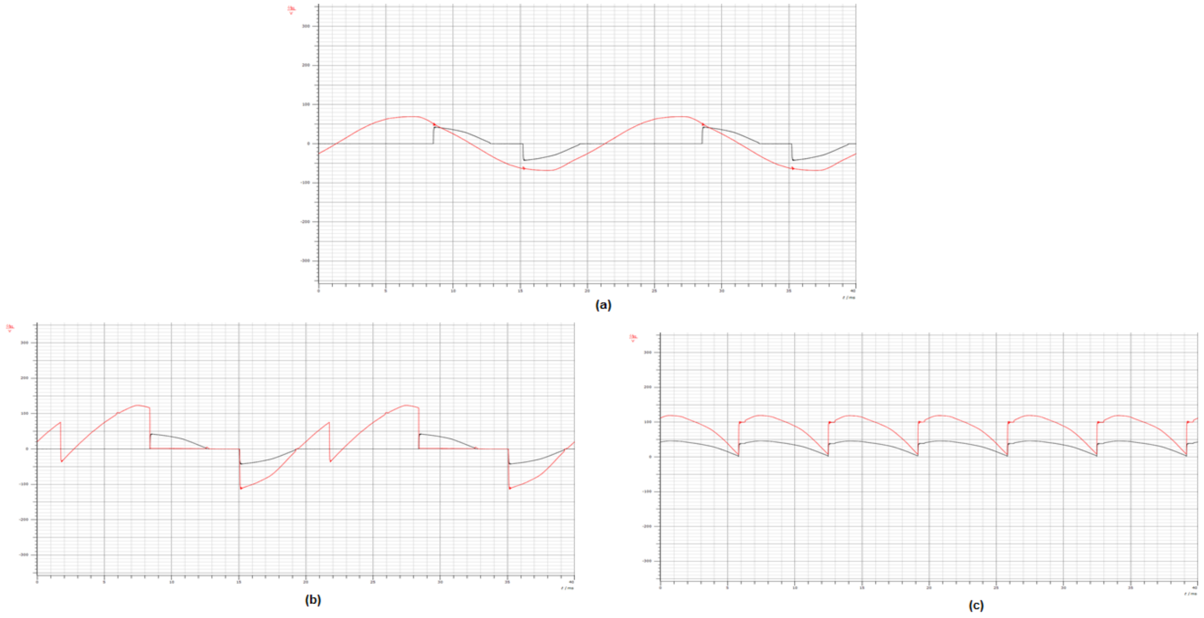


Fig. 2.7: Semi Converter with Resistive at firing angle of 90º (a) : input Voltage & input Current (b) SCR Voltage & input Current (c) Output Voltage & Output Current

Table 7: RMS and average values of input and output voltages and currents of R Semi converter for $\alpha = 90°$

Quantity	*Average [V]*	*RMS*	*Firing angle [deg]*
Input voltage [V]	-	51	45
Input current [A]	-	0.238	45
Output voltage [V]	85	94	45
Output current [A]	0.28	0.31	45

- **Calculations of FF, RF, and TUF at 45deg**

$$FF = \frac{Vrms}{Vdc} = \frac{94}{85} = \mathbf{1.1}$$

$$RF = \sqrt{(FF^2 - 1)} = \mathbf{0.47}$$

$$TUF = \frac{Pdc}{3 * VsIs} == \mathbf{0.7}$$

- **Theoretical RMS and AVG values and FF, RF, TUF calculations at 45 deg :**

The average output voltage is given by:

$$V_{dc} = \frac{3\sqrt{3}Vm}{2\pi}(1 + cos\alpha) = 66V$$

The root-mean square is given by

$$Vrms = \sqrt{3}Vm\sqrt{\frac{3}{4pi}(\frac{2\pi}{3} + \sqrt{3(cos\alpha)^2})} = 68V$$

- **Calculations of FF, RF, and TUF at 90 deg based on the measured rms and average values**

$$FF = \frac{Vrms}{Vdc} = \frac{62.1}{45} = \mathbf{1.38}$$

$$RF = \sqrt{(FF^2 - 1)} = \mathbf{0.95}$$

- **Theoretical RMS and AVG values and FF, RF, TUF calculations at 90 deg:**

The average output voltage is given by

$$V_{dc} = \frac{3\sqrt{3}Vm}{2\pi}(1 + cos\alpha) = 35.9V$$

The root-mean square is given by

$$V_{rms} = \sqrt{3}Vm\sqrt{\frac{3}{4pi}(\pi - \alpha + \frac{sin2\alpha}{2}} = 28.6\text{V}$$

The firing angle was set to 0^o and then increased gradually in steps of 30^o up to 150^o. Table 8 summarizes the measured and calculated values of average output voltage and current.

Table 8: Effect of delay angle on average value of output voltage and current of half-wave converter

Delay angle [deg]	0	30	60	90	120	150
Average output voltage [V]	110.4	97.9	74.4	45.1	19.8	3
Average output current [A]	0.35	0.318	0.24	0.14	0.063	0.009
Normalized average output voltage	**1**	**0.89**	**0.68**	**0.41**	**0.18**	**0.03**
Normalized average output current	1	0.88	0.67	0.4	0.16	0.28
Theoretical average output voltage [V] Vdc/Vm	105	90	77	51	25	7
Normalized theoretical output voltage	**1**	**0.86**	**0.73**	**0.48**	**0.24**	**0.067**

Plot of the normalized output voltages for theoretical and experimental data is shown in the following figure :

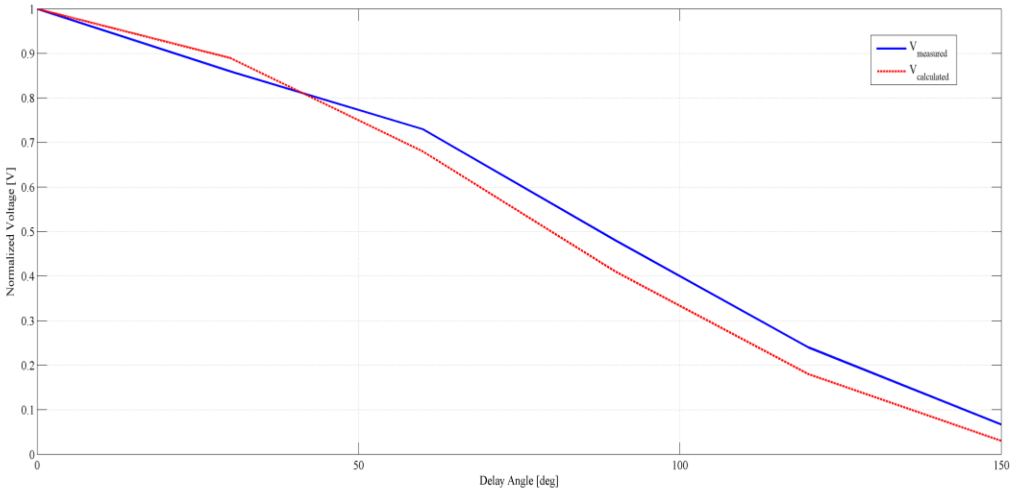


Fig. 2.8: The normalized measured and calculated output voltage as a function of delay angle for semi converter with resistive load.

- The output current and voltage have the same shape and polarity which means this converter is only able to operate in first quadrant.
- Each SCR turns off when its anode current drops below the holding current at the end of the corresponding half cycle .
- The factors through which, the performance of the converter is judged are found to be greater at firing angle 90 deg than 45 deg , thus , operating at high firing angle degrades the operation of the converter and it becomes worse !.The theoretical results are fairly close to the experimental results in both cases of delay angles. This converter is better to be used than the half–wave converter since the ripple factor is lower and the transformer supplies or uses greater ratio of its capacity as suggested by the high value of TUF.

2.2.2 Three Phase Semi Converter with Resistive-Inductive Load

A resistive-inductive load of 300 Ω in series with 50mH was connected to the half-wave converter output. The converter was fed with a phase-to-neutral voltage of 45V via a transformer. The converter was driven at a firing angle of 45° and then at 90°.

CASSY software was utilized to plot the measured quantities which included the input and output voltages and currents as well as the SCR voltage and current as shown in the following figure:

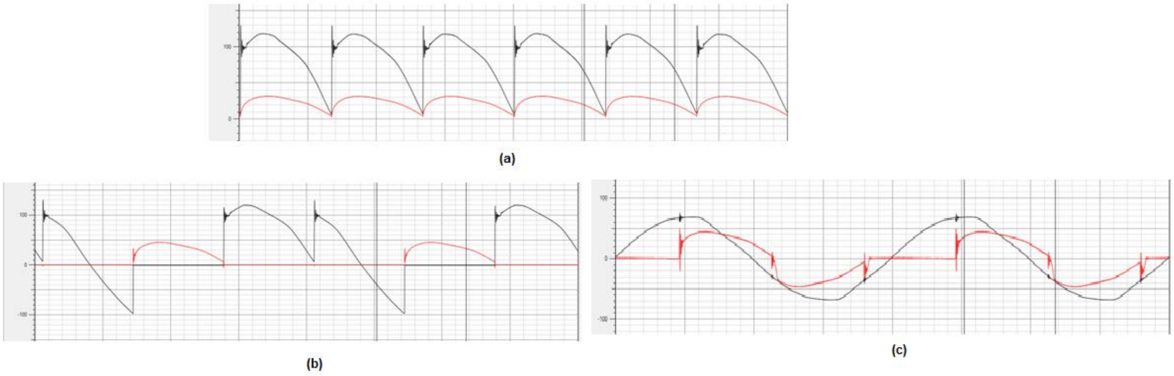


Fig. 2.9: Semi Converter with Resistive-inductive load at firing angle of 45° (a) : input Voltage & input Current (b) SCR Voltage & input Current (c) Output Voltage & Output Current

Table 9: RMS and average values of input and output voltages and currents of R-L Semi converter for $\alpha = 45^\circ$

Quantity	*Average [V]*	*RMS*	*Firing angle [deg]*
Input voltage [V]	0	49	45
Input current [A]	0	0.24	45
Output voltage [V]	86.5	92	45
Output current [A]	0.28	0.3	45

The same steps were repeated but for firing angle = 90^{o}

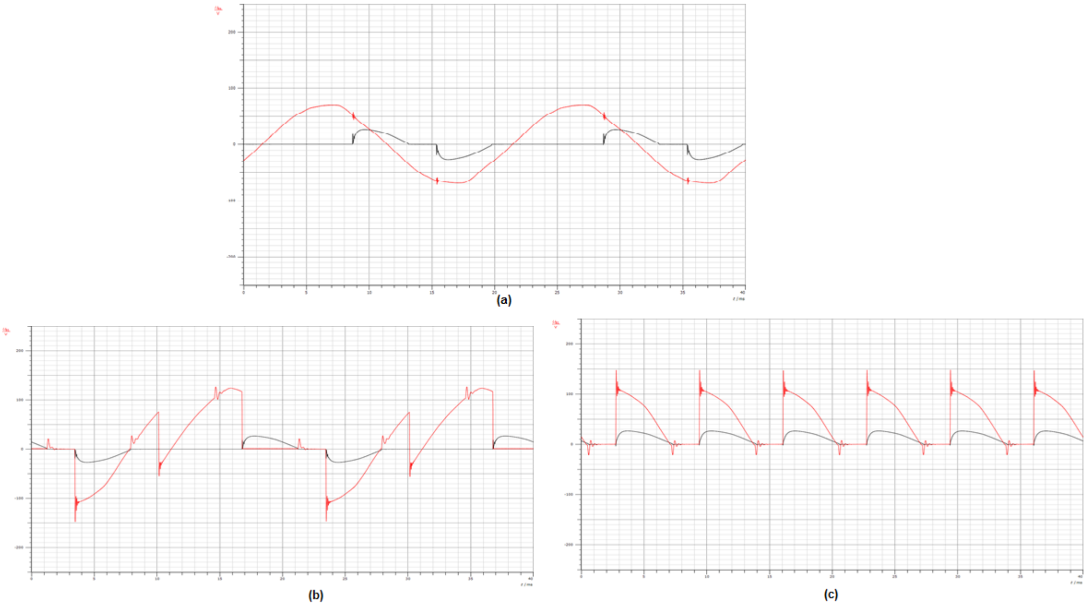


Fig. 2.10: Semi Converter with Resistive at firing angle of 90^{o} (a) : input Voltage & input Current (b) SCR Voltage & input Current (c) Output Voltage & Output Current

Table 10: RMS and average values of input and output voltages and currents of R-L Semi converter for $\alpha = 90°$

Quantity	*Average [V]*	*RMS*	*Firing angle [deg]*
Input voltage [V]	-	51	90
Input current [A]	-	0.238	90
Output voltage [V]	51	68	90
Output current [A]	0.165	0.212	90

Frequency of output voltage and current = 300Hz

- **Calculations of FF, RF, and TUF at 45deg**

$$FF = \frac{Vrms}{Vdc} = \frac{92}{86} = \mathbf{1.06}$$

$$RF = \sqrt{(FF^2 - 1)} = \mathbf{0.35}$$

- **Theoretical RMS and AVG values and FF, RF, TUF calculations at 45 deg :**

The average output voltage is given by:

$$V_{dc} = \frac{3\sqrt{3}Vm}{2\pi}(1 + cos\alpha) = 89V$$

The root-mean square is given by

$$Vrms = \sqrt{3}Vm\sqrt{\frac{3}{4pi}(\frac{2\pi}{3} + \sqrt{3(cos\alpha)^2})} = 92V$$

- **Calculations of FF, RF, and TUF at 90 deg based on the measured rms and average values**

$$FF = \frac{Vrms}{Vdc} = \mathbf{1.33}$$

$$RF = \sqrt{(FF^2 - 1)} = \mathbf{0.88}$$

➢ Theoretical RMS and AVG values and FF, RF, TUF calculations at 90 deg:

The average output voltage is given by

$$V_{dc} = \frac{3\sqrt{3}Vm}{2\pi}(1 + cos\alpha) = 53V$$

The root-mean square is given by

$$V_{rms} = \sqrt{3}Vm\sqrt{\frac{3}{4pi}(\pi - \alpha + \frac{sin2\alpha}{2}} = 65\text{V}$$

- The calculated rms and average voltages are -to a good extent- close to the measured values.
- Waveforms confirm that the polarity of voltage and current is the same, and the voltage is never negative due to the existence of the diodes in the lower legs of this topology, which in turn, they become reverse biased when the input voltage drops to negative at the half of the cycle.
- When the other pair of SCR and diode become conducting, the polarity of the negative input voltage is reversed so it appears positive thus the output voltage and current are never fall to negative side.
- Moreover, the current appears to become zero when the voltage reverses its polarity or drops to very small value, this indicates that the load does not sustain the current above the holding current of the SCR so it turns off instead of circulating through the conducting SCR , this case would not happen if the value of the inductor was more than 50mH (larger time constant $(\tau = \frac{L}{R})$).
- The two circuits with resistive and R-L loads behave similarly concerning their current and voltage waveforms and their rms and average values! .This circuit does not cause the transformer to saturate since the average input current appears to have a zero value!

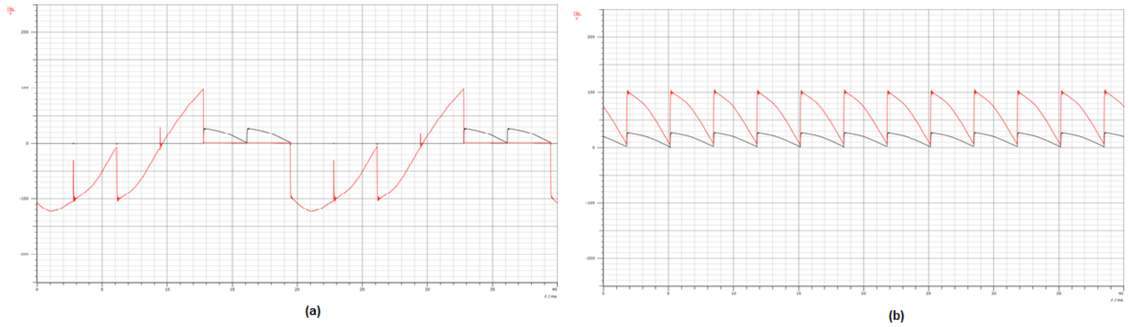
2.3 Three Phase Full Converter

This section is concerned with studying the single-phase full-converter circuits for a resistive load and resistive-inductive under 45 deg and 90 deg firing angles.

2.3.1 Three Phase Full Converter with Resistive Load

A resistive load of 300Ω was connected to the full- converter circuit in (A3.1). The converter was fed with a phase-to-neutral voltage of 45V via a transformer. The converter was driven at a firing angle of 45^o and then at 90^o.

CASSY software was utilized to plot the measured quantities which included the input and output voltages and currents as shown in the following figure:



(a)

(b)

Fig. 2.11: Full Converter with Resistive at firing angle of 45^o (a) SCR Voltage & input Current (b) Output Voltage & Output Current

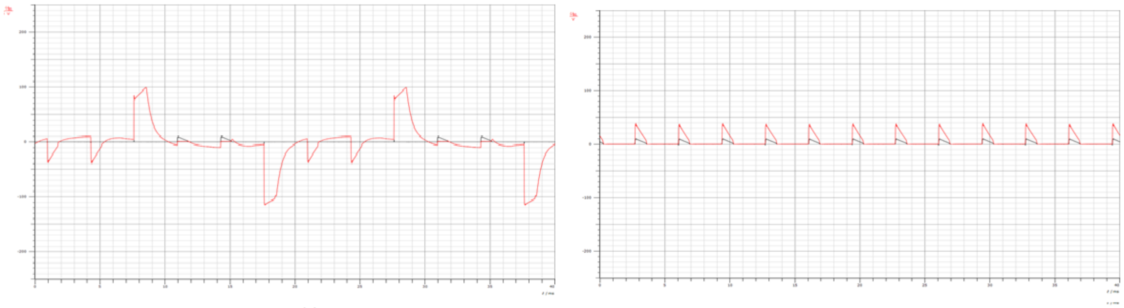

(a) (b)

Fig. 2.12: Full Converter with Resistive at firing angle of 90° (a) SCR Voltage & input Current (b) Output Voltage & Output Current

The rms and average values of the input and output voltage and current for both firing angles are listed in table 9:

Table *11:* RMS and average values of input and output voltages and currents of R full-converter

Quantity	*Average [V]*	*RMS*	*Firing angle [deg]*
Input voltage [V]	0	50.6	45
Input current [A]	0	0.22	45
Output voltage [V]	64	70	45
Output current [A]	0.208	0.23	45
Output voltage [V]	12	21	90
Output current [A]	0.035	0.07	90

It was found that the Peak to Peak Ripple of the Output voltage at 45 is 95V and at 90 is 39 V.

It was found that the frequency of the Output for both cases is 300Hz.

- **Calculations of FF, RF, and TUF at 45deg**

$$FF = \frac{Vrms}{Vdc} == \mathbf{1.09}$$

$$RF = \sqrt{(FF^2 - 1)} = \mathbf{0.44}$$

- **Theoretical RMS and AVG values and FF, RF, TUF calculations at 45 deg :**

The average output voltage is given by:

$$V_{dc} = \frac{3\sqrt{3}Vm}{2\pi}(cos\alpha) = 69V$$

The root-mean square is given by

$$Vrms = \sqrt{3}Vm\sqrt{\frac{1}{2} + \frac{3\sqrt{3}}{4\pi}cos2\alpha} = 72\ V$$

- **Calculations of FF, RF, and TUF at 90deg**

$$FF = \frac{Vrms}{Vdc} == \mathbf{1.8}$$

$$RF = \sqrt{(FF^2 - 1)} = \mathbf{1.5}$$

- **Theoretical RMS and AVG values and FF, RF, TUF calculations at 90 deg :**

The average output voltage is given by:

$$V_{dc} = \frac{3\sqrt{3}Vm}{\pi}\left(1 + \cos\left(\alpha + \frac{\pi}{3}\right)\right) = 15V$$

The root-mean square is given by

$$Vrms = \sqrt{3}Vm\sqrt{\frac{1}{2} + \frac{3\sqrt{3}}{4\pi}cos2\alpha} = 36\ V$$

The firing angle was set to 0^o and then increased gradually in steps of 30^o up to 150^o. Table 12 summarizes the measured and calculated values of average output voltage and current.

Table 12: Effect of delay angle on average value of output voltage and current of Full-wave converter

Delay angle [deg]	0	30	60	90	120	150
Average output voltage [V]	108	84.5	39.5	5.5	0	0
Average output current [A]	0.35	0.27	0.12	0.016	0	0
Normalized average output voltage	**1**	**0.72**	**0.36**	**0.053**	**0**	**0**
Normalized average output current	1	0.77	0.36	0.05	0	0
Theoretical average output voltage [V] Vdc/Vm	112	98	55	15	/	/
Normalized theoretical output voltage	**1**	**0.86**	**0.5**	**0.14**	**/**	**/**

Plot of the normalized output voltages for theoretical and experimental data for angle between 0 and 90 because theoretical values for angle greater than 90 cannot be calculated using the given formulas. is shown in the following figure :

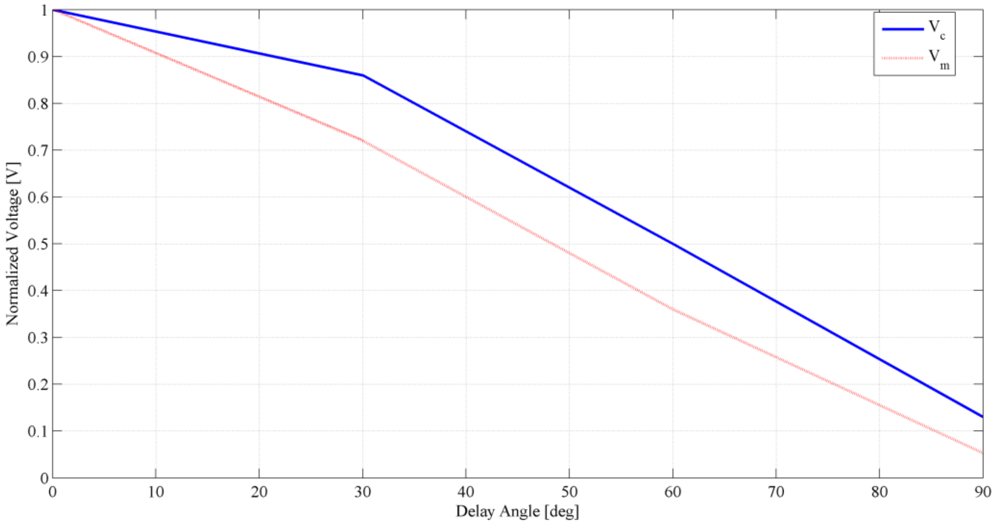


Fig. 2.13: The normalized measured and calculated output voltage as a function of delay angle for Full converter with resistive load.

2.3.2 Three Phase Full Converter with Resistive-Inductive Load

A resistive- inductive load of 200Ω in series with 50mH was connected to the full- converter circuit in (A3.2). The converter was fed with a phase-to-neutral voltage of 45V via a transformer. The converter was driven at a firing angle of 45^{o} and then at 90^{o}. CASSY software was utilized to plot the measured quantities which included the input and output voltages and currents as shown in the following figure:

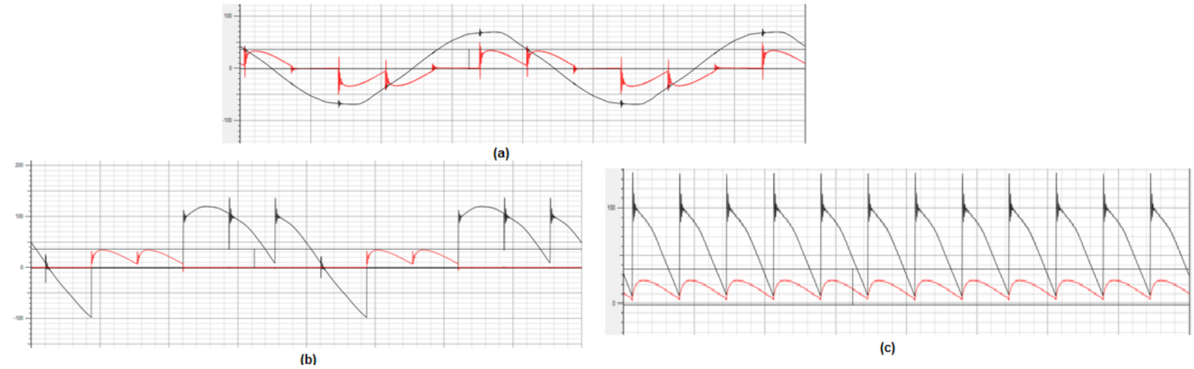


Fig. 2.14: Full Converter with Resistive-Inductive at firing angle of 45^{o} (a) : input Voltage & input Current (b) SCR Voltage & input Current (c) Output Voltage & Output Current

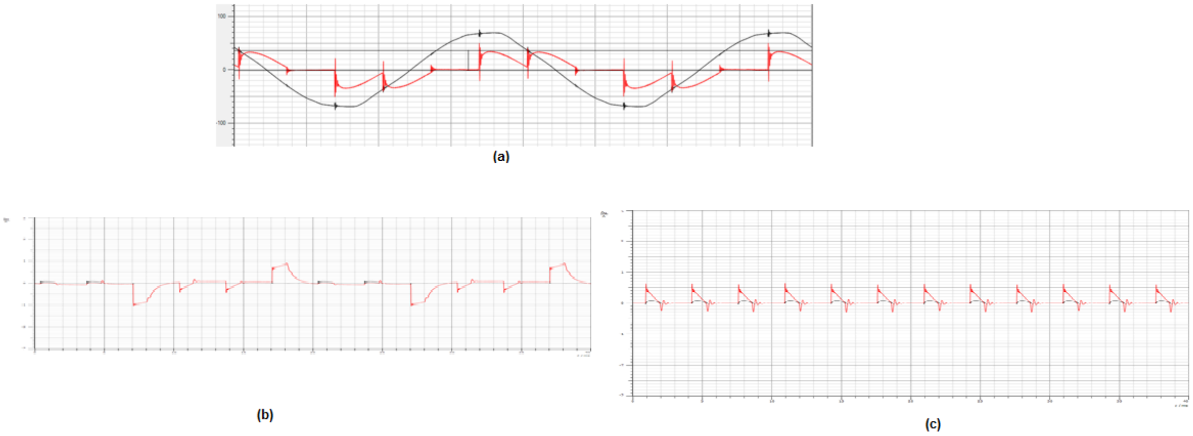


Fig. 2.15: Full Converter with Resistive-Inductive at firing angle of 45^{o} (a) : input Voltage & input Current (b) SCR Voltage & input Current (c) Output Voltage & Output Current

The rms and average values of the input and output voltage and current for both firing angles are listed in table 12:

Table *12:* RMS and average values of input and output voltages and currents of R full-converter

Quantity	*Average [V]*	*RMS*	*Firing angle [deg]*
Input voltage [V]	0	50.6	45
Input current [A]	0	0.22	45
Output voltage [V]	36.7	70	45
Output current [A]	0.206	0.206	45
Output voltage [V]	5.2	12.9	90
Output current [A]	0.031	0.015	90

It was found that the Peak to Peak Ripple of the Output voltage at 45 is 95V and at 90 is 39 V.

It was found that the frequency of the Output for both cases is 300Hz.

- **Calculations of FF, RF, and TUF at 45deg**

$$FF = \frac{Vrms}{Vdc} == \mathbf{2.2}$$

$$RF = \sqrt{(FF^2 - 1)} = \mathbf{0.49}$$

- **Theoretical RMS and AVG values and FF, RF, TUF calculations at 45 deg :**

The average output voltage is given by:

$$V_{dc} = \frac{3\sqrt{3}Vm}{2\pi}(cos\alpha) = 68V$$

The root-mean square is given by

$$Vrms = \sqrt{3}Vm\sqrt{\frac{1}{2} + \frac{3\sqrt{3}}{4\pi}cos2\alpha} = 72\,V$$

- **Calculations of FF, RF, and TUF at 90deg**

$$FF = \frac{Vrms}{Vdc} == \mathbf{2.4}$$

$$RF = \sqrt{(FF^2 - 1)} = \mathbf{2}$$

- **Theoretical RMS and AVG values and FF, RF, TUF calculations at 90 deg :**

The average output voltage is given by:

$$V_{dc} = \frac{3\sqrt{3}Vm}{\pi}\left(1 + \cos\left(\alpha + \frac{\pi}{3}\right)\right) = 15V$$

The root-mean square is given by

$$Vrms = \sqrt{3}Vm\sqrt{\frac{1}{2} + \frac{3\sqrt{3}}{4\pi}cos2\alpha} = 0\ V$$

- The SCRs are turned off when the input voltage falls to small and negative values and output current becomes zero until the next pair of SCRs is triggered .
- if the load were highly inductive , the output current would appear continuous and sustained even when the voltage reverses its polarity , the sparks that appear is the output voltage are caused by the abrupt change of the inductor current (derivative action $V = Ldi/dt)$So the derivative is high at this instant which causes these sparks to arise in the output voltage!

Conclusion

This experiment has examined three different topologies of three –phase power converters under different loading conditions. The analysis has been carried out to find the values of some important factors and parameters, through which, the performance of the converter can be described. These factors have shown that the half-wave converter is not good choice due to having low utilization of the transformer capacity and the shape of the output voltage is not well-behaved and a large amount of harmonics exists which requires filtering . However, the situation becomes better in the semi, and full- wave converter topologies. The type of load has been shown to have a strong impact on the output waveforms and the average and rms values.

References

---

[1] M.Abu- Khaizaran, “Power Electronics Course Lecture Notes”, Dept of electrical and computer engineering, Birzeit university, Ramallah, Palestine, 2015.

[2] Burlington Butterworth–Heinemann, "*Power electronics handbook devices, circuits and applications*", 3rd ed., 2011.