Chapter 2
Controlled Rectifier

Abstract This chapter discussed the variants of thyristor based power electronics for different firing angles and the different combinations of the load like the resistance and the Inductance. The illustrations of the topologies with waveforms in Simulink® are demonstrated.

Keywords Firing angle · Ripple

Introduction

In the last chapter, we studied the uncontrolled bridge rectifier. The parameters for *R* and *L* were varied and the effect of this variation on output voltage and current of the rectifier was studied. In practical applications it is required to control the voltage and current at the DC link.

The block diagram (Fig. 2.1) represents a typical system in an industrial application. As discussed in the previous chapter, AC voltage source from a utility supply is rectified to DC using power electronics devices (diodes as explained chapter) and connected to a load that requires DC voltage and current. The utility generator generates a voltage that is not constant and varies in a certain range. According to Eq. (1.5) in the previous chapter, a change in AC voltage would cause a proportional change in the DC voltage.

A load in an industrial application is generally designed such that it requires a constant DC voltage and any change in DC voltage will cause undesired behavior of the load. Since the load and the AC utility are not controllable and the load requires a constant DC voltage, the only way to maintain the voltage for the load constant is to control the Power Electronics devices, such that the output from the circuit consisting of these devices can be controlled to a value required by the load. Such devices that can be controlled to maintain the voltage required by the load are called '*controlled devices*'. A **thyristor** forms the very basic of controlled device.

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The Thyristor Rectifier

Figure 2.2 shows the three-phase Thyristor Bridge. The circuit is similar to the diode bridge described in Chap. 1, with the diodes replaced with Thyristors. A thyristor is a three-terminal device, somewhat similar to a junction transistor. When a small current flows into the Gate terminal, a current flow is established from anode to cathode. This is called the ON condition of the thyristor. When the AC voltage across the device is negative, the current from anode to cathode stops. This is called OFF condition of the thyristor. There are other techniques to have a better control on the instance at which the thyristor turns OFF. Such techniques are called ‘Commutation techniques’, which will not be discussed in this book.

In the 360° of the sine wave of the input AC voltage, the *Firing Angle* is the instance (in terms of degrees) when the device is turned ON. This instance is typically in the positive half of the AC voltage across the device. In most literatures, this angle is denoted by the Greek letter alpha and generally varies from 0° to 180°.

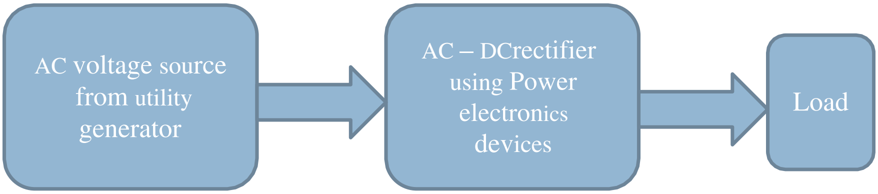

Fig. 2.1 Power scheme in a typical industrial application

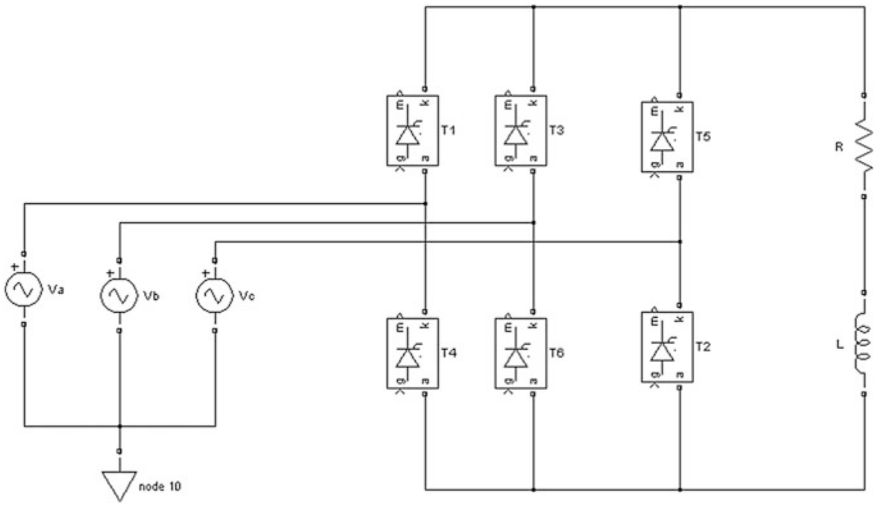

Fig. 2.2 Three-phase thyristor bridge

Table 2.1 Table for design of experiments for studying effect of firing angle on the operation of the thyristor rectifier. The Discontinuous term mentioned in the table indicates the DC link current Idc is zero

VL-L	Firing angle degree	Cosine	V_{dc}	I_{dc}	Current ripple
Time constant = 0					
250	0	1	336	3.36	0.48
250	30	0.866158	296	2.96	2
250	45	0.707388	249	2.49	2.5
250	59	0.515485	194	1.95	3.01
250	60	0.50046	194	0	Discontinuous
E	Firing degree	Cosine	V_{dc}	I_{dc}	Current ripple
Time constant = 0.001					
250	0	1	336	3.35	0.18
250	30	0.866158	296	2.915	0.7
250	45	0.707388	296	2.92	0.95
250	60	0.50046	190	1.7	1.15
250	75	0.25946	132	0.94	1.2
250	76	0.242574	0	0	Discontinuous
E	Firing degree	Cosine	V_{dc}	I_{dc}	Current ripple
Time constant = 0.1					
250	45	0.707388	296	2.92	0

Figure 2.2 shows a three-phase thyristor bridge with an *R-L* load.

Table 2.1 shows the details of a design of experiments performed with the circuit shown in Fig. 2.2 for a variation of Firing angle and the load. The variation of load is expressed in terms of the ratio *L*/*R*, shown as 'Time Constant'.

As mentioned in Chap. 1, an inherent phenomenon in a power electronics system is the deviation of the output of the system alternating above and below the desired output. This undesired phenomenon is called '*ripple*'. The table also shows the effect of inductance and firing angle on the peak to peak ripple of the output current.

A model is shown in Fig. 2.2, created using MATLAB®, and Simulink® and the parameters mentioned in this table are measured from the Simulink® model (Figs. 2.3, 2.4 and 2.5).

From Table 2.1, it can be seen that the DC voltage V_{dc} and the DC current I_{dc} change with the firing angle alpha. The magnitude of the DC link voltage and current reduces as the firing angle increases and the ripple in DC voltage and current increases due to the discontinuity in the current. As the inductance increases the ripple decreases due to the increased time constant.

Mathematically, for a three-phase thyristor converter, the output voltage is related to input voltage and the firing angle, expressed as:

$$V_o = 3 * \sqrt{3} * (V_m/\pi) * \cos\alpha \tag{2.1}$$

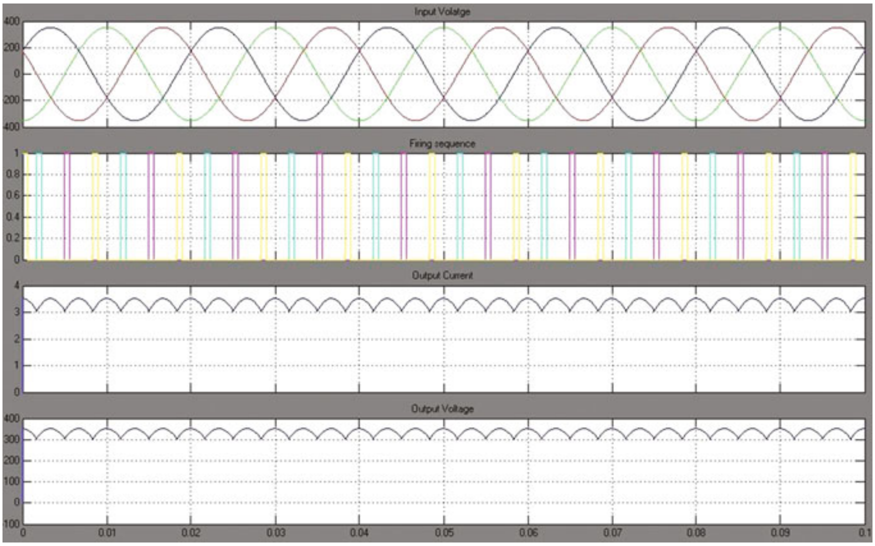

Fig. 2.3 The waveform for input voltage firing sequence, output voltage and output current for R = 100 Ω, L = 0 H, firing angle of 45°

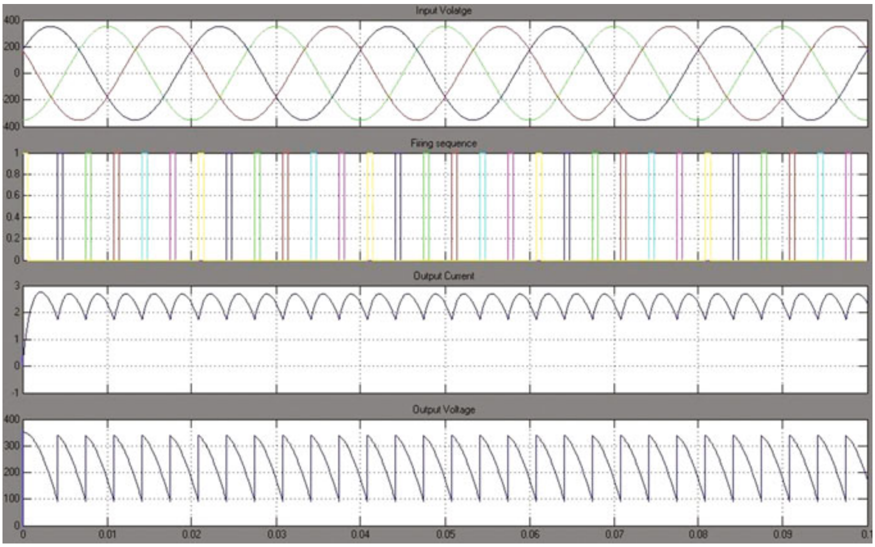

Fig. 2.4 The waveform for input voltage firing sequence, output voltage and output current for R = 100 Ω, L = 0.1 H, firing angle of 45°

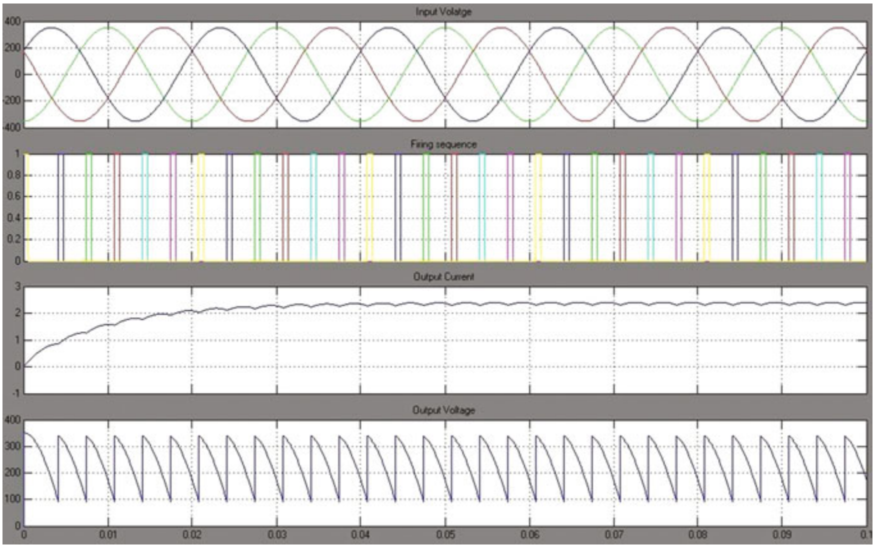

Fig. 2.5 The waveform for input voltage firing sequence, output voltage and output current for R = 100 Ω, L = 1 H, firing angle of 45°

where:

V_o Average voltage output from the converter
V_m Peak of the input voltage
α Firing angle

The observations in the DoE are also further detailed in terms of the waveforms of output voltage, output current, and the input voltage are shown in Figs. 2.3, 2.4 and 2.5.

Thus, the primary purpose of the inductance in the power circuit of the thyristor converter is to reduce the ripple in the output voltage and current.

A typical industrial Power Electronic system consists of two major parts, i.e., the *Power circuit* and the *Control circuit*. In this chapter the power circuit of the thyristor rectifier was explained with the DoE and instantaneous waveforms of the input and output.

The next chapter will deal with the basics of closed loop control and the Control circuits used in power electronics systems.

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