CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Power electronics may be considered a revolutionary field in electrical engineering because of the new insights obtained during its development. This has actually been the case from the beginning, when mercury arc rectifiers and thyratrons were employed in grid-controlled circuits. After this first generation of power devices and converters, power electronics with silicon power diodes and thyristors was developed to overcome many of the problems of the first generation, such as the operation in low efficiency. As mentioned in Reference 1, the so-called power electronics, with gas tube and glass-bulb electronics, was known as industrial electronics, and the power electronics with silicon-controlled rectifiers began emerging in the market in the early 1960s.

The different definitions of power electronics lead to the same concept or idea: that the control of power flow between an apparatus that furnishes electrical energy and another one that demands electrical energy. For instance, the definition given in References 2 and 3 say, respectively: "… power electronics involves the study of electronic circuits intended to control the flow of electrical energy. These circuits can handle power flow at levels much higher than the individual devices ratings … " and "… power electronics deal with conversion and control of electrical power with the help of electronic switching devices."

Power electronics involves several academic disciplines creating a complex system, including semiconductor physics, control theory, electronics, power systems, and circuit principles. The comprehensive aspect of power electronics makes the presentation of its contents difficult. The interdisciplinary nature of power electronics requires the integration of the practices and assumptions of all the academic disciplines involved, as well as calling for significant prerequisites on the part of the students enrolled for the course. Figure 1.1 illustrates this by analogy, with the prerequisite skills needed for a power electronics course being shown as the roots of a tree, the various power electronics devices as the trunk, and the resulting technologies and applications (power quality, renewable energy systems, etc.) as the branches.

Since the dawn of solid-state power electronics, the use of semiconductor devices has been the major technology to drive power processors. A comparison

Advanced Power Electronics Converters: PWM Converters Processing AC Voltages,
Forty Fifth Edition. Euzeli Cipriano dos Santos Jr. and Edison Roberto Cabral da Silva.

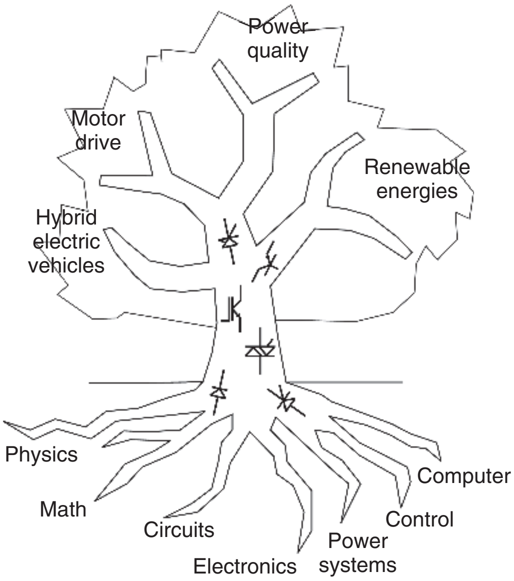

Figure 1.1 Interdisciplinary nature and new insights obtained from power electronics.

of the semiconductor devices formerly used in controlled rectifiers with new technologies underlines this dramatic development. In addition to the improvement of power switches, there has also been great activity in terms of circuit topology innovations.

A power electronic converter is the centerpiece of many electrical systems. Common applications include, but are not limited to, motor drive systems, renewable energies, robotics, electrical and hybrid vehicles, and circuits promoting power quality. These applications have required considerable research worldwide to develop semiconductor devices, configurations that process ac and dc variables, control and diagnosis, fault-tolerant systems, and the like.

In addition to the technical side mentioned already, the educational aspects have considerable importance, as students usually consider power electronics courses to be particularly difficult, perhaps because of their interdisciplinary nature. Achieving student motivation is thus a fundamental task of educators involved in the field of power electronics.

In this context, this book discusses a novel methodology for presenting an important set of power electronics converters, that is, topologies that process ac voltage. The common approach to teaching converters is to consider each type individually, in a separated and isolated manner. The direct consequence is that the learning process becomes passive as the power electronics configurations are presented without any consideration of their origin and development. Since the teaching process is based on the topology itself, students develop no ability to construct new topologies, different from the conventional ones. Section 1.2 outlines this new methodology.

1.2 BACKGROUND

Although presenting the basics of power devices as well as an overview of the main power converter topologies in Chapter 2, this book focuses primarily on configurations processing ac voltage through a dc-link stage. This book is ideally suited for students who have already taken an introductory course in power electronics. It also serves as a reference book to senior undergraduate and graduate students in electrical engineering courses. However, students can easily manage despite the lack of knowledge of power devices and basic concepts of converters, because they are explained in Chapter 2.

Systems with power electronics conversion have been used to guarantee grid and load requirements in terms of controllability and efficiency of the electrical energy demanded, especially in industrial applications. Power electronics topologies convert energy from a primary source to a load (or to another source) requiring any level of processed energy.

Classifications of the power electronics topologies can be done in terms of the type of variable under control (i.e., ac or dc), as well as the number of stages of power conversions used, as observed in Fig. 1.2. Figure 1.2(a) shows, in a general way, many of the possibilities related to energy conversion. Figure 1.2(b) highlights a direct ac–ac conversion, which converts an ac voltage (v_1) with a specific frequency (f_1) to another ac voltage with a different (or same) voltage (v_2) and frequency (f_2); this converter is normally called a cycle converter. Figure 1.2(c) depicts the ac–dc or dc–ac conversion, while Fig. 1.2(d) shows a dc–dc converter. Even admitting

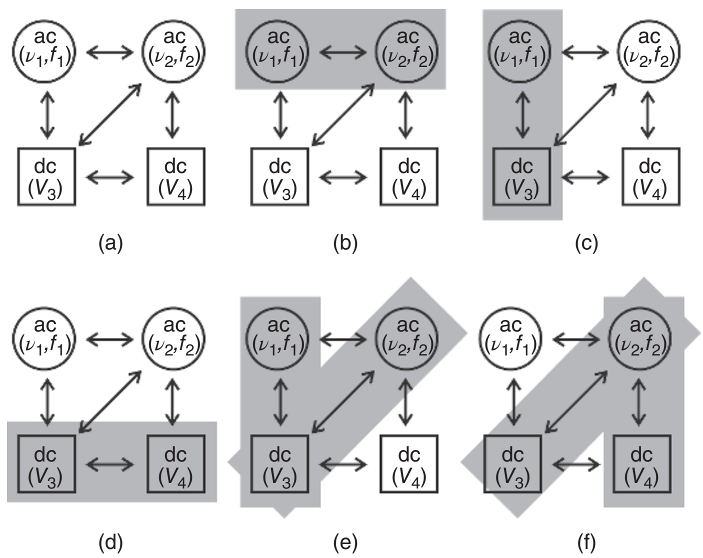

Figure 1.2 Power conversion: (a) all possibilities of conversion, (b) cycle converter, (c) rectifier or inverter, (d) chopper, (e) ac–dc–ac, and (f) dc–ac–dc.

that Fig. 1.2(e) and 1.2(f) could be considered as extended versions of the previous cases, those conversion systems (ac–dc–ac and dc–ac–dc) are presented in Fig. 1.2 because of the large use in different applications.

Special attention is given to the conversion systems presented in Fig. 1.2(c) and 1.2(e), dealing with configurations that process ac voltage (at input and/or output converter sides) with one dc stage. A systematic approach is taken for the presentation of those configurations, instead of just showing them separately, as is normally done in a conventional presentation. Another aspect of this book is that only the subjects related to the converters themselves will be considered, which means that the contents dealing with either ac filters or transformers will be omitted. This will give more room for exploring the details of each topology and its concept. In this way, the method of conceptual construction of power electronics converters can be highlighted appropriately.

1.3 HISTORY OF POWER SWITCHES AND POWER CONVERTERS

Configurations of power electronics converters have provided an attractive alternative for the applications needing energy processing, considering the acceptable level of losses associated with the conversion process itself, as well as improvement in reliability. As previously mentioned, power electronics converters must control the power flow, which means that the development of the devices used in those converters is crucial to guarantee the expected features. In this section, a historic view of the power electronics devices will be furnished, highlighting the main events that contributed to the current development.

The history of power electronics predates the development of the semiconductor devices employed nowadays. The first converters were conceived in the early 1900s, when the mercury arc rectifiers were introduced. Until the 1950s the devices used to build power electronics converters were grid-controlled vacuum tube rectifier, ignitron, phanotron, and thyratron. There were two important events in the power electronics development: (i) in 1948, when Bell Telephone Laboratories invented the silicon transistor, with applications in very low power devices such as in portable radios and (ii) in 1958, when the General Electric Company developed the thyristors or SCR, first using germaniums and later silicon. It was the first semiconductor power device.

Besides these two events, many developments have been achieved in terms of switching development. Between 1967 and 1977, the gate turnoff (GTO) (gate-controlled switch) and gate-assisted turnoff thyristor (GATT) (gate-assisted turnoff switch) were invented. Power transistors, MOSFETs (metal oxide semiconductor field-effect-transistors), MCTs (MOS-controlled thyristor) and IGBTs (insulated-gate-bipolar transistors) have been invented since the end of 1970s. In addition, it is worth mentioning that the area of power electronics was deeply influenced by microelectronics development, and the history of power electronics is closely related to advances in integrated circuits to control switching power supplies.

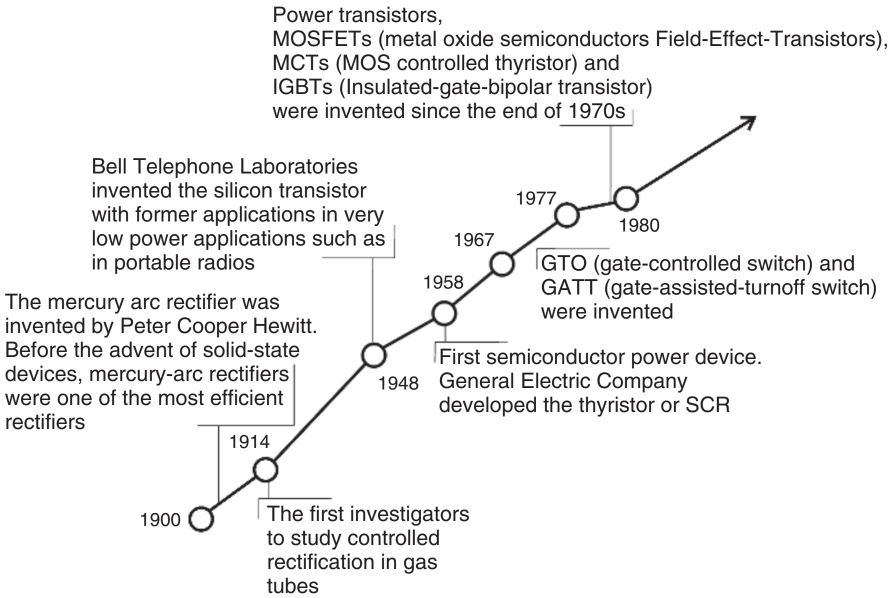

Figure 1.3 Timeline of historical events in the power electronics devices evolution.

Figure 1.3 depicts the timeline showing the development of power electronics devices.

An important chapter in the history of power electronics converters was the development of switching power suppliers. In 1958, the IBM 704 computer, which was developed for large-scale calculations, used as a switching power supplier the primitive vacuum tube-based switching regulator. But the revolution in power supplier concepts came in the late 1960s, when the switching power supplies replaced the linear ones. In a linear power supply, regulated dc voltages are obtained from the ac utility grid throughout the following sequence of steps: (i) 60 Hz power transformer, to converter 120 ac voltage at the primary transformer side to low voltage at secondary transformer side; (ii) such voltage is converted to dc with a simple diode rectifier; and (iii) a linear regulator drops the voltage to a desired value. Indeed, it is possible to identify many problems related to this technology, such as low efficiency (50–65% of the power is wasted as heat), and it was heavy and large (mainly due to the low frequency transformer, heatsink and fans to deal with the heat). The advantages are that it has a very stable output voltage and the conversion system is noise-free.

To overcome the disadvantages of the linear regulators, General Electric published a design of an early stage switching power supply in 1959.

The concept of switching power suppliers is very different from linear regulators. Instead of conducting power 100% of the time (i.e., turning excess power into heat), the switches and passive elements are connected to rapidly turn the power on and off. Unlike linear regulators, the ac utility voltage is converted directly to dc voltage, and the gating signal controls the time of the switching, regulating the average voltage desired at the output converter end.

Another important development in power electronics configurations was the controlled rectifiers, especially with the production of the silicon-controlled rectifier (SCR or thyristor). Such a device allowed the control of high power by just changing the signal applied to its gating circuit with higher efficiency rather than the older technology of employing a mercury arc rectifier.

1.4 APPLICATIONS OF POWER ELECTRONICS CONVERTERS

The range of applications for power electronics converters is so large that it goes from low power residential applications to high power transmission lines. Many of those applications can be considered as traditional ones (e.g., rectification circuits and motor drive systems). On the other hand, a few emerging applications have generated wide interest (e.g., renewable energy systems). A brief discussion matching the power electronics converters with those applications will be introduced here, with the details of those applications being presented throughout the chapters.

Figures 1.4 and 1.5 summarize some examples that demonstrate the presence of power electronics in a wide range of applications. Figure 1.4(a) shows schematically the application of power electronics in hybrid/electric vehicles. From the power

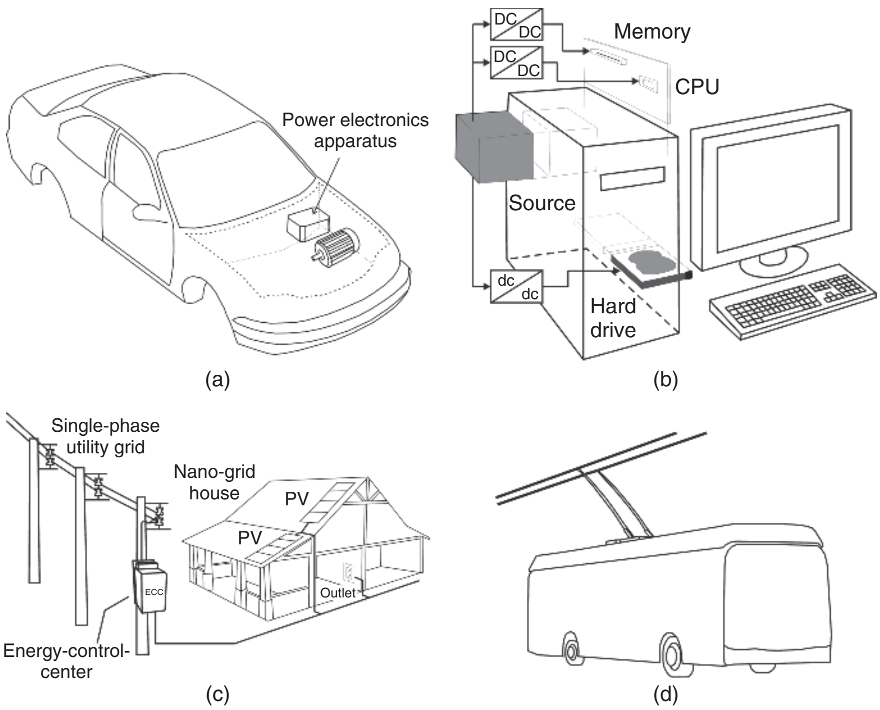

Figure 1.4 Applications of power electronics using converters that process ac voltage.

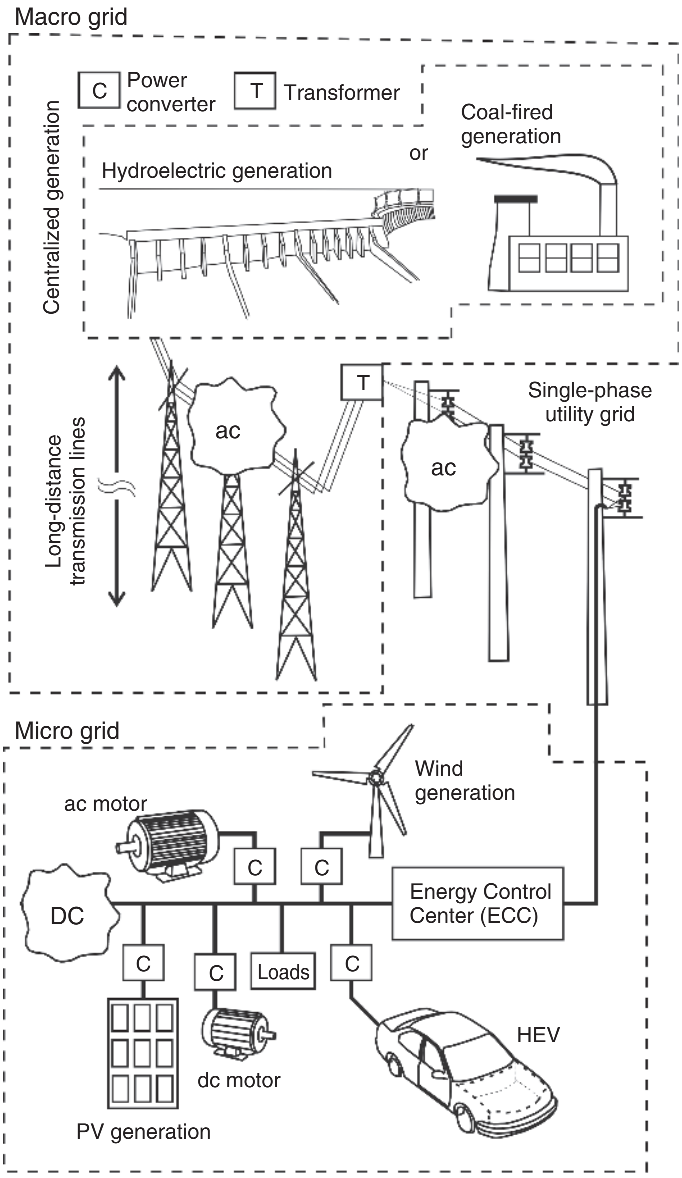

Figure 1.5 Application of power electronics in a distributed generation system. C stands for converter.

electronics point of view, the hybrid and fully electric automobiles differ one from another, mainly due to the power ratings of the inverters used. While a typical inverter rating is about 50 kW for the hybrid vehicle, the inverter rating for a fully electric vehicle is about 200 kW. The inverter motor drive system that furnishes energy to the power-train is by far the most important power electronics system used in this kind of application, but the battery charge and other peripheral systems are also crucial. The main features expected in this application are high efficiency performance, compact on-board energy storage, and low manufacturing cost for market competition with conventional thermal-engine vehicles.

Desktop and laptop computers can be considered as systems with on-board distribution schemes where different dc bus voltages are required. Inside these equipment can be found many power electronics converters, as seen in Fig. 1.4(b). An ac–dc converter produces a dc voltage bus from an ac utility grid, which will be employed by different dc–dc converters to supply the microprocessor, disk drive, memory, and so on. In the case of laptops, a battery charger is added with a power management system to control sleep modes, which guarantees extension in battery life via power consumption reduction.

Figure 1.4(c) shows the application of the power electronics converters in renewable energy systems, which nowadays is a hot topic in the political agenda of many industrialized countries, mainly due to environmental issues and as an alternative way to establish a decentralized generation system. It is worth mentioning that, besides the advantages of renewable energy, this kind of system presents a high price energy generation, especially when it is compared to conventional sources such as hydroelectric power and coal. In this sense, power electronics converters must deal with efficiency, reliability, and cost reduction, in order to make those alternative sources of energy more competitive.

Figure 1.4(d) shows a trolley bus, which is an electric bus that receives electrical energy directly from overhead wires (generally suspended from roadside posts) by using spring-loaded trolley poles.

A well-defined traditional power distribution system has a radial topology and unidirectional power flow to feed end-users. However, in the last few years, there has been research and development in replacing this paradigm by a new and complex multisource system with active functions and bidirectional power flow capability. In this new scenario, the utility grid is supposed to guarantee load management and demand side management, as well as using market price of electricity, and forecasting of energy (e.g., based on wind and solar renewable sources) in order to optimize the distribution system as a whole.

A microgrid can be defined as a localized grouping of electricity generation, energy storage, and loads that are normally connected to a traditional centralized grid (macrogrid), as seen in Fig. 1.5. Figure 1.5 shows a microgrid with a dc bus, where the power converters (represented generically by the letter C) interface distributed sources and loads with the dc bus. The point of common coupling (PCC) between micro- and macrogrid can be disconnected, which means that the microgrid can then operate autonomously. In this case, an island detection system is necessary, which safely disconnects the microgrid. The interface between micro- and macrogrid is possible due to advances made in the power electronics

The important equipment in this scenario is the Energy-Control-Center (ECC), consisting of a bidirectional ac–dc (or dc–ac) power conversion converter used to interface the utility ac grid and dc bus. The multiple dispersed generation sources and the ability to isolate the microgrid from a larger network would provide highly reliable electric power.

Another important area in which power electronics is becoming more and more common is in aerospace industry. Many loads classically powered by hydraulic networks were replaced by electrical power loads (e.g., pumps and braking). Besides facing the common challenges, the power electronics converters must deal with harsh environment constraints in terms of temperature, low pressure, humidity, and vibrations.

1.5 SUMMARY

Following the introduction, this chapter presents in Section 1.2 the background of the book, highlighting the type of configurations that this book will deal with (i.e., dc–ac and ac–dc–ac converters). Section 1.3 gives a brief history of the power electronics devices and power electronics converters, focusing on the development of switching power suppliers and SCR rectifiers. Finally, some applications are considered in Section 1.4 to show the wide range of applications of power electronics converters. Readers can find further discussion from References 4 to 13.

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