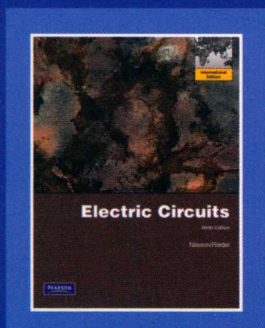


国外电子与通信教材系列

Pearson

詹姆斯·尼尔森

Electric Circuits, Ninth Edition



电路分析基础 (第二版) (英文版)

[美] James W. Nilsson 著
Susan A. Riedel

王宏祥 张 民 改编

中国工信出版集团



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内 容 简 介

本书系统全面地讲解了电子电路及电子系统的基本元件、基本概念、基本分析理论和计算方法, 主要内容包括电路基本元件、简单电阻电路分析、电路常见分析法、运算放大器基本应用电路、一阶和二阶电路的分析、正弦稳态分析及其功率计算、平衡三相电路、变压器、选频电路及滤波器等。此外, 本书结合多年教学经验和生活中的实际应用, 给出了大量例题和习题、详尽的图表资料和丰富的实用电路范例。

本书适合作为电气、电子、计算机与自动化等本科专业电路分析或电路理论课程的双语教材, 也可供相关学科的科技人员自学或参考。

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导 读

本书是根据*Electric Circuits, Ninth Edition*改编的双语教学教材。原书内容丰富，系统完整，自成体系，经过不断的实践与修订，如今已成为电路理论课程的优秀教材，受到很高的评价，是欧美国家电路类课程采用最广泛的教材。两位作者James W. Nilsson和Suan A. Riedel都是在美国大学任教几十年的资深教授，曾获得许多荣誉和奖励。本改编版在原书内容的基础上，结合国内高等教育中电路分析课程开展英语或双语教学的特点，进行了部分内容的调整，主要包括以下内容：

- 电路变量与电路元件
- 简单电阻电路分析
- 一般电路分析方法
- 含运算放大器的电路分析
- 电容和电感元件
- 一阶 RC 和 RL 电路的响应
- 二阶 RLC 电路的响应
- 正弦稳态电路分析
- 平衡三相电路
- 频率选择电路

电路分析是电子信息和电气工程类专业的一门专业基础课，其先修课程为高等数学和大学物理，同时也是其他专业基础课的先修课程，为模拟电子电路、数字电子电路、高频电子电路、信号与系统等许多后续课程提供理论支持。

与其他专业基础课相比，电路分析是一门既有理论性、又有很强实践性和专业性的课程。电路分析的核心是研究电路中的普遍规律，根据电路模型探讨各种电路的一般性分析和计算方法，在给定电路结构和参数的条件下，分析计算电路中各部分的电压、电流、功率和能量，研究电路中的激励和响应之间的关系，分析电路的特性，为电路综合和设计提供必要的理论基础。主要内容包括电路的基本概念、电路中的基本定律和定理，以及电路的基本分析方法。

电路分析课程的学习要领是，理解电流参考方向和电压参考极性的基本概念，在集总电路模型的假设下，抓住决定电路特性的两个约束：拓扑约束和元件约束，掌握三大基本分析方法：叠加方法、分解方法和变换域分析方法。其中，关于变换域分析方法，因为与信号与系统、数字信号处理等后续课程教材中的内容重叠较多，本书仅包含了正弦激励下的相量域（频域）的部分内容。

本书第1章重点介绍电路与电路分析的基本概念，对电路中的电流、电压、功率、能量等基本物理量进行了定义，介绍了理想基本电路元件和集总电路模型的概念，在此基础上对高中阶段学习的电源模型进行扩展，引入了理想电压源和电流源、独立电源和受控电源的概念及其电压电流约束关系。最后介绍了在电流参考方向和电压参考极性满足关联参考方向（Passive Sign Convention）定义下的电阻性元件的电压电流约束关系：欧姆定律。

在学习完第1章基本概念的基础上,从第2章起陆续开始介绍电路中的基本定律和定理,以及一般电路的分析方法。第2章首先定义了电路分析中经常用到的一些术语,包括节点、支路、通路、回路、网孔等,然后揭示了一般电路中电流和电压满足的普遍规律,即基尔霍夫电流定律(KCL)和基尔霍夫电压定律(KVL)。这两个定律就是决定电路特性的第一个约束关系,即拓扑约束,这是整个电路分析的基础,是学好电路分析课程的关键。至此,对于电阻性电路来说,决定电路特性的两个约束关系,即拓扑约束和元件约束都已经具备,理论上可以进行一般电路电压电流的计算和电路特性分析了。本章后面的内容介绍了一般电阻性电路分析中经常用到的两个简化方法:源变换方法和叠加方法,以及三角形-星形电阻网络的等效变换。

第3章是全书的重点,这一章在基尔霍夫电流定律和基尔霍夫电压定律的基础上,介绍了两个对所有平面电路都普适的电路分析方法:节点电压分析法和网孔电流分析法。节点电压分析法以一组完备的节点电压为未知变量,列出 $(n-1)$ (n 为电路的节点数量)个独立的基尔霍夫电流定律方程联立求解;而网孔电流分析法以一组完备的网孔电流作为未知变量,列出 m (m 为电路的网孔数量)个独立的基尔霍夫电压定律方程联立求解。这两个方法功能强大,任选其一就可以解决一般的电路分析计算问题。在学习中,应注意对节点电压和网孔电流基本概念的理解。至此,读者会发现自己的电路分析能力将会有质的飞越。在以上知识点的掌握下,辅以必要的练习,一般电阻性电阻的电压电流计算问题应该都已经不在话下。这一章后面介绍的戴维南和诺顿等效方法、最大功率传输定理,对于电路等效和简化分析,都起到非常重要的作用。

第4章是包含运算放大器的电路分析方法,首先介绍了运算放大器的基本概念、电路符号、各端子的定义及其工作模式,然后推导出了关于理想运算放大器端电压和端电流的两个重要结论:虚短和虚断。采用虚短和虚断的概念,辅以第3章中介绍的节点电压分析法,基本上可以解决所有含理想运算放大器电路的分析计算。本章后面介绍的同相放大电路、反相放大电路、求和放大电路、差分放大电路、电压比较器等,既为以上介绍的含运算放大器电路分析方法提供了示例,同时也是运算放大器的典型应用实例,使同学们对电路分析的具体应用有更为直观的体会。另外,在学习中还应注意理想运算放大器的饱和问题。

前面四章内容都是关于电阻性电路的分析的。特别需要指出的是,前面所介绍的基本概念、基本电路定律和定理、电路分析方法、电路等效变换方法等,虽然都是以电阻性电路为例,但是这些方法实际上同样适用于后面章节要介绍的动态电路的时域和相量域分析。以相对来说较为简单的电阻性电路为例来介绍这些一般电路的分析方法,也较为容易理解和掌握。

电阻性电路的元件约束关系比较简单,相应的电路分析问题也比较简单,但所能完成的功能也很有限。实际应用中,很少有纯电阻电路,大多数电路都会使用像电容、电感这样的动态电路元件。动态电路的分析比电阻性电路的分析要复杂一些,但所完成的功能也更强、更多样。本书从第5章开始进入包含电容和/或电感元件的动态电路分析。动态电路与电阻性电路的区别就是电路中至少包含了一个动态元件(电容或电感)。本章首先介绍了电容器和电感器元件的电压电流的时间域约束关系,再加上前面介绍的基尔霍夫电流定律和基尔霍夫电压定律拓扑约束关系,理论上可以确定动态电路的特性,解决动态电路的时域电压电流分析计算。第3章介绍的各种电路分析方法对动态电路也同样适用。在这一章的学习中,需要重点掌握电容电感元件的微分和积分形式的电压电流约束关系,并在此基础上理解“动态”的含义,以及动态电路中“阶数”、固有响应、阶跃响应的基本概念,理解一阶RC和RL电路中“时间常数”的物理意

义及其计算方法,掌握用三要素方法分析计算一阶电路的响应,并分别从数学和物理意义上理解为什么可以用三要素方法直接写出所有一阶 RC 和 RL 电路的响应。

第6章在学习一阶 RC 和 RL 电路的基础上,介绍了二阶并联和串联 RLC 电路的概念,以及二阶电路的固有响应和阶跃响应,讨论了二阶电路参数对电路响应的影响,结合具体电路探讨了欠阻尼、过阻尼和临界阻尼响应的概念和物理意义。

动态电路的时域响应虽然比较直观,物理意义清晰,也较容易理解,但是采用第5章和第6章中的方法,对于阶数较高的动态电路的分析,由于涉及高阶微分方程的求解,将会变得非常困难,尤其是当电路激励电源为交流电源时,更为复杂。第7章以最简单的正弦交流电源激励为例,通过引入相量的概念,介绍了动态电路稳态响应的相量域(频域)分析求解方法,具体包括正弦电压电流的相量变换和逆变换、基本电路元件(电阻、电容和电感)的相量形式的电压电流约束关系、相量形式的基尔霍夫电流定律和基尔霍夫电压定律,以及在此基础上的相量形式的节点电压分析法和网孔电流分析法;用于电路等效简化的源变换方法、戴维南和诺顿等效方法;阻抗和导纳的概念及其串并联等效,等等。应重点理解相量、阻抗等基本概念,重点掌握相量域的正弦稳态响应分析求解方法。特别要指出的是,在动态电路正弦稳态响应分析中,功率的概念和计算远比直流激励的电阻性电路复杂,结合三种基本电路元件的功率计算,应重点理解瞬时功率、平均功率、有功功率、无功功率、复功率、视在功率等基本概念和物理意义,掌握电路负载匹配时获得最大平均功率的计算方法。

第8章介绍平衡三相电路,主要包括平衡三相电压、三相电压源、 Y - Y (星形-星形)和 Y - Δ (星形-三角形)平衡三相电路的分析方法,以及平衡三相电路的功率计算,重点理解平衡三相电压、线电压、相电压、线电流、相电流等基本概念及其计算方法。

前面在第7章重点介绍了确定的单一频率的正弦交流电源激励下的电路的稳态响应,但在实际应用中,电路的激励电源往往不只包含单一频率,而是包含很多频率,即有一定的频带宽度。第9章的主要内容就是分析当电路激励源的频率变化时电路的电压或电流响应,即电路的频率响应。本章应重点理解频率选频电路(滤波器)、传递函数、通带、阻带、低通滤波器、高通滤波器、带通滤波器、截止频率、中心频率、带宽、品质因子等基本概念,掌握串联 RL 串联 RC 电路分别实现低通滤波器和高通滤波器的定性分析与定量计算,掌握串联 RLC 电路实现带通滤波器和带阻滤波器的定性分析与定量计算。

通过本书的学习,读者已经掌握了电路分析的基本概念、理论和分析方法,为从事相关电路分析和综合设计工作以及相关专业的后续课程学习打下了扎实的基础。

回顾本书的知识结构和章节构成,不难看出本书主要以“先电阻性电路,后动态电路;先直流、后交流;先时域响应,后相量域(频域)响应”为线索,按照由易到难、由浅入深的顺序,依次展开。在学习过程中,建议多注意从数学和物理层面对电路中的定律、基本概念等多思考,深入理解,并辅以必要的习题练习,以求达到事半功倍的效果。

在北京邮电大学国际学院的“电子系统基础”课程中,我们采用了本书作为教材。通过十多年的教学反馈,笔者深有体会,书中丰富的例题和详细的讲解,对于初学者的理解和自主学习都大有裨益。

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Chapter 1

Circuit Variables and Circuit Elements

电路变量与电路元件

Electrical and computer engineering are exciting and challenging professions for anyone who has a genuine interest in, and aptitude for, applied science and mathematics. Over the past century and a half, electrical and computer engineers have played a dominant role in the development of systems that have changed the way people live and work. Satellite communication links, telephones, digital computers, televisions, diagnostic and surgical medical equipment, assembly-line robots, and electrical power tools are representative components of systems that define a modern technological society. As an electrical or computer engineer, you can participate in this ongoing technological revolution by improving and refining these existing systems and by discovering and developing new systems to meet the needs of our ever-changing society.

We begin our study with an overview of circuit analysis. This is followed by an introduction to the concepts of voltage, current, the basic circuit elements, power, and energy. Next we introduce both independent and dependent voltage and current sources. We conclude this introductory chapter with a discussion of electrical resistance and Ohm's law.

1.1 Circuit Analysis: an Overview

电路分析概述

Before becoming involved in the details of circuit analysis, we need to take a broad look at engineering design, specifically the design of electric circuits. The purpose of this overview is to provide you with a perspective on where circuit analysis fits within the whole of circuit design. Even though this book focuses on circuit analysis, we try to provide opportunities for circuit design where appropriate.

All engineering designs begin with a need, as shown in Fig. 1.1. This need may come from the desire to improve on an existing design, or it may be something brand-new. A careful assessment of the need results in design specifications, which are measurable characteristics of a proposed design. Once a design is proposed, the design specifications allow us to assess whether or not the design actually meets the need.

A concept for the design comes next. The concept derives from a complete understanding of the design specifications coupled with an insight into the need, which comes from education and experience. The concept may be realized as a sketch, as a written description, or in some other form. Often the next

step is to translate the concept into a mathematical model. A commonly used mathematical model for electrical and computer systems is a **circuit model**.

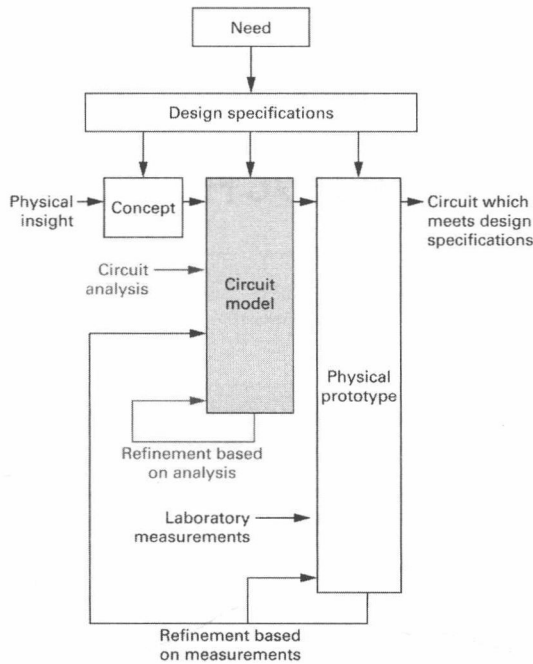


Figure 1.1 A conceptual model for electrical engineering design.

The elements that comprise the circuit model are called **ideal circuit components**. An ideal circuit component is a mathematical model of an actual electrical component, like a battery or a light bulb. It is important for the ideal circuit component used in a circuit model to represent the behavior of the actual electrical component to an acceptable degree of accuracy. The tools of **circuit analysis**, the focus of this book, are then applied to the circuit. Circuit analysis is based on mathematical techniques and is used to predict the behavior of the circuit model and its ideal circuit components. A comparison between the desired behavior, from the design specifications, and the predicted behavior, from circuit analysis, may lead to refinements in the circuit model and its ideal circuit elements. Once the desired and predicted behaviors are in agreement, a physical prototype can be constructed.

The **physical prototype** is an actual electrical system, constructed from actual electrical components. Measurement techniques are used to determine the actual, quantitative behavior of the physical system. This actual behavior is compared with the desired behavior from the design specifications and the predicted behavior from circuit analysis. The comparisons may result in refinements to the physical prototype, the circuit model, or both. Eventually, this iterative process, in which models, components, and systems are continually refined, may produce a design that accurately matches the design specifications and thus meets the need.

From this description, it is clear that circuit analysis plays a very important role in the design process. Because circuit analysis is applied to circuit models, practicing engineers try to use mature circuit models so that the resulting designs will meet the design specifications in the first iteration. In this book,

we use models that have been tested for between 20 and 100 years; you can assume that they are mature. The ability to model actual electrical systems with ideal circuit elements makes circuit theory extremely useful to engineers.

Saying that the interconnection of ideal circuit elements can be used to quantitatively predict the behavior of a system implies that we can describe the interconnection with mathematical equations. For the mathematical equations to be useful, we must write them in terms of measurable quantities. In the case of circuits, these quantities are voltage and current, which we discuss in Section 1.2. The study of circuit analysis involves understanding the behavior of each ideal circuit element in terms of its voltage and current and understanding the constraints imposed on the voltage and current as a result of interconnecting the ideal elements.

1.2 Voltage, Current, and the Basic Circuit Elements

电压、电流与基本电路元件

Electric Charge

The concept of electric charge is the basis for describing all electrical phenomena. Let's review some important characteristics of electric charge.

- The charge is bipolar, meaning that electrical effects are described in terms of positive and negative charges.
- The electric charge exists in discrete quantities, which are integral multiples of the electronic charge, 1.6022×10^{-19} C.
- Electrical effects are attributed to both the separation of charge and charges in motion.

Voltage and Current

In circuit theory, the separation of charge creates an electric force (voltage), and the motion of charge creates an electric fluid (current).

The concepts of voltage and current are useful from an engineering point of view because they can be expressed quantitatively. Whenever positive and negative charges are separated, energy is expended. **Voltage** is the energy per unit charge created by the separation. We express this ratio in differential form as

$$v = \frac{dw}{dq}, \quad (1.1)$$

where

v = the voltage in volts,

w = the energy in joules,

q = the charge in coulombs.

The electrical effects caused by charges in motion depend on the rate of charge flow. The rate of charge flow is known as the **electric current**, which is expressed as

$$i = \frac{dq}{dt}, \quad (1.2)$$

where

i = the current in amperes,
 q = the charge in coulombs,
 t = the time in seconds.

Equations (1.1) and (1.2) are definitions for the magnitude of voltage and current, respectively. The bipolar nature of electric charge requires that we assign polarity references to these variables. We will do so in the next section.

Although current is made up of discrete, moving electrons, we do not need to consider them individually because of the enormous number of them. Rather, we can think of electrons and their corresponding charge as one smoothly flowing entity. Thus, i is treated as a continuous variable.

One advantage of using circuit models is that we can model a component strictly in terms of the voltage and current at its terminals. Thus two physically different components could have the same relationship between the terminal voltage and terminal current. If they do, for purposes of circuit analysis, they are identical. Once we know how a component behaves at its terminals, we can analyze its behavior in a circuit. However, when developing circuit models, we are interested in a component's internal behavior. We might want to know, for example, whether charge conduction is taking place because of free electrons moving through the crystal lattice structure of a metal or whether it is because of electrons moving within the covalent bonds of a semiconductor material. However, these concerns are beyond the realm of circuit theory. In this book we use circuit models that have already been developed; we do not discuss how component models are developed.

1.3 The Ideal Basic Circuit Element

理想基本电路元件

An **ideal basic circuit element** has three attributes: (1) it has only two terminals, which are points of connection to other circuit components; (2) it is described mathematically in terms of current and/or voltage; and (3) it cannot be subdivided into other elements. We use the word *ideal* to imply that a basic circuit element does not exist as a realizable physical component. We use the word *basic* to imply that the circuit element cannot be further reduced or subdivided into other elements. Thus the basic circuit elements form the building blocks for constructing circuit models, but they themselves cannot be modeled with any other type of element.

Figure 1.2 is a representation of an ideal basic circuit element. The box is blank because we are making no commitment at this time as to the type of circuit element it is. In Fig. 1.2, the voltage across the terminals of the box is denoted by v , and the current in the circuit element is denoted by i . The polarity reference for the voltage is indicated by the plus and minus signs, and the reference direction for the current is shown by the arrow placed alongside the current. The interpretation of these references given positive or negative numerical values of v and i is summarized in Table 1.1. Note that algebraically the notion of positive charge flowing in one direction is equivalent to the notion of negative charge flowing in the opposite direction.

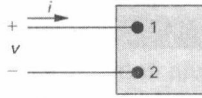


Figure 1.2 An ideal basic circuit element.

TABLE 1.1 Interpretation of Reference Directions in Fig. 1.2.

POSITIVE VALUE	NEGATIVE VALUE
v voltage drop from terminal 1 to terminal 2 <i>or</i> voltage rise from terminal 2 to terminal 1	voltage rise from terminal 1 to terminal 2 <i>or</i> voltage drop from terminal 2 to terminal 1
i positive charge flowing from terminal 1 to terminal 2 <i>or</i> negative charge flowing from terminal 2 to terminal 1	positive charge flowing from terminal 2 to terminal 1 <i>or</i> negative charge flowing from terminal 1 to terminal 2

The assignments of the reference polarity for voltage and the reference direction for current are entirely arbitrary. However, once you have assigned the references, you must write all subsequent equations to agree with the chosen references. The most widely used sign convention applied to these references is called the **passive sign convention**, which we use throughout this book. The passive sign convention can be stated as follows:

Whenever the reference direction for the current in an element is in the direction of the reference voltage drop across the element (as in Fig. 1.2), use a positive sign in any expression that relates the voltage to the current. Otherwise, use a negative sign.

We apply this sign convention in all the analyses that follow. Our purpose for introducing it even before we have introduced the different types of basic circuit elements is to impress on you the fact that the selection of polarity references along with the adoption of the passive sign convention is *not* a function of the basic elements or the type of interconnections made with the basic elements. We present the application and interpretation of the passive sign convention in power calculations in Section 1.4.

There are five ideal basic circuit elements: voltage sources, current sources, resistors, inductors, and capacitors. In this chapter we discuss the characteristics of voltage sources, current sources, and resistors. Although this may seem like a small number of elements with which to begin analyzing circuits, many practical systems can be modeled with just sources and resistors. They are also a useful starting point because of their relative simplicity; the mathematical relationships between voltage and current in sources and resistors are algebraic. Thus you will be able to begin learning the basic techniques of circuit analysis with only algebraic manipulations.

We will postpone introducing inductors and capacitors until Chapter 5, because their use requires that you solve integral and differential equations. However, the basic analytical techniques for solving circuits with inductors and capacitors are the same as those introduced in this chapter. So, by the time you need to begin manipulating more difficult equations, you should be very familiar with the methods of writing them.

DRILL EXERCISES

1.1 The current at the terminals of the element in Fig. 1.2 is

$$\begin{aligned} i &= 0, & t < 0; \\ i &= 20e^{-5000t} \text{ A}, & t \geq 0. \end{aligned}$$

Calculate the total charge (in microcoulombs) entering the element at its upper terminal.

Answer: 4000 μC .

1.2 The expression for the charge entering the upper terminal of Fig. 1.2 is

$$q = \frac{1}{\alpha^2} - \left(\frac{t}{\alpha} + \frac{1}{\alpha^2} \right) e^{-\alpha t} \text{ C}.$$

Find the maximum value of the current entering the terminal if $\alpha = 0.03679 \text{ s}^{-1}$.

Answer: 10 A.

1.4 Power and Energy

功率和能量

Power and energy calculations also are important in circuit analysis. One reason is that although voltage and current are useful variables in the analysis and design of electrically based systems, the useful output of the system often is nonelectrical, and this output is conveniently expressed in terms of power or energy. Another reason is that all practical devices have limitations on the amount of power that they can handle. In the design process, therefore, voltage and current calculations by themselves are not sufficient.

We now relate power and energy to voltage and current and at the same time use the power calculation to illustrate the passive sign convention. Recall from basic physics that power is the time rate of expending or absorbing energy. (A water pump rated 75 kW can deliver more liters per second than one rated 7.5 kW.) Mathematically, energy per unit time is expressed in the form of a derivative, or

$$p = \frac{dw}{dt}, \quad (1.3)$$

where

$$\begin{aligned} p &= \text{the power in watts,} \\ w &= \text{the energy in joules,} \\ t &= \text{the time in seconds.} \end{aligned}$$

Thus 1 W is equivalent to 1 J/s.

The power associated with the flow of charge follows directly from the definition of voltage and current in Eqs. (1.1) and (1.2), or

$$p = \frac{dw}{dt} = \left(\frac{dw}{dq} \right) \left(\frac{dq}{dt} \right) = vi, \quad (1.4)$$

where

p = the power in watts,
 v = the voltage in volts,
 i = the current in amperes.

Equation (1.4) shows that the **power** associated with a basic circuit element is simply the product of the current in the element and the voltage across the element. Therefore, power is a quantity associated with a pair of terminals, and we have to be able to tell from our calculation whether power is being delivered to the pair of terminals or extracted from it. This information comes from the correct application and interpretation of the passive sign convention.

If we use the passive sign convention, Eq. (1.4) is correct if the reference direction for the current is in the direction of the reference voltage drop across the terminals. Otherwise, Eq. (1.4) must be written with a minus sign. In other words, if the current reference is in the direction of a reference voltage rise across the terminals, the expression for the power is

$$p = -vi. \quad (1.5)$$

The algebraic sign of power is based on charge movement through voltage drops and rises. As positive charges move through a drop in voltage, they lose energy, and as they move through a rise in voltage, they gain energy. Figure 1.3 summarizes the relationship between the polarity references for voltage and current and the expression for power.

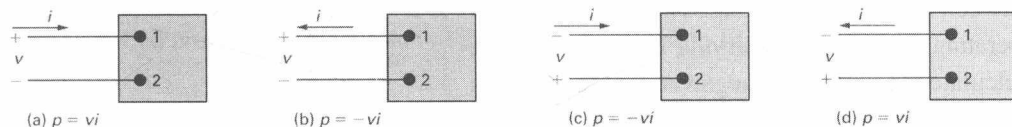


Figure 1.3 Polarity references and the expression for power.

We can now state the rule for interpreting the algebraic sign of power:

If the power is positive (that is, if $p > 0$), power is being delivered to the circuit inside the box.

If the power is negative (that is, if $p < 0$), power is being extracted from the circuit inside the box.

For example, suppose that we have selected the polarity references shown in Fig. 1.3(b). Assume further that our calculations for the current and voltage yield the following numerical results:

$$i = 4 \text{ A} \quad \text{and} \quad v = -10 \text{ V}.$$

Then the power associated with the terminal pair 1, 2 is

$$p = -(-10)(4) = 40 \text{ W}.$$

Thus the circuit inside the box is absorbing 40 W.

To take this analysis one step further, assume that a colleague is solving the same problem but has chosen the reference polarities shown in Fig. 1.3(c). The resulting numerical values are

$$i = -4 \text{ A}, \quad v = 10 \text{ V}, \quad \text{and} \quad p = 40 \text{ W}.$$

Note that interpreting these results in terms of this reference system gives the same conclusions that we previously obtained — namely, that the circuit inside the box is absorbing 40 W. In fact, any of the reference systems in Fig. 1.3 yields this same result.

DRILL EXERCISES

1.3 Assume that a 20 V voltage drop occurs across an element from terminal 2 to terminal 1 and that a current of 4 A enters terminal 2.

- (a) Specify the values of v and i for the polarity references shown in Fig. 1.3(a)-(d).
 (b) State whether the circuit inside the box is absorbing or delivering power.
 (c) How much power is the circuit absorbing?

Answer: (a) Circuit 1.3(a): $v = -20$ V, $i = -4$ A; circuit 1.3(b): $v = -20$ V, $i = 4$ A; circuit 1.3(c): $v = 20$ V, $i = -4$ A; circuit 1.3(d): $v = 20$ V, $i = 4$ A; (b) absorbing; (c) 80 W.

1.4 Assume that the voltage at the terminals of the element in Fig. 1.2 corresponding to the current in Drill Exercise 1.1 is

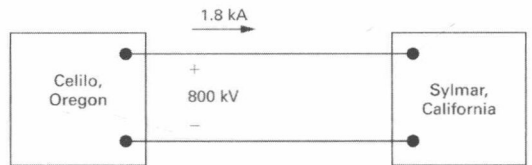
$$v = 0, \quad t < 0;$$

$$v = 10e^{-5000t} \text{ kV}, \quad t \geq 0.$$

Calculate the total energy (in joules) delivered to the circuit element.

Answer: 20 J.

1.5 A high-voltage direct-current (dc) transmission line between Celilo, Oregon and Sylmar, California is operating at 800 kV and carrying 1800 A, as shown. Calculate the power (in megawatts) at the Oregon end of the line and state the direction of power flow.



Answer: 1440 MW, Celilo to Sylmar.

1.5 Voltage and Current Sources

电压源和电流源

Before discussing ideal voltage and current sources, we need to consider the general nature of electrical sources. An **electrical source** is a device that is capable of converting nonelectric energy to electric energy and vice versa. A discharging battery converts chemical energy to electric energy, whereas a battery being charged converts electric energy to chemical energy. A dynamo is a machine that converts mechanical energy to electric energy and vice versa. If operating in the mechanical-to-electric mode, it is called a generator. If transforming from electric to mechanical energy, it is referred to as a motor. The important thing to remember about these sources is that they can either deliver or absorb electric power, generally maintaining either voltage or current. This behavior is of particular interest for circuit analysis and led to the creation of the ideal voltage source and the ideal current source as basic circuit elements. The challenge is to model practical sources in terms of the ideal basic circuit elements.

An **ideal voltage source** is a circuit element that maintains a prescribed voltage across its terminals regardless of the current flowing in those terminals. Similarly, an **ideal current source** is a circuit element that maintains a prescribed current through its terminals regardless of the voltage across those