"十二五"普通高等教育本科重点规划教材

English for Electrical Engineering(Second Edition)

电气工程专业英语

（第二版）

陈青　丛伟　编

中国电力出版社
CHINA ELECTRIC POWER PRESS

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内 容 提 要

本书为“十二五”普通高等教育本科重点规划教材。

本书共分7个单元，内容包括电机、电力系统、分布式发电技术、智能电网、智能变电站、电动汽车、专业英语的阅读翻译与写作等。本书结合电气工程类专业的教学要求，选编了大量的科技资料原文，并反映最新的技术进展，内容生动，图文并茂。本书还对常用的电气工程类专业英语词汇和短语进行了归纳整理，便于读者拓展自己的专业词汇，提高阅读与专业相关的英文资料的能力。本书内容尽可能做到丰富、新颖，教师可以针对不同的授课对象灵活调整授课内容。

本书既可作为普通高等学校电气工程及其自动化专业的本科和硕士研究生专业英语教材，也可作为高职高专电力技术类专业的专业英语教材，亦可作为相关工程技术人员学习专业英语的参考用书。

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前 言

本书为“十二五”普通高等教育本科重点规划教材，在上一版基础上重新修订和改编，根据教育部新颁布专业目录中“电气工程及其自动化专业”的宽口径特点而编写。

本书共分为7个单元，所选内容不仅包含了电机、电力系统的专业基础知识，还包含了分布式发电、智能电网、智能变电站、电动汽车等电力系统新技术。本书充分考虑了专业英语的课程特点，为满足教学需要，用一个单元的篇幅对专业英语的阅读翻译与写作方法进行了讨论，旨在进一步提高读者的阅读、翻译和写作技巧。本书还对常用的电气工程类英语词汇、短语进行了总结归纳，方便了读者的查阅和使用。

本书在选材和内容的设置上突出了“内容前沿、循序渐进、实用性强、难易结合”的特点，注重电气工程基础知识与最新技术的衔接，适应课程内容改革的需要。本书主要作为普通高等学校电气工程专业的本科及硕士研究生的专业英语教材，也可作为高职高专电气技术类专业的专业英语教材，亦可作为相关工程技术人员学习专业英语的参考用书。

本书由山东大学陈青教授、丛伟副教授编写。承蒙武汉大学胡钋教授百忙中对本书进行审阅，并提出了很多有价值的修改意见；研究生邢鲁华、王菲、王瑞、张志明、盖午阳在资料整理、校对过程中做了大量的工作，在此一并表示衷心的感谢！

由于编者水平所限，书中难免存在疏漏和有误之处，敬请读者在使用过程中不吝指教，以共同提高本书的质量和实用性。

编 者
2015年5月

第一版前言

为贯彻落实教育部《关于进一步加强高等学校本科教学工作的若干意见》和《教育部关于以就业为导向深化高等职业教育改革的若干意见》的精神，加强教材建设，确保教材质量，中国电力教育协会组织制订了普通高等教育"十一五"教材规划。该规划强调适应不同层次、不同类型院校，满足学科发展和人才培养的需求，坚持专业基础课教材与教学急需的专业教材并重、新编与修订相结合。本书为新编教材。

本书为普通高等教育"十一五"规划教材，根据教育部新颁布专业目录中"电气工程及其自动化专业"的宽口径特点而编写。

本书分为6个单元，所选文章内容不仅包括了电磁场理论、电路、电子技术、微机原理等专业基础课程的内容，还包含了电机学、电力电子、电力系统运行与分析等电气工程方向专业课程的内容，除此之外，单独设置了一个单元介绍电力系统新技术之一——分布式发电技术。本书充分考虑了专业英语的课程特点，为满足教学需要，用一个单元的篇幅对专业英语的阅读翻译与写作方法进行了讨论，旨在进一步提高读者的阅读、翻译和写作技巧。本书还对常用的电气工程类英语词汇、短语进行了总结归纳，方便了读者的查阅和使用。

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由于时间仓促、编者水平所限，书中难免存在疏漏和有误之处，敬请读者不吝指教，以共同提高本书的质量。

编　者

2009年9月

目　　录

Unit 1 Electrical Machines

1.1 Alternating-Current Machines

1.1.1 General

Electric machines find extensive application today in every branch of industry. They convert energy from mechanical to electrical form and from electrical to mechanical form. The machine converting energy from mechanical to electrical form is known as a generator and that converting from electrical to mechanical form is known as a motor.

The conversion process is essentially reversible[1], hence a generator can be made to act as a motor and a motor as a generator. An electric machine can also function as a frequency converter, phase converter, dc converter, etc.

Depending on the kind of current they generate or utilize, electric machines fall into two large classes, alternating-current (ac) machines and direct-current (dc) machines. AC machines can be of the single-phase and polyphase[2] types. Of these, the widest uses are made of three-phase synchronous and induction machines and also commutator machines which allow for the efficient adjustment of the rotational speed over a wide range.

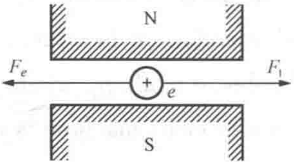


Figure 1-1 Schematic diagram illustrative of the principle of an electric machine

For its operation, an electric machine depends on electromagnetic induction and electromagnetic forces. Figure 1-1 illustrates the principle of operation of an electric machine. If we place a conductor in the magnetic field between the poles of a permanent magnet[3] of an electromagnet and enable it to move under the action of force F_1 perpendicular[4] to the magnet lines, an EMF will be set up in the conductor, which is equal to $E = BLv$, where B is the magnetic flux density[5], L is the length of the conductor cutting the magnetic lines, and is the speed with which the conductor travels in the magnetic field. The EMF generated in the conductor is shown to be in the direction away from the observer, according to the right-hand rule.

If we now connect the conductor to a load, the EMF will fore the current to flow in the closed loop in the direction of the EMF. The current interacting with the magnetic field between the poles produces an electromagnetic force F_e which, according to the left-hand rule, is in the direction opposite to that of the force F_1 moving the conductor in the field. When $F_1 = F_e$, the conductor will travel at a constant speed. Consequently, this simplified electric machine converts the mechanical energy expended on the conductor movement to the electric energy delivered to an external resistive load and, hence, operates as a generator. This same machine can be made to run as a motor, If we connect the conductor to an external source of EMF, the current flowing through the conductor produces an electromagnetic force F, which tends to move the conductor in the field as it overcomes the opposing force of a mechanical load. To increase the EMF and electromechanical forces, electric machines are built up with windings that consist of a large number of conductors interconnected[6] so that their EMFs become additive, i. e. have the same direction. An EMF is possible to induce in a stationary conductor by moving the field with respect to it.

New Words

[1] reversible	*adj*	可逆的
[2] polyphase	*adj*	多相的
[3] permanent magnet		永磁体
[4] perpendicular	*adj*	垂直的
[5] magnetic flux density		磁通密度
[6] interconnect	*vt&vi*	互联

1. 1. 2 Synchronous Generator Principle and Construction Features

In synchronous machines, the speed of a rotor is equal to the rotational speed of a stator field and, therefore, it is a function of both the frequency of the line current and the number of pairs of poles, $n = 60f/p$, where $f = pn/60$.

A synchronous machine is reversible, as is any other electric machine, i. e. it can run as a motor and as a generator.

The prime mover of a synchronous generator is a hydro-turbine or a steam turbine, or an internal combustion engine[1].

The field winding of the generator commonly receives power from an exciter which is a dc generator fitted on the shaft of the generating unit. The capacity of the exciter[2] is small in the order of 1% to 5% of the rated capacity of the generator. In small machine the field windings are often fed from an ac supply line via a semiconductor rectifier.

If the magnetic field between the poles N and S is uniform[3], the EMF wave is sinusoidal. During one period, as the loop turns by one revolution, the EMF undergoes one complete cycle of changes.

If the loop driven by a prime mover revolves at a constant speed n in a minute the alternating EMF induced in the loop repeats itself at a frequency $f = n/60$.

It is possible to generate the EMF in conductors as they move in the stationary magnetic field and as the field revolves with respect to the stationary conductors. In the first case, the field winding intended to excite the magnetic field is on the stator, and the armature winding where the field induces the EMF is on the rotor. In the second case, the armature is stationary, while the field winding revolves on the rotor.

In the text above, we considered the action of the synchronous generator with the stationary field winding(stationary poles) and the revolving armature which gives up its generated energy to a load through sliding contacts formed by slip rings and brushes. The sliding contact in a high-power circuit is responsible for heavy power losses and is completely unacceptable at high voltages. Therefore, this type of generator is designed for low powers, up to 15kVA, at voltages up to 380/220V.

The second type of synchronous generator with a stationary armature and a revolving field has received the widest application. The field winding here consists of several series[4] connected coils arranged on the poles of the rotor. The exciter(dc generator) fitted on the common shaft supplies the field current to the field winding through brushes and slip rings.

Figure 1-2 illustrates the general view[5] of a synchronous generator with an exciter. The stator of a synchronous generator is similar in construction to that of an induction machine. The rotor of a synchronous generator can have salient poles[6] or non-salient poles that do not project out from the surface of the core. The first rotor is known as a salient pole rotor, and the second as a round, or a cylindrical, or a non-salient pole[7] rotor.

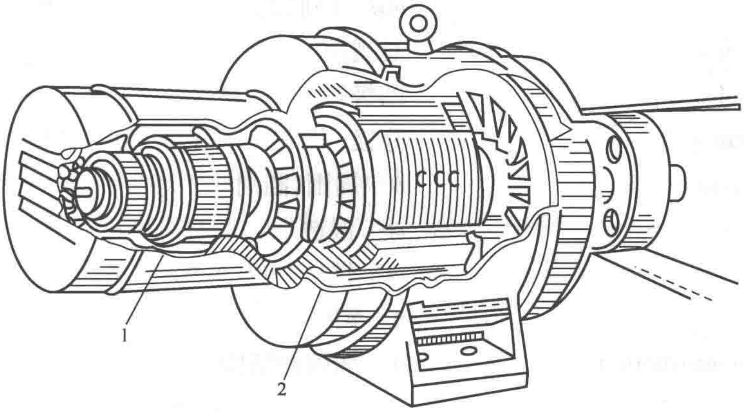
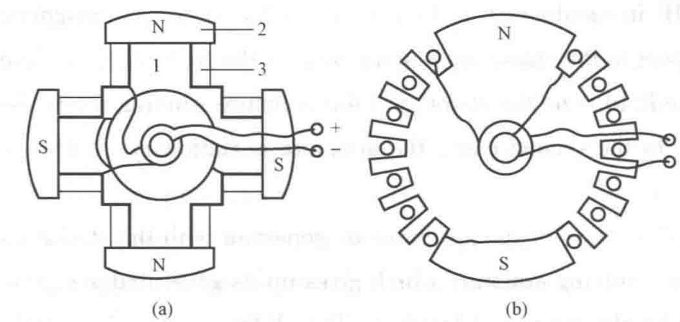


Figure 1-2 Cutaway view of a synchronous generator 1 with exciter 2

In slow-speed machines (with a large number of poles), the rotor has salient poles uniformly located around its circumference[8] [Figure 1-3(a)]. The pole consists of core 1, pole piece 2, and coil 3 of the field winding.

The prime movers for salient pole generators are commonly hydro-turbines which are slow-speed sources of mechanical power. The mechanical strength of a salient pole rotor is not



(a) (b)

Figure 1-3 The rotor structure of a synchronous machine

(a) Salient pole rotor of a synchronous machine;

(b) Round rotor of a synchronous machine

1—Core;2—Pole piece;3—Coil of the field winding

sufficient to stand up to high speeds, for which reason high-speed machines are built with round rotors [Figure 1-3(b)]. The core of such a rotor is usually a one-piece forging[9] with slots milled[10] on its surface. After completing the field winding on the rotor, the coils are fastened in the slots by wedges[11] driven into the slots and the end connections of rugged-construction[12] endures heavy loads arising at high speeds.

The prime movers of non-salient pole machines are usual steam turbines which run at high speeds.

New Words

[1] internal combustion engine	内燃机
[2] exciter	*n* 励磁机
[3] uniform	*adj* 不变的,均衡的
[4] series	*adj* 串联的
[5] general view	总视图
[6] salient poles	凸极
[7] non-salient poles	隐极
[8] circumference	*n* 周围,圆周
[9] forge	*vt* 锻造
[10] mill	*vt* 铣
[11] wedge	*n* 锲
[12] rugged-construction	*n* 加固的结构

1.1.3 Synchronous Generator Performance

In open-circuit conditions when the stator(armature) winding is open and the generator does not supply power to a load, there is no current in the stator winding. The magnetic flux produced by the field current induces an EMF in the three-phase stator winding.

In closed-circuit conditions when the generator operates into a load, a current flows in the stator winding. At a balanced load, the armature(stator) currents are equal in magnitude and shifted in phase by one-third of a period (120°). The armature currents produce a magnetic field revolving at a speed $n_1 = 60f/p = n$, i. e. this field revolves in synchronism with the field of the rotor winding. The EMF induced in the stator winding depends on the magnetic flux of the poles. If the magnetic flux is small, the EMF is also small, and vice versa. At a constant speed of the rotor, the EMF is proportional to the magnetic flux excited by the direct current flowing in the field winding. An increased current in the field winding produces a stronger magnetic flux, which results in a higher EMF. Consequently, since the EMF varies with the field current, it is possible to control the voltage at generator terminals by properly changing the field current.

In open circuit conditions, the voltage across the generator terminals is equal to the EMF generated in the armature. In the loaded generator, the voltage is not equal to the EMF because of the voltage drop across the resistance and reactance of the stator winding. Besides, the currents flowing through the stator winding produce the armature reaction flux which acts on the flux of the field winding, so that the magnetic flux under load is not equal to the magnetic flux at no load. That is why, changes in the load, i. e. changes in the armature current, will cause changes in the terminal voltage if the field current remains constant.

Figure 1-4(a) shows the external characteristics of a synchronous generator at resistive and reactive loads. These characteristies are the plots of the terminal voltage as a function of the load current at a constant rotor speed and constant field current. What accounts for the different shapes of the curves at resistive, inductive, and capacitive loads is a nonuniform[1] action of the armature reaction field on the flux of poles.

Any load requires a constant line voltage for its normal operation. The line voltage is kept constant with changes in the load on the generator by changing the field current.

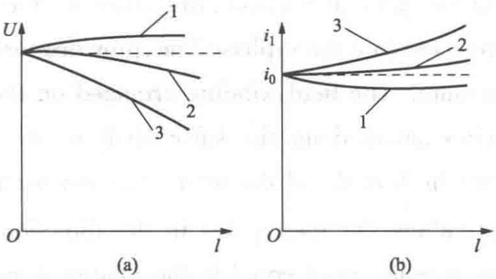


Figure 1-4 Characteristics of a synchronous generator at different loads

(a) External characteristics of a synchronous machine;
(b) Control characteristics of a synchronous machine
1—capacitive load; 2—resistive load; 3—inductive load

Figure 1-4 (b) illustrates the control characteristics which are the plots of field current versus load current at a constant line voltage. They actually show the range over which it is necessary to change the field current with changes in the load current in order to maintain the terminal voltage constant. At a resistive load, and increase in the armature current causes a slight dip in the voltage because the armature reaction decreases the magnetic flux to a small degree. This load calls for an insignificant increase in the field current to keep the voltage invariable. At an inductive load, an opposing armature reaction field appears, which reduces the flux of poles. The field current now need be higher than it is in the previous case, to compensate for the opposing armature reaction field and, thus, to obtain a constant net flux[2] which induces a constant voltage. At a capacitive load, the magnetic flux grows, so the field current must be reduced to decrease the armature current and, thus, provide for the constant voltage.

Synchronous generators most often operate into a common external circuit, of a power plant or a power system. The voltage U_c and frequency of such a power circuit are invariable. The voltage U_c, across the generator terminals in equal and opposite to the circuit voltage, $U_s = -U_c$, The net armature flux Φ_n revolving at a speed $n_1 = 60f/p$ in space leads the voltage U_g by 90°. With the power circuit voltage U_c invariable, the amplitude of the net armature flux Φ_n remains invariable too. At a resistive load on the generator, the armature current I is in phase with U. The armature reaction flux Φ_s is in phase with I, so their phaser that only differ in length are laid on the same axis. The net magnetic flux is the phasor sum of the field winding flux Φ_m (flux of poles) and armature reaction flux Φ_s.

New Words

[1] nonuniform	*adj*	不均匀的
[2] net flux		净磁通

1.1.4 Synchronous Motors

A synchronous motor does not principally differ in design from a synchronous generator. As with the generator stator, the stator of the motor carries a three-phase winding which, when connected to a three-phase line, provides for the magnetic field revolving at a speed $n_1 = 60f/p$ in a minute. The field winding arranged on the rotor receives direct current from a rectifier or an exciter mounted on the same shaft as the rotor. The field (excitation) current produces the magnetic flux Φ_m of the rotor. The net magnetic field Φ_n excited by the stator current tends to carry along the rotor poles in the direction of its rotation. The rotor can turn at precisely[1] synchronous speed equal to the rotational speed of the stator field. The speed of a synchronous motor is thus strictly constant if the power line frequency is invariable.

The main advantage of a synchronous motor is that it can operate on a leading current, i. e. it can act as a capacitive load for the power line. Such a motor raises $\cos\varphi$ of the entire network as it makes up for the reactive power[2] of other loads of the consumer.

As in a generator, the reactive power ($\cos\varphi$) of a motor is varied by adjusting the field current. At a certain field current corresponding to rated excitation, the power factor $\cos\varphi$ is unity. A decrease in the field current gives rise to lagging (inductive) current in the stator; and increase in the field current that overexcites the motor causes a leading (capacitive) current to appear in the stator.

An advantage of this motor over an induction counterpart[3] is that it is less sensitive to changes in the supply voltage. In the former, the torque is proportional to the line voltage raised to the first power, whereas in the latter, it varies as the square of the voltage.

The torque results from the interaction of the magnetic fields of rotor and stator. It is only the magnetic flux of the stator field that depends on the line voltage.

Synchronous motors largely come in salient pole designs, normally operated on a leading current at $\cos\varphi = 0.8$, with the field current supplied from exciters or from ac circuits via semiconductor rectifiers.

The synchronous motor connected to the supply line cannot produce the starting torque. With the rotor stationary, the revolving stator field travels at synchronous speed with respect to the rotor field and, hence, does not interact with the rotor field. To start the motor, the rotor should first be set in motion to enable it to accelerate to or almost to the synchronous speed.

The motor is made self-starting through induction-motor action provide by a squirrel-cage[4] winding (damper winding) inserted in the rotor pole faces[5]. With the stator winding connected to the three-phase power line, the motor starts on the cage winding, just like an ordinary squirrel-cage motor. As the motor comes up almost to synchronous speed (95% of this speed), the exciter is cut in to supply the field winding. The torque developed is now enough to pull the rotor into synchronism.

At starting, the field winding must be closed through a resistance that is 10 to 12 times the resistance of the winding itself. This winding must not be left open or short circuited during the starting period. Should it prove open, the stator field would cut the conductors of the field winding at a great rate and induce a large EMF in the winding, which may cause breakdown of its insulation and, thus, offer a hazard to attendants[6]. Should the field winding be shorted out when starting the motor under load, the rotor would accelerate nearly to half the synchronous speed and fail to pull into synchronism.

The operation of a synchronous machine on a leading current makes this machine suitable for use as a synchronous capacitor. The synchronous capacitor is a synchronous machine running without load and designed to improve the power factor of the ac system. It supplies reactive power to the ac system and insignificantly differs in design from an ordinary synchronous motor. Since the former carries no load, its shaft and rotor are lighter than those of the latter and its air gap is smaller.

The basic disadvantage of a synchronous motor is that it requires an ac and a dc source for its operation. The need to supply direct current to the field winding makes this motor rather inefficient at low powers. That is why low-power synchronous motors with dc excitation do not find any use. Reluctance motors[7] enjoy wide application where power demands are low. The rotor of this type of synchronous motor has salient poles. For motors of very small powers, the rotor is made cylindrical. It is cast from aluminum in the mold with soft iron cores inserted into it to form salient poles. The cylindrical shape facilitates the rotor machining and balancing and also reduces the windage loss[8], which is of importance for small-power motors.

In a reluctance motor, the rotor develops the torque by virtue of its orientation[9] in the magnetic field in such a way that the reluctance offered to the field is the lowest. The rotor always takes a definite position in space, such that the magnetic lines of the revolving stator field continue through the rotor iron and the rotor normally operates at the synchronous speed of the stator field.

New Words

[1] precisely	*adv*	精确地
[2] reactive power		无功功率
[3] counterpart	*n*	对应物
[4] squirrel-cage	*n*	鼠笼
[5] pole face		极面
[6] attendant	*n*	值班员
[7] reluctance motor		磁阻电机,反应式同步电机
[8] windage loss		通风损耗
[9] orientation	*n*	方向,目标

1.2 Synchronous Machine Theory and Modeling

1.2.1 Physical Description

Let's recall the schematic[1] of the cross section of a three-phase synchronous machine with one pair of field poles. The machine consists of two essential elements: the field and the armature. The field winding carries direct current and produces a magnetic field which induces alternating voltages in the armature windings.

Armature and Field Structure

The armature windings usually operate at a voltage that is considerably higher than that of the field and thus they require more space for insulation. They are also subject to high transient[2] currents and must have adequate mechanical strength. Therefore, normal practice is to have the armature on the stator. The three-phase windings of the armature are distributed 120° apart in space so that, with uniform rotation of the magnetic field, voltages displaced by 120° in time phase will be produced in the windings. Because the armature is