Instructor's Manual
to accompany

Electrical Machines, Drives and Power Systems

Sixth Edition

Theodore Wildi

Professor Emeritus, Laval University
Department of Electrical Engineering

PEARSON Prentice Hall

Upper Saddle River, New Jersey
Columbus, Ohio

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PREFACE

This Instructor's Manual is a supplement the Sixth Edition of ***Electrical Machines, Drives, and Power Systems.*** Its main purpose is to support the instructor in his busy schedule, to ensure that the problems can be solved, and that they yield the answers given at the back of the textbook.

This manual contains the solution to over 1000 problems, complete with sketches and comments whenever they are deemed to be useful.

The textbook lists the problems according to three levels of learning: *practical*, *intermediate* and *advanced*. This facilitates the allocation of assignments, so they are appropriate for the class, or the individual student.

The Industrial Application Problems are similar to the regular problems but are framed as they might be encountered in the field.

Problems form an important part of the learning process. They provoke a better understanding of the subject matter by making students draw on their own resources. Problems can be as challenging as a game, but, as in every game, the players want to know how successful they have been. The answer to a problem provides that essential competitive stimulus. When students "get the right answer" it imbues them with confidence in their newly-acquired knowledge and encourages them to tackle the next assignment.

The Manual includes a set of figures that can be used for overhead projection. They are drawn from the textbook, and have been selected on account of their pedagogical value. Instructors will find them useful to supplement their lectures.

It is hoped that the hundreds of photos and figures in the textbook will help instructors convey the message that vast opportunities are opening up in the exciting field of electric power.

We welcome your questions and comments. They may be e-mailed to the following address: wildi@wildi-theo.com.

You may also be interested in visiting my web site: http://www.wildi-theo.com.

Theodore Wildi

CONTENTS

BRIEF OVERVIEW OF CHAPTERS

CHAPTER 1 Units

This chapter gives the essentials of SI units and their use in the textbook. It also shows a graphical method of making conversions between English units, U.S. Customary Units and the SI. The important topic of per unit notation is also discussed. The per unit methodology is widely used in describing the magnitude of electromechanical quantities.

CHAPTER 2 Fundamentals of Electricity and Magnetism

This chapter gives a brief review of electrical and magnetic fundamentals. It also includes a simple way of writing circuit equations that many students and instructors will find interesting and pleasing to use. It can be employed in ac or dc circuits using either double subscript or sign notation.

CHAPTER 3 Fundamentals of Mechanics and Heat

The performance and service life of electrical machines, transformers and transmission lines are affected by their mechanical and thermal properties. Consequently, this chapter covers the fundamental elements of mechanics and heat. Mechanical energy and inertia are discussed as well as the dynamic relationship between torque, speed and acceleration of electrical machines. The section on heat shows the basic methods of cooling electrical machines and some practical thermal equations.

CHAPTER 4 Direct-current Generators

This chapter on dc generators is simultaneously an introduction to dc motors. It reveals the method whereby a dc voltage is produced, together with the process of commutation and the problem of sparking at the brushes.

CHAPTER 5 Direct-current Motors

Here are discussed the various types of dc motors and their behavior when they accelerate, run at constant load, and how inertia comes into play when they are brought to a halt by dynamic braking

CHAPTER 6 Efficiency and Heating of Electrical Machines

The physical elements that cause a machine to heat up are covered here. The impact on the power rating of the machine is revealed. A particularly useful section explains the relationship between temperature rise and the service life of electrical equipment. It is directly related to insulation classifications that are part of national and international standards (Sections 6.5 to 6.8).

CHAPTER 7 Active and Reactive Power

In electric power technology, the terms active, reactive and apparent power constantly crop up. The reason is that they facilitate the understanding of power flow in ac machines, transformers, transmission lines, and electronic converters. The ingenious power triangle method of solving ac circuits is also revealed (Section 7.11). At an intermediate level, the notion of conjugate current is used to determine the active and reactive components of power by vector algebra (Section 7.15).

CHAPTER 8 Three-Phase Circuits

The chapter begins with a user-friendly introduction to 3-phase circuits and a simple method of solving them. The treatment of industrial loads is then explored together with the notion of power factor correction. The important topic of phase sequence is also discussed, to prepare the student for an understanding of the direction of rotation of motors and the synchronization of ac generators. As another aspect of phase sequence and phasor relationships, Section 8.21 shows how a single-phase load can be made to appear as a perfectly balanced load on a three-phase line.

CHAPTER 9 The Ideal Transformer

This introductory chapter highlights the basic principles of transformers in general. In addition to the usual voltage and current transformations, the chapter goes on to show the meaning of polarity and how impedances can be shifted from primary to secondary and vice versa. The study of the ideal transformer also paves the way for developing the equivalent circuit and phasor diagrams of practical industrial transformers.

CHAPTER 10 Practical Transformers

The factors that cause a practical transformer to diverge from the ideal are explained. A particularly easy way of understanding leakage reactance is developed and incorporated into the equivalent circuit diagram. It is well known that the notion of leakage reactance is fundamental to an understanding of transformers and all rotating ac machines. Also, an interesting table makes use of per unit values to describe the properties of transformers over a tremendous power range (Section 10.15).

CHAPTER 11 Special Transformers

Autotransformers, current transformers, voltage transformers and high leakage reactance transformers are discussed in this chapter to give the student an idea of the many industrial applications of transformers. The dozens of photographs and technical details provide a visual appreciation of these important devices.

CHAPTER 12 Three-Phase Transformers

Three-phase transformers are the workhorses of transmission and distribution systems, and of industrial and commercial installations. Of particular interest is how these transformers can generate phase shifts and multiphase outputs, in addition to the usual voltage and current transformations.

CHAPTER 13 Three-Phase Induction Motors

This introductory chapter lays the groundwork for an understanding of the widely-used induction motor. The process whereby torque is developed and the relationship between frequency and speed are clearly explained. The construction of the motor, and a detailed description of the windings offer a practical view of the machine, to supplement the theory. The linear motor is also discussed, together with its practical application in linear drives. The principle of magnetic levitation is shown to be a useful attribute of the linear induction motor.

CHAPTER 14 Selection and Application of 3-Phase Induction Motors

The practical aspects of induction motors is the object of this chapter. It first describes industrial standards and goes on to explain the behavior of the motor under plugging, braking, single-phasing, overload, and other abnormal conditions. The use of a wound-rotor motor as a frequency converter alerts the student to other features that can be exploited.

CHAPTER 15 Equivalent Circuit of the Induction Motor

This special chapter is intended for students that want to enlarge their understanding of the induction motor. The theory is presented in a particularly simple way, using the prior knowledge of the properties of a conventional transformer. A comparison is made of the performance of a 5 hp versus a 5000 hp motor, particularly as regards the torque-speed curve. The circuit diagram is then used to illustrate (and calculate) how an induction motor can be made to behave as a generator (Section 15.8).

CHAPTER 16 Synchronous Generators

Synchronous generators are the source of 99 percent of all the electrical energy that is consumed; consequently, they deserve an important place in power technology. The different types of generators are shown in photographs, accompanied by valuable technical data. The synchronization of alternators is explained as well as the important concept of the infinite bus.

One surprising feature of a synchronous generator is its very high internal impedance. Indeed, the impedance of some alternators is so high that the short circuit current is only slightly larger than the rated current. However, because the impedance is mainly reactive, the internal power loss is relatively low. Particular attention should be paid to Section 16.7 which discusses the reasons why large alternators are preferred over smaller ones. As in every design problem, the trade-off is that the higher efficiency of larger machines demands increasingly complex cooling systems.

We also want to emphasize the importance of Section 16.23 which develops an equation for the active power transferred between two ac sources. This equation $P = E_1 E_2 \sin \delta / X_S$ is encountered again and again in subsequent chapters, including those dealing with transmission lines and electronic converters.

CHAPTER 17 Synchronous Motors

The synchronous motor ranges from the millihorsepower mite in electric clocks to the gigantic 200 000 hp machines used in pumped storage installations. The distinguishing feature of synchronous motors is their ability to operate at unity and leading power factors. Indeed, some of these machines operate at no load, their only purpose being to generate or absorb reactive power. The astounding thing is that these machines, having only magnetic fields, can function as if they were capacitors.

The equivalent circuit of a synchronous motor is simpler than that of an induction motor. It offers a fine opportunity to use phasors in describing machine behavior.

CHAPTER 18 Single-Phase Motors

Single-phase motors are manufactured by the millions every year and so a knowledge of the more important types is useful. Surprisingly, a single-phase motor is more complex than a three-phase motor. In this chapter, we offer the cross-field theory and the revolving field theory to explain its performance. The revolving field theory is then used to develop, in a simple understandable way, the equivalent circuit of the single-phase motor (Sections 18.17 to 18.19). To our knowledge, this constitutes a first in this category of textbook.

The inherent noisiness of standard single-phase motors (Section 18.9) should be brought to the student's attention.

Another topic describes a servo system to remotely actuate a a distant object. The principle is based on two 3-phase wound-rotor motors powered by a single-phase source (Section 18.16).

CHAPTER 19 Stepper Motors

This chapter describes the principle of stepper motors. They are unique in the sense that the number of rotor poles is always different from the number of stator poles. The big advantage of stepper motors is that the number of revolutions is directly related to the number of pulses applied to the stator. Consequently, these machines can be used to precisely control the position of an object without requiring feedback. However, the motor is always combined with a power supply that can generate and count the number of pulses applied to the stator. Most stepper motors are rated at less than 50 watts. It is shown that inertia plays an important role in the behavior of these machines.

CHAPTER 20 Basics of Industrial Motor Control

Many industrial components that control electric motors are simple, non-electronic devices. They are described in this chapter, together with the conventional circuit diagrams and symbols encountered in industry. The student will discover how motors are started, stopped, and reversed by using simple switches. Section 20.17 then gives an introduction to electric drives, including the notion of quadrants, followed by a brief view of variable frequency control of an induction motor.

CHAPTER 21 Fundamental Elements of Power Electronics

This chapter covers such a broad range that it is impossible to sum it up in a few words. Rather, we suggest a quick glance through the Section headings to become familiar with the contents. The user-friendly presentation is arranged so that even the non-initiated will be able to understand the meaning and thrust of power electronics. No complicated mathematics, no nitty-gritty detail to mask the basic principles.

Distortion power factor, displacement power factor and total harmonic distortion are introduced in Sections 21.12 to 21.14. These terms have become important in today's power electronic environment.

The application of thyristors has been grouped into six fundamental circuits that describe the majority of all industrial applications (Sections 21.20 to 21.25). They give the student a broad understanding of how *line-commutated* converters are used in industry. (The term *naturally-commutated* is sometimes used instead of line-commutated).

The development of GTOs and IGBTs has permitted the development of *self-commutated* converters that can initiate and terminate conduction at will. (The term *force-commutated* is sometimes used instead of self-commutated). Section 21.36 begins with a brief description of these switching converters. The text then goes on to analyze the operation of a dc-to-dc converter, sometimes called a chopper. Particular attention should be paid to Sections 21.41 and 21.42 because the 2-quadrant and 4-quadrant converters are fundamental to a large number of electronic devices and drives. It is recognized that in this emerging world of megawatt electronic power, switching converters have become just as important as induction motors and transformers.

The transformation of a dc-to-dc converter into a dc-to-ac converter is explained in Section 21.44. The really exciting part then begins with Section 21.45 where the notion of pulse width modulation (PWM) is introduced. The PWM converter is probably one of the most useful converters that was ever invented. It permits the conversion of a dc voltage into a voltage of any frequency, magnitude and phase angle by simply modifying the signals applied to the semiconductor gates. Indeed, even the waveshape of the output can be modeled to anything we please. The beauty of the situation is that power can flow in either direction (dc side to ac side and vice versa) without changing connections. Furthermore, the output impedances on both the ac and dc sides are inherently low.

CHAPTER 22 Electronic Control of Direct-Current Motors

The speed and torque control of dc motors is first described by using thyristors that convert ac power into dc. Section 22.7 is worth examining in detail because it gives a systematic way of determining whether a converter is operating in the rectifier or inverter mode.

Sections 22.8 and 22.9 cover two special versions of thyristor rectifiers. Although quite popular in industry, their behavior is somewhat more complex and a summary treatment in class is usually sufficient. On the other hand, Sections 22.10 and 22.11 are very pertinent to dc motor drives because they make use of the 4-quadrant dc-to-dc self-commutated converter. Instructors will find the detailed description of instantaneous current flow through the motor and converter of particular interest because it removes all ambiguity as to what goes on during the switching process.

Finally, the literature often makes reference to the brushless dc machine. Sections 22.12 through 22.16 describe in a novel and interesting way how this motor evolved, together with its practical application.

CHAPTER 23 Electronic Control of Alternating Current Motors

Many electronic drives involve synchronous motors and induction motors. We have segregated the drives into seven distinct types which account for at least 90 % of all industrial ac drives. Sections 23.2 to 23.6 cover drives that use thyristors. They include cycloconverters used in ocean liners and cement-mills to back-to-back drives for small fans. Section 23.7 then describes solid-state induction motor starters that have found an enormous market in new installations and retrofitting applications. Section 23.7 is therefore a must assignment.

Section 23.12 covers an interesting application of a wound-rotor motor for variable speed control. The energy usually lost in external resistors is recovered by using a line-commutated thyristor inverter in the rotor circuit.

Self-commutated switching converters that generate rectangular voltages and currents (Sections 23.8 to 23.11) are often employed to drive induction motors. Today, they involve IGBTs and GTOs, but many older installations used thyristors that were specially configured to operate as if they were GTOs. Consequently, in these four Sections the actual circuit configuration of the semiconductors is not shown.

The subdivision dealing with speed control by pulse width modulation is particularly adapted to modern drives. It begins with a brief review of PWM (Sections 23.13 and 23.14). The harmonic frequencies in PWM are much higher than the fundamental frequency and so they are easy to filter out. Consequently, the fundamental frequencies that are generated by a PWM converter can range from 400 Hz to zero, which opens the way to vector control of induction motors. Because of the resulting wide speed range, it is necessary to cover the behavior of the induction motor in greater detail. Thus, Section 23.15 introduces the notion of flux orientation in a dc motor with a view to comparing it to the flux orientation in an induction motor. Sections 23.16 to 23.19 then go on to show how the rotor voltages, currents, torques and slip speeds are related to each other. This is an in-depth look at basic principles that are really an extension of Chapters 14 and 15. It is interesting to note that slip speed is a more useful concept than slip when discussing variable speed control.

Sections 23.20 to 23.22 make use of the equivalent circuit diagram of the induction motor to understand the problems that arise when the speed is very low. It is seen that the constant volts per hertz rule produces a drastic reduction in torque when the speed is less than about 10% of rated synchronous speed. To compensate for this, the volts per hertz must be raised as the speed approaches zero.

A word about the equivalent circuit diagram (Sections 23.20 and 23.21) to is in order. The circuit is essentially similar to that of a transformer. It is therefore simple and easy to solve, particularly when using a computer program.

Sections 23.23 to 23.26 explain the basic principles of vector control. It is seen that the magnetomotive forces of the currents flowing in a three-phase stator can be combined vectorially to produce a resultant mmf having a specific magnitude and direction. Similarly, the magnetomotive forces of the currents flowing in the rotor can be combined vectorially to produce a resultant mmf having another specific magnitude and direction. The vector sum of these resultant rotor and stator mmfs produces a third mmf which gives rise to the mutual flux in the machine. The rotor current corresponding to the resultant rotor mmf interacts with the mutual flux to produce the torque.

But that is only part of the story. It is the presence of the high-speed computer, incorporated in the vector drive, that makes it possible to ensure that during transient conditions the mutual flux is always oriented correctly with respect to the currents flowing in the rotor.

Another feature that deserves particular attention is the electric traction drive described in Sections 23.27 to 23.30. It shows how the voltage and phase shift of a PWM converter can be controlled so as to force the required active and reactive power to flow between the overhead line and the electric train. In particular, the power is made to flow at unity power factor. Furthermore, because of the PWM mode of operation, the fundamental voltage generated on the ac side of the converter is inherently sinusoidal and only the high frequency harmonics need to be filtered out. This is a remarkable example of how a switching converter can resolve several problems simultaneously. On account of the wide applicability of this principle, the study of Sections 23.27 to 23.30 is highly recommended.

CHAPTER 24 Generation of Electrical Energy

This chapter is particularly interesting because it gives in a nutshell all the essential elements concerning the generation of electric power. The purpose of pumped storage systems, the reason for cooling towers, the distinction between light-water and heavy-water nuclear reactors, are some of the many points that are explained in a simple way. Even if time does not permit class study of this subject, it should be given as a reading assignment to every student of electric power. The same remark applies to Chapters 25 and 26.

CHAPTER 25 Transmission of Electrical Energy

Transmission is the term used whenever electric power is carried over high-voltage (HV) and extra-high-voltage (EHV) lines. In the same style as the previous chapter on generation, this chapter highlights the essential features of transmission, using simple mathematics. A transmission line is composed of a string of L, R, C components that determine its power-handling capacity and voltage regulation. The effect of these components is explained in simple terms by making use of phasor diagrams. Another topic of interest is the so-called BIL of electrical apparatus, a term that describes its tolerance level to lightning strokes and switching transients (Sections 25.10 to 25.12).

CHAPTER 26 Distribution of Electrical Energy

The distribution of electric power covers all systems operating roughly between 120 V single-phase, and 69 kV, 3-phase. This chapter describes the equipment used to transport, regulate, protect, interrupt and transform electric power for use by the ultimate consumer. Also covered are the important questions of grounding and the safety measures needed to prevent electric shocks (Sections 26.18 to 26.22).

CHAPTER 27 The Cost of Electricity

Everyone is interested in the cost of electricity. The basic elements that make up an electricity bill are presented here, together with the reasons that justify the various tariff structures.

CHAPTER 28 Direct-current Transmission

Direct current transmission has become a viable alternative to high-voltage ac transmission and is being exploited throughout the world. This chapter makes use of knowledge previously gained in Chapter 21 concerning line-commutated thyristor converters, harmonics and reactive power. It gives an overview of existing dc transmission lines, including back-to-back converters (Section 28.19). The latter are used whenever power has to be exchanged between two large ac systems whose frequencies are not synchronized.

CHAPTER 29 Transmission and Distribution Solid-State Controllers

This pioneering chapter discusses the current state of the electronic control of large blocks of ac power. This has been made possible by the development of IGBTs and GTOs that can switch large currents at high voltages. The chapter reveals how the reactance of a line can be reduced by series compensation and how this enables the control of power flow (Section 29.1 and 29.2). It also shows how capacitors and inductors can be replaced by electronic converters that create either lagging or leading reactive power by switching alone. This remarkable achievement is having repercussions throughout the power industry (Section 29.3).

As an example of what is happening, you are invited to read Section 29.6 that describes a 20 MW frequency converter that has absolutely no moving parts. Then read on in Section 29.5 that discusses a unified power flow controller (UPFC) that can electronically modify the phase-shift and magnitude of an injected voltage and thereby control the magnitude and direction of active and reactive power flow between two interconnected regions.

CHAPTER 30 Harmonics

Industrial and commercial enterprises, government and private institutions, as well as electrical utilities are becoming increasingly aware of distortion and the quality of electric power. The main problem is the effect of harmonics on electrical equipment and distribution systems. Harmonics are becoming very important because they are generated by electronic drives, computers and other switching devices that are being installed everywhere.

This important chapter explains the origin of harmonics and their effects. It shows that harmonics are always created by non-linear loads. Thus, when a perfect sine wave of voltage or current is applied to a load that contains linear and non-linear elements, the latter will always generate harmonic voltages and currents.

In effect, a non-linear load behaves like a frequency converter. It converts a portion of the fundamental power it absorbs into harmonic power. One striking example of a non-linear load is a simple switch that opens and closes periodically. The switch absorbs power at the fundamental frequency and converts it into harmonic power of many different frequencies.

Another important feature is that a periodic switch can either absorb or deliver reactive power at the *fundamental* frequency. This makes it possible to simulate the properties of capacitors and inductors by using an appropriate switching procedure.

The book reveals a simple method of analyzing a distorted wave. It helps the student get a better grasp of the meaning of harmonics. The method is based on Fourier series, but in a very user-friendly way. Software on harmonic analysis is available that yields an immediate solution. However, students find it more interesting when they actively participate in the harmonic-solving procedure. In this regard, a spreadsheet is easy to set up and the computation is straightforward. Problems toward the end of the chapter were solved this way.

Although this chapter appears at the end of the book, it may be referred to whenever the need arises.

The chapter also discusses electronic converters that are being developed to meet Power Quality requirements at the distribution level. Some of these devices behave like active filters capable of neutralizing harmonics at the consumer premises.

It is important to note that the material covered in this chapter rests upon concepts developed in previous chapters. Consequently, although the applications are new, the underlying knowledge is the same.

With power regulation becoming an important issue, the development of these electronic power devices will have a profound impact on the transmission and distribution of electric power.

Chapter 31 Programmable Logic Controllers

Programmable logic controllers (PLCs) have been in service for the past thirty years. During that time, the transmission of information, including automatic controls, has grown enormously. In consequence, it is now possible to control not only the operation of specific machines or processes, but the entire operation of a business including shipping, inventory, sales and finance.

This chapter explains the basic principles of PLCs. The many examples make it easy to understand how hardware devices can be converted into virtual items that are easily manipulated and interconnected.

A final broad section on the *Modernization Of An Industry* offers the student an opportunity to see how a business gradually moves from older to more modern concepts.

CHAPTER 1

1-4 Because they are used so often

1-7	MW	1-18	mK	1-29	MA
1-8	TJ	1-19	mrad	1-30	kA
1-9	mPa	1-20	–	1-31	km
1-10	kHz	1-21	mT	1-32	nm
1-11	GJ	1-22	mm	1-33	mL
1-12	mA	1-23	*r*		
1-13	µWb	1-24	MΩ		
1-14	cm	1-25	MPa		
1-15	*L*	1-26	ms		
1-16	mg	1-27	pF		
1-17	µs	1-28	kV		

1-34 Liter per second, (L/s) or
cubic meter per second (m^3/s)

1-35 Hertz, (Hz)

1-36 radian, (rad)

1-37 Weber, (Wb)

1-38 kilogram per cubic meter, (kg/m^3)

1-39 watt, (W)

1-40 kelvin, (K) or degree celcius, (°C)

1-41 kilogram, (kg)

1-42 Btu → joule

1-43 horsepower → watt

1-44 line of flux → weber

1-45 inch → meter (in Canada, metre)

1-46 angstrom → meter

1-47 cycle per second → hertz

1-48 gauss → tesla

1-49 line per square inch → tesla

1-50 °F → degree celsius or kelvin

1-51 bar → pascal

1-52 pound mass → kilogram

1-53 pound force → newton

1-54 kilowatthour → joule

1-55 gallon per minute → liter per second
(in Canada: litre per second)

1-56 mho → siemens

1-57 pascal

1-58 revolution → radian

1-59 degree → radian

1-60 oersted → ampere per meter (in Canada: ampere per metre)

1-61 ampere-turn → ampere

1-62 $10\ m^2 = 10 \times 10.76\ ft^2 = 10 \times \frac{10.76}{9} = 11.95\ yd^2$

1-63 $250\ MCM = 250\ (\div 1.97) = 126.9\ mm^2$

1-64 $1645\ mm^2 = 1645\ (\div 100)\ (\div 6.4516) = 2.549\ in^2$

1-65 $13000\ cmil = 13000\ (\times 507)\ (\div 10^6) = 6.591\ mm^2$

1-66 $640\ acre = 640\ (\times 4047)\ (\div 10^6) = 2.59\ km^2$

1-67 $81000\ W = 81000\ (\div 1000)\ (\div 1.055) = 76.77$ Btu/s

1-68 $33\,000$ ft·lbf /min $= 33\,000\ (\times 22.6)(\div 1000)(\div 1000)$
$= 0.746$ kW

1-69 $250\ ft^3 = 250\ (\div 27)\ (\div 1.308) = 7.079\ m^3$

1-70 10 ft·lbf $= 10 \times 1.356 \times 10^6 = 13.56 \times 10^6$ µJ

1-71 10 lbf $= 10\ (\times 4.448)\ (\div 9.806) = 4.536$ kgf

1-72 $60\,000\ lines/in^2 = 60\,000\ (\times 15.5)\ (\div 10^6) = 0.93$ T

1-73 $1.2\ T = 1.2\ (\times 10) = 12$ kilogauss

1-74 $50\ oz = 50\ (\div 16)\ lb = 50\ (\div 16)\ (\div 2.205) = 1.417$ kg

1-75 76 oersted $= 76 \times 79.6 = 6049.6$ A/m

1-76 $5000\ m = 5000\ (\div 1000)\ (\div 1.609) = 3.107$ miles

1-77 80 A·h $= 80\ (\times 3600) = 288\,000$ C

1-78 25 lbf $= 25 \times 4.448 = 111.2$ N

1-79 $25\ lb = 25\ (\div 2.205) = 11.34$ kg

1-80 $3\ t = 3\ (\times 1000)\ (\times 2.205) = 6615$ lb

1-81 $100\,000$ lines $= 100\,000\ (\div 100)(\div 10^6) = 0.001$ Wb

1-82 $0.3\ lb/in^3 = 0.3\ (\times 27.68)\ (\times 1000) = 8304\ kg/m^3$

1-83 2 in Hg $= 2\ (\times 25.4) = 50.8$ mm Hg
$= 50.8\ (\div 7.5)(\div 1000)(\times 10)$
$= 0.0677$ bar $= 67.7$ mbar

To make this conversion, we make use of two charts – length and pressure –

1-84 $200\ psi = 200\ (\times 6.89)\ (\times 1000) = 1.378 \times 10^6$ Pa

1-85 $70\ psi = 70\ (\times 6.89)\ (\times 1000)\ (\times 1) = 482.3 \times 10^3\ N/m^2$

1-86 $15\ r/min = 15\ (\div 9.55) = 1.57$ rad/s (from note 5 Table 1D)

1-87 $120°C = 120 + 273 = 393$ K

1-88 $200°F = (200 - 32)(\div 18) + 273 = 366.3$ K

1-89 a temperature difference of 120°C equals a temperature difference of 120 K.

Proof as follows:

temperature 1	θ_1 °C	$\equiv \theta_1 + 273$ K
temperature 2	θ_2 °C	$\equiv \theta_2 + 273$ K
temperature difference	$(\theta_1 - \theta_2)$ °C	$\equiv (\theta_1 - \theta_2)$ K

1-90 $R_{160\ \Omega}$ (pu) = 100/60 = 1.67

$R_{3000\ \Omega}$ (pu) = 3000/60 = 50

$R_{20\ \Omega}$ (pu) = 20/60 = 0.33

1-91 $I_B = P_B/E_B$ = 25 000/2400 = 10.4 A

$Z_B = E_B/I_B$ = 2400/10.4 = 231 Ω

1-92 $R_B = E_B{}^2/P_B = 12470^2/250\ 000 = 622\ \Omega$

$R = 5.3 \times R_B = 3.3\ \text{k}\Omega$

1-93 a. 1 mile (pu) $= 1.609 \times 10^3/4 = 402$

b. 1 foot (pu) $= 1/(3.28 \times 4) = 0.076$

c. base area $= 4 \times 4 = 16\ \text{m}^2$

d. base volume $= 4^3 = 64\ \text{m}^3$

e. volume (pu) = 6000/64 = 93.75

f. area (pu) $= 2 \times (2.59 \times 10^6)/16 = 3.24 \times 10^3$

INDUSTRIAL APPLICATION – CHAPTER 1

1-94 92.6 % = 92.6 per hundred = 0.926 per unit

1-95 The rated power $P = 15 \times 746 = 11\ 190$ W

The rated torque $T = \frac{9.55\ P}{n}$ (Eq. 3-5)

$= \frac{9.55 \times 11\ 190}{890}$

$= 120$ N·m

Torque pu $= \frac{25}{120} = 0.208$

Speed pu $= \frac{1260}{890} = 1.416$

power pu $= 0.208 \times 1.416 = 0.295$

Note that the per unit value of power is abtained by simply multiplyng the per unit values of torque and speed. There is no need to carry along the conversion factor 9.55.

1-96 The base voltage of $A = E_A = \sqrt{R_A P_A}$

$= \sqrt{100 \times 24} = 49$ V

The per-unit value of $R_B = \frac{50}{100} = 0.5$

The per unit value of $P_B = \frac{75}{24} = 3.125$

The per unit value of $E_B = \sqrt{0.5 \times 3.125} = 1.25$

R_C pu $= \frac{300}{100} = 3$

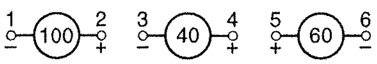
P_C pu $= \frac{40}{24} = 1.67$

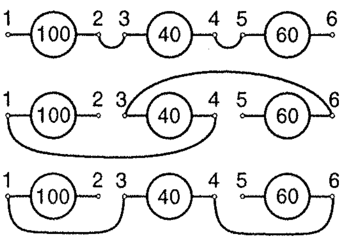
E_C pu $= \sqrt{3 \times 1.67} = 2.236$

1-97 *LRA* pu $= \frac{218}{36} = 6.05$ *NLA* pu $= \frac{14}{36} = 0.389$

Note that the full-load current is taken as the base current.

CHAPTER 2

2-1 

2-2 

(a) (b) (c)

a. $E_{16} = E_{12} + E_{23} + E_{34} + E_{45} + E_{56}$

$= (-100) + 0 + (-40) + 0 + (+60) = -80$ V

$\therefore$ terminal 1 is negative with respect to term 6

2-2 b. $E_{25} = E_{21} + E_{43} + E_{65}$

$= (+100) + (+40) + (-60) = +80$

$\therefore E_{25} = +80$ and so terminal 2 is (+) with respect to terminal 5

c. $E_{52} = E_{56} + E_{43} + E_{12}$

$= (+60) + (+40) + (-100) = 0$

There is no voltage between terminals 5 and 2

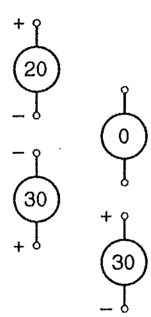
2-3

at instant 1, $E_1 = +20$ V

at instant 2, $E_1 =$ 0 V

at instant 3, $E_1 = -30$ V

at instant 4, $E_1 = +30$ V



2-4 $E = Blv = 0.6 \times 2 \times 60\,000/3600 = 20$ V

2-5 $E = N\,\Delta\phi/\Delta t = 200\,(3 - 1.2) \times 10^{-3}/0.2 = 1.8$ V

2-7 $\mu_r = 800\,000 \times B/H$

at 0.2 T, H = 500 A/m $\mu_r = 8 \times 10^5 \times 0.2/500 = 320$

at 0.6 T, H = 3000 A/m $\mu_r = 8 \times 10^5 \times 0.6/3000 = 160$

at 0.7 T, H = 5000 A/m $\mu_r = 8 \times 10^5 \times 0.7/5000 = 112$

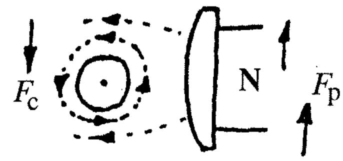
2-8 $H = 800\,000\,B = 800\,000 \times 0.6 = 480\,000$ A/m

$H = U/l \quad \therefore U = Hl = 480\,000 \times \frac{8}{1000} = 3840$ A

or 3840 ampere turns

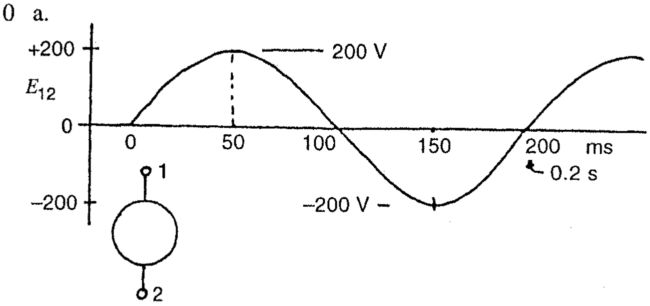
2-9 a. $F = BIl = 0.6 \times 2 \times 800 = 960$ N

b. Because to every action there is an equal and opposite reaction (Newton's third law), the force acting on the pole is also 960 N.

c. 

rotation No, F_c is the force acting on the conductor (ref. section 2-23); $\therefore$ Force on the pole is F_p.

2-10 a.



b. $E_{12} = E_m \sin\phi = E_m \sin 360\,ft$

$= 200 \sin 360 \times 5\,t = 200 \sin 1800\,t$

at $t = 5$ ms $E_{12} = 200 \sin 1800 \times 0.005$

$= 200 \sin 9° = 31.3$ V

at $t = 75$ ms $E_{12} = 200 \sin 1800 \times 0.075$

$= 200 \sin 135° = 141$ V

at $t = 150$ ms $E_{12} = -200$ V, by inspection

2-11 $I = 50\sqrt{2} = 70.7$ A

2-12 a. $I = E/R = 120/10 = 12$ A

b. $E = 120\sqrt{2} = 169.7$ V

c. $P = EI = 120 \times 12 = 1440$ W

d. $P_{peak} = 169.7 \times (12\sqrt{2}) = 2880$ W

2-13 $f = 253/11 = 23$ Hz

2-14 

60 Hz

360° corresponds to 1/60 s

$\therefore$ 36° corresponds to 1/600 s = 1.67 ms

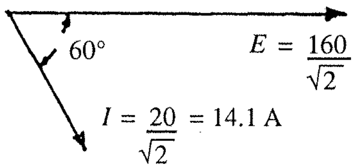
2-15 a. I_1 lags behind I_3 by 60°

b. I_3 lags behind I_2 by 90°

c. E lags behind I_1 by 150°

2-16 $E = 160 \sin \phi \quad I = 20 \sin (\phi - 60)$

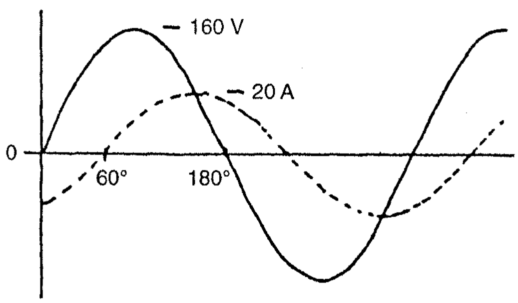
a.



$E = \frac{160}{\sqrt{2}} = 113$ V

$I = \frac{20}{\sqrt{2}} = 14.1$ A

b.



2-16 c. The instantaneous power is zero at 0°, 60°, 180°, 240°, etc. Because the power waveshape is not distorted, the positive and negative peaks occur exactly in the middle between the zero power points. The peak negative power occurs at 30°.

The peak positive power occurs at $\frac{60 + 180}{2} = 120°$

at this instant,

$e = 160 \sin 120 = 138.56$ V

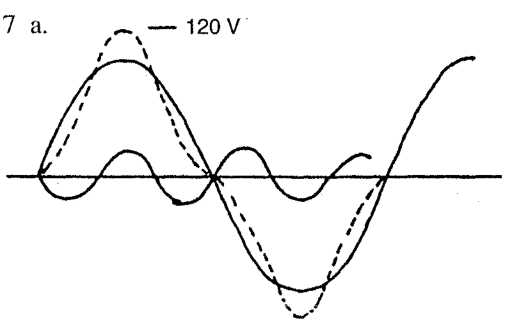
$i = 20 \sin (120 - 60) = 17.32$ A

$\therefore$ peak positive power = 138.56 × 17.32 = 2400 W

note that this power is expressed in watts – not volt-amperes.

peak negative power = 160 sin 30° × 20 sin (30 – 60)°
= 80 × (– 10) = – 800 W

2-17 a.



b. The peak is 120 V

2-18 A_1 is (–) thus A_2 is (+)
Current flows from A_2 to B_2 thus box A is the source.

2-19 No, because B_1 is at the same potential as A_1 and B_2 is at the same potential as A_2

2-20 $e_2 = 20 \cos (360\ ft - \theta)$
$\theta = 150°, \quad F = 180$ Hz
$e_2 = 20 \cos (64\ 800\ t - 150)$
$t = 0 \quad e_2 = 20 \cos (-150°) = -17.3$ V

$e_2 = 20 \cos ((64800 \times 262) - 150) = 17.3$ V

$t = 4$ min, 22 s = 262 s

2-21 (a) $-E_1 + IR = 0$ (b) $-E_1 - IR = 0$
(c) $E_1 + IR = 0$ (c) $-E_2 + E_1 - IR = 0$

2-22 (a) $I + 7 = 4$ $\therefore I = -3$A
(b) $9 + 4 + I = 0$ $\therefore I = -13$ A
(c) $8 + 2 + 3 = 4 + I$ $\therefore I = 9$ A

2-23 (a) $-10 - 5 I_1 = 0 \quad 5 I_1 + 2 I_2 = 0 \quad I_1 + I_3 = I_2$
(b) $-98 - 7 I_3 + 42 I_1 = 0 \quad -42 I_1 + 15 I_2 = 0$
$I_1 + I_2 + I_3 = 0$
(c) $-48 + 6 I_3 - 4 I_2 = 0 \quad 4 I_2 + (7 + 12) I_1 = 0$
$I_3 + I_2 - I_1 = 0$
(d) $-40 - 12 I_4 + 4 I_3 + 60 = 0$
$-60 - 4 I_3 + 6 I_2 = 0$
$-6 I_2 + 2 I_1 = 0$
$I_1 + I_2 + I_3 + I_4 = 0$

2-24 (a) Period of one cycle = 4 seconds
$\therefore$ frequency $= \frac{1}{T} = \frac{1}{4} = 0.25$ Hz
(b) Peak power = $E^2/R = 100^2/10 = 1000$ W
(c) Energy per cycle = 1000 W × 2 s = 2000 J
(d) Average power = energy/time = 2000 J/4 s = 500 W
(e) Effective voltage = dc voltage that produces the same power in the same resistance. $E^2/10\ \Omega = 500$ W
(f) $\therefore E^2 = 5000$ and so $E = \sqrt{5000} = 70.7$ V
(g) Average voltage $= \frac{100 \text{ V} \times 2 \text{ s}}{4 \text{ s}} = 50$ V

2-25 (a) Period of one cycle = 8 seconds
frequency $= \frac{1}{T} = \frac{1}{8} = 0.125$ Hz

(b) Peak power = (peak voltage)$^2/R$
$= 100^2/10\ \Omega = 1000$ W

(c) Energy per cycle = 1000 W × 2 s × 2 = 4000 J

(d) Average power = 4000 J/8 s = 500 W

(e) The dc current that would produce the same average power in the same resistor is $E^2_{dc}/10\ \Omega = 500$ W
$\therefore E_{dc} = \sqrt{5000} = 70.7$ V

2-25 (f) The effective voltage E is, by definition equal to E_{dc}.
$\therefore E = 70.7$ V
(g) The average voltage in Fig. 2.64 is

$$E_{average} = \frac{100 \text{ V} \times 2 \text{ s} + (-100 \text{ V}) \times 2 \text{ s}}{8 \text{ s}} = 0 \text{ V}$$

2-26 (a) $E_{21} + 20\, I_1 = 0$ and $E_{21} - 100 \angle 0°$
$I_3 = I_1 + I_2$ $\quad E_{21} + I_2 (50\text{j}) = 0$

(b) $+ E_A + 20\, I_1 = 0$ and $E_A = 120 \angle 30°$
$+ E_A + I_2 (-30\text{j}) = 0$ $\quad I_3 = I_1 + I_2$

(c) $E_{21} + 20\, I_1 = 0$ and $E_{12} = 120 \angle -60°$
$E_{21} - I_2 (-30\text{j}) = 0$ $\quad I_1 = I_3 + I_2$

(d) $E_{ba} - 20\, I_1 = 0$ and $E_{ba} = -10 \angle 30°$
$E_{ba} + 60\text{j}\, I_2 = 0$ $\quad -E_A = -20 \angle 45°$
$E_{ba} - E_A - I_3 (-30\text{j}) = 0$ $\quad I_4 + I_1 + I_3 = I_2$

(e) $E_{ab} + 7\, I + I\, (-24\text{ j}) = 0$
$E_{ac} + I\, (-24\text{ j}) = 0$
$E_{bc} - 7\, I = 0$ and $E_{ab} = -100 \angle 0°$

2-26 (f) $E_{21} + E_B - I\,(40\text{ j}) - I\,(-45\text{ j}) = 0$
$E_{13} + 40\text{j}\, I - E_B = 0$ and $E_{21} = -30 \angle -30°$
$E_{23} - I(-45\text{ j}) = 0$

Note that Figs. 2.65 (d) and (f) use sign notation and double subscript notation in the same circuit. This is unusual, but it does show that both notations can be used in the same circuit. See also (g) below.

(g) $-E_3 + 40\text{ j}\, I_3 + E_{32} = 0$
$-E_3 + E_{12} = 0$ ←*
$E_{23} - 30\, I_2 = 0$
$E_{23} + 40\text{j}\, I_1 = 0$
$I_2 + I_3 = I_1$

* In this equation, we move upward across E_3 and then downward from 1 to 2 to close the loop. As a result, E_3 carries a minus sign because it is the terminal we first meet when moving upward.

CHAPTER 3

3-1 $F = 9.8\ m = 9.8 \times 40 = 392$ N. It takes 392 N to lift the block

3-2 Force $= 9.8 \times 7.5 = 735$ N.

Energy $= Fd = 735 \times 4 = 2940$ J

3-4 Torque $= 200 \times 0.3 = 60$ N·m

3-5 $P = \dfrac{nT}{9.55} = \dfrac{4000 \times 600}{9.55} = 251$ kW $= 251\ (\times 1.34) = 336$ hp

3-6 600 lb $= 600\ (\div 2.205) = 272$ kg

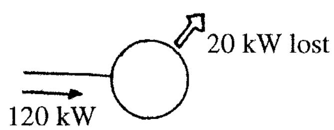
$F = 9.8 \times 272 = 2666$ N

200 ft $= 200\ (\div 3.28) = 61$ m

Work done $= Fd = 2666 \times 61 = 162\ 626$ J

Power $= W/t = 162\ 626/15 = 10842$ W $= 10.8$ kW
$= 10.8\ (\times 1.34) = 14.5$ hp

3-7 a.



$P_i = 120$ $\quad P_o = 120 - 20 = 100$ kW

hp $= 100 \times 1.34 = 134$ hp

b. $\eta = P_o/P_i = 100/120 = 0.833 = 83.3\ \%$

c. 20 kW $= 20\ (\div 1.055) = 18.96$ Btu/s (see Appendix)

18.96 Btu/s $= 18.96 \times 3600 = 68\ 256$ Btu/h

3-8 500 lb·ft^2 $= 500\ (\div 23.73) = 21.07$ kg·m^2 (Appendix)

$E_k = 5.48 \times 10^{-3}\ Jn^2 = 5.48 \times 10^{-3} \times 21.07 \times 60^2 = 415.7$ J

3-9 a. E_k 0 to 200 r/min $= 5.48 \times 10^{-3} \times 5 \times 200^2 = 1096$ J

b. E_k 0 to 400 r/min $= 5.48 \times 10^{-3} \times 5 \times 400^2 = 4384$ J

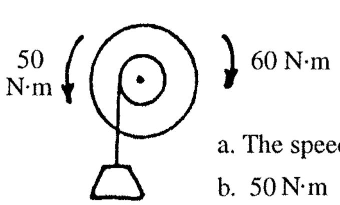
$\therefore$ E_k from 200 to 400 r/min $= (4384 - 1096) = 3288$ J

c. E_k at 3000 r/min $= 5.48 \times 5 \times 3000^2 \times 10^{-3} = 246\ 600$ J

$\therefore$ from 300 to 400 r/min

the fly wheel releases energy $= (246\ 600 - 4384)$
$= 242\ 216$ J $= 242$ kJ

3-11 a.



a. The speed will be clockwise

b. 50 N·m

3-12 a. The load torque exceeds the motor torque. The speed will decrease.

b. The shaft will eventually rotate ccw.

3-13 According to the text, the system is stationary
$\therefore n = 0$ and $P = 0$

3-14 $P = nT/9.55 = 50 \times 40/9.55 = 209$ W

3-15 P received by the motor $= 209$ W

3-16 Net force acting on pulley $= (28 - 5) = 23$ lbf
$= 23\ (\times 4.448) = 102$ N

radius arm $= 6" = 6\ (\div 12)\ (\div 3.28)$
$= 0.1524$ m

$\therefore$ Torque $= 15.54$ N·m

$P = nT/9.55 = 1160 \times 15.54/9.55$
$= 1888$ W $= 1.89$ kW
$= 1.89\ (\times 1.34) = 2.53$ hp

3-17 $\Delta n = 9.55\ T\Delta t/J$ (Eq. 3-14)

a. $1800 - 1600 = \dfrac{9.55\ T\ (8)}{5}$ $\quad \therefore T = 13.1$ N·m

b. $E_k = 5.48 \times 10^{-3} \times 5 \times 1800^2 = 88.8$ kJ

c. The motor develops $T = 13.1$ N·m

$\therefore P = 1600 \times 13.1/9.55 = 2195$ W

d. The torque is still 13.1 N·m

$\therefore P = 2195 \times \dfrac{1750}{1600} = 2400$ W

3-18 a. When the speed is constant, the moment of inertia does not come into play. $P = nT/9.55$

$\dfrac{120}{1.34} \times 1000 = \dfrac{700\ T}{9.55}$ $\quad \therefore T = 1222$ N·m

b. $\Delta n = 9.55\ T\Delta t/J$

$\therefore (750 - 700) = 9.55\ T\ (5)/2500\ (\div 23.73)$

$T = 110$ N·m

3-18 The torque of 110 N·m is that needed to accelerate the machine. We must add the torque required for the load (= 1222 N·m). The motor torque is $T = 1222 + 110 = 1332$ N·m during the speed rise.

3-19 a. $P = nT/9.55$ $\quad \dfrac{80}{1.34} \times 1000 = \dfrac{1200 \times T}{9.55}$; $T = 475$ N·m

b. $nT = 9.55\ Fv$ (Eq 3-16)

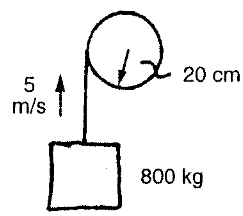
$v = 30$ mi/h $= 30\ (\div 2.237) = 13.4$ m/s (Appendix)

$\dfrac{80}{1.34} \times 1000 = F \times 13.4$ $\quad \therefore F = 4455$ N

3-20 $Q = m\,c\,\Delta t = 100 \times 380\ (100 - 20) = 3.04$ MJ
(Table AX2 in appendix)

3-21 $Q = 3.04 \times \frac{960}{380} = 7.68$ MJ

3-22



$F = 9.8$ m $= 9.8 \times 800 = 7840$ N
$T = 7840 \times 0.2 = 1568$ N·m
circumference $= 2\,\pi r = 2\,\pi \times 0.2 = 1.2566$ m
1 s corresponds to 5 m or
$5/1.2566 = 3.979\ r$
$\therefore$ speed $= 3.979 \times 60 = 239$ r/min

3-23 The new speed = 239/5 = 47.8 r/min
The torque is unchanged because the weight exerts the same force.

$\therefore\ T = 1568$ N·m $= 1568\ (\div 1.356)$
$= 1156$ ft·lbf

INDUSTRIAL APPLICATION – CHAPTER 3

3-24 From Appendix AXO, 50 gal (U.S.) $= 50 \times 3.785$
$= 189.25\ \text{dm}^3$

$\therefore$ mass $m = 189.25$ kg

Specific heat of water, $C = 4180$ J/(kg·°C)

$\Delta t = (180 - 55) = 125\ °\text{F} \equiv \frac{125}{1.8} = 69.44\ °\text{C}$

Note that a temperature difference of 125 °F is equal to a difference of 69.44 °C. However, a temperature of 125 °F is equal to a temperature of

$125 - 32 \div 1.8 = 51.67$ °C see Appendix AX0 and AX2

$Q = mc\,\Delta t$ (3.17)
$= 189.25 \times 4180 \times 69.44 = 54.93 \times 10^6$
$= 54.93$ MJ $= 54.93\ (\times 1000 \div 1.055)$ Btu
$= 52\,070$ Btu

Time for a 2000 W heater to furnish this energy =

$$\frac{54.93 \times 10^6\ \text{J}}{2000\ \text{W}} = 27\,465\ \text{s} = \frac{27\,465}{3600} = 7.63\ \text{hours}$$

3-25 The emissivity of paint $= 5 \times 10^{-8}$ (see Table 3B), while that of aluminum paint is 3×10^{-8}. Thus, according to (3.21) the aluminum paint surface will only radiate $\frac{3 \times 10^{-8}}{5 \times 10^{-8}} = 0.6$ as much power for the same temperature difference. Hence aluminum paint will cause temperature to rise.

3-26 Area A $= 100 \times 30 = 3000\ \text{m}^2$ k = radiation constant (or emissivity) of cement $= 5 \times 10^{-8}$ from Table 3B.

Power released by convection

$P = 3\,A\,(t_1 - t_2)^{1.25} = 3 \times 3000\,(25 - 23)^{1.25}$
$= 21\,406$ W $= 21.4$ kW

Power released by radiation = ?

$T_1 = 25 + 273.15 = 298.15$ K

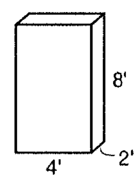
$T_2 = 23 + 273.15 = 296.15$ K

$P = kA\,(T_1^4 - T_2^4)$
$= 5 \times 10^{-8} \times 3000\,(298.15^4 - 296.15^4)$
$= 31\,486$ W $= 31.5$ kW

Total heat released = 21.4 + 31.5 = 52.9 kW

Note that more heat is released by radiation than by convection.

3-27 Total surface available for radiation and convection is:



$A = (4 + 2 + 4 + 2)\,8 + 4 \times 2 = 104\ \text{ft}^2$
$= 104 \div 10.76 = 9.66\ \text{m}^2$

Let us assume the temperature inside the panel is 35 °C.

We then find $P_{convection} = 3 \times 9.66\,(35 - 30)^{1.25} = 217$ W

P by radiation =

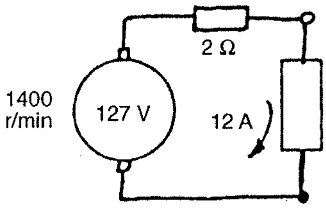
$5 \times 10^{-8} \times 9.66\left[(35 + 273.15)^4 - (30 + 273.15)^4\right] = 275$ W

Total power released = 275 + 217 = 492 W

Because 2000 W are dissipated inside the panel, the temperature will be greater than 35 °C. After several trials, we find that the temperature is about 47 °C. In effect, $3 \times 9.66\,(47 - 30)^{1.25} + 5 \times 10^{-8} \times 9.66\,[320.15^4 - 303.15^4] = 1000 + 995 = 1995$ W, which is very close to 2 kW.

CHAPTER 4

4-9



a. $E = 127 - 2 \times 12 = 103$ V
b. $I^2R = 12^2 \times 2 = 288$ W
c. $P = 127 \times 12 = 1524$ W

$$T = 9.55\ P/n = \frac{9.55 \times 1524}{1400} = 10.4 \text{ N·m}$$

4-10 a. voltage increases to $1.2 \times 115 = 138$ V
b. polarity reverses
c. voltage increases but not quite by 10 % owing to saturation.

4-11 Armature current at full load $= \frac{100\ 000}{250} = 400$ A
Shunt field current = 250/100 = 2.5 A
a. No-load mmf = $2.5 \times 2000 = 5000$ A
b. Series mmf = $7 \times 400 = 2800$ A
Full-load mmf = 2800 + 5000 = 7800 A.

4-12 If the speed is 1330 r/min the induced voltage for a given field current falls everywhere in the ratio of 1330/1500 = 0.887. In other words, in order to obtain 120 V of 1330 r/min, we would need the same excitation as for

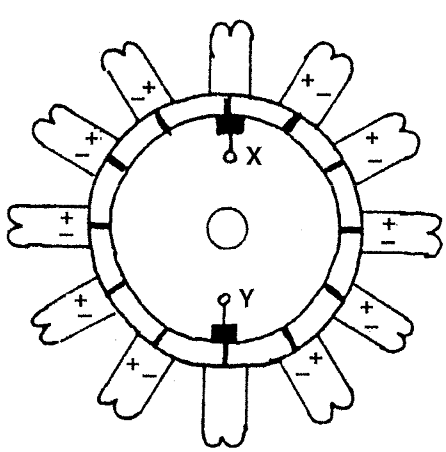
$$\frac{120}{0.886} = 135 \text{ V at 1500 r/min.}$$

The saturation curve shows that the exciting current = 2 A.

4-13 A = 18 V; B = 18 V; C = 18 V A and C are opposite in polarity to B and D.

4-14 at 90°, $E_A = 20$ V; at 120°, $E_A = 18$ V

4-15



Yes, the polarity reverses

4-16 $E = Zn\,\phi/60 = (12 \times 72) \times 960 \times 20 \times 10^{-3}/60 = 276.5$ V
The figure shows that the armature has 6 slots per pole and it further states that there are 12 poles. Conductors per coil side = 6 and there are 2 coil sides per slot – again from the figure $\therefore Z = 12 \times 72$

4-17 a. 12 brush sets
b. ther are six (+) and six (–) brush sets.
Current/brush set = 1800/6 = 300 A. The current in each brush set moves to the right and to the left in the armature coils (see, for example Fig. 4-38a.)
∴ current per coil = 150 A.

4-18 The average voltage of the 5 coils between the brushes is 240 V/5 = 48 V. Consequently $E_{34} > 40$ V.

4-19 E_{XY} is (+) based on either Lenz's law or on Fleming's 3-finger rule.

4–20 a. E_{34} is (–)
b. Segment 35 is (–) with respect ot segment 34. (See Fig. 4-38a.

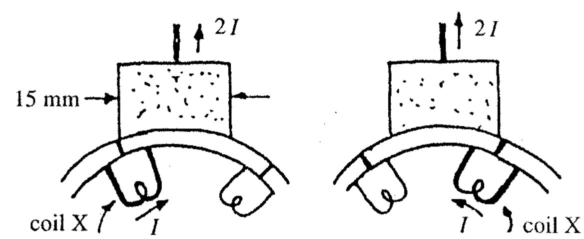
4-21 a. The number of coils is equal to the number of segments = 243

Total number of conductors $Z = 243 \times 2 = 486$
$E = Zn\,\phi/60 = 486 \times 1200 \times 30 \times 10^{-3}/60 = 292$ V

b. Surface area per pole $= \frac{\pi d l}{\text{poles}} = \frac{\pi \times 559}{6} \times \frac{235}{10^6}$

A = $68.7 \times 10^{-3}\text{m}^{-2}$
B = ϕ/A = $30 \times 10^{-3}/68.78 \times 10^{-3} = 0.436\ T$

c.



The diagram shows that the current in a typical coil X reverses in the time it takes to move across the brush. Circuit of commutator is

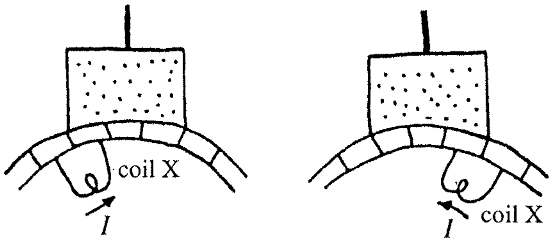
$$\pi d = \pi \times 450 = 1413.7 \text{ mm}$$

Time for 1 revolution $= \frac{1}{1200}$ min $= \frac{1}{20}$ s

Time to move 15 mm is:

$$T = \frac{15}{1413.7} \times \frac{1}{20} = 5.3 \times 10^{-4} \text{ s} = 530\ \mu\text{s}$$

4-22 Time for 1 revolution = 1/1800 min = 1/30 s
Time to move 3 bars is 3/75 × 1/30 = 1.33 ms



4-23 a. $I = \frac{250 \times 10^3}{750} = 333$ A

b. 4 poles gives 4 brush sets, 2 (+) and 2 (–)
current/brush set = 333/2 = 166.5 A
current/coil = 166.5/2 = 83.25 A

INDUSTRIAL APPLICATION – CHAPTER 4

4-24 (a) I = 240 000/500 = 480 A

(b) Total power input = 240 000/0.94 = 255 319 W.
Total losses = 255 319 – 240 000 = 15 319 W.

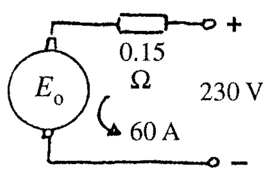
(c) I^2R losses = 0.023 × 240 000 = 5520 W.
Note that the base is taken to be the rated power (240 kW) of the generator.

4-25 Specific power = watts per kilogram
mass = 2600 ÷ 2.205 = 1179 kg.
240 000/1179 = 203.5 W/kg.

4-26 Total losses minus losses in shunt field
= 53 319 – 60 × 5^2 = 13 819 W
mechanical power to drive generator
= 240 000 + 13 819 = 253 819 W.
$P = nT/9.55$ (3.5)
∴ 253 819 = 1750 T/9.55 ∴ T = 1385 N·m
Note that the shunt field is separately excited.

CHAPTER 5

5-9

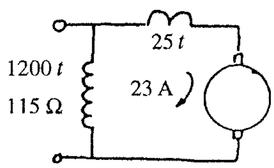


a. $E_o = 230 - 60 \times 0.15 = 221$ V
b. $P = 230 \times 60 = 13.8$ kW
c. $P_{mcc} = 221 \times 60 = 13.26$ kW
$= 13.26\ (\times 1.34)$
$= 17.8$ hp

5-10 a. $I = 230/0.15 = 1533$ A

b. $R = 230/115 = 2\ \Omega$. The temperature already has 0.15 Ω and so $R_{external} = 1.85\ \Omega$.

5-11



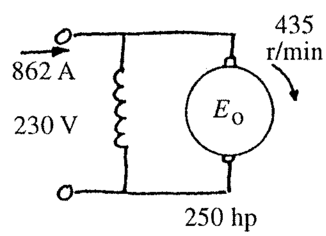
a. $\text{mmf} = \frac{230}{115} \times 1200 + 25 \times 23$
$= 2400 + 575 = 2975$ A

b. 2400 A

5-12 At 1500 r/min $E = 115 \times \frac{1500}{1200} = 144$ V

At 100 r/min $E = 115 \times \frac{100}{1200} = 9.6$ V

5-13 a. $P_o = 250\ (\div 1.34)$
$= 186.6$ kW
$P_i = 230 \text{ V} \times 862$ A
$= 198.3$ kW
Losses $= 198.3 - 186.6$
$= 11.7$ kW
$\eta = (P_o/P_i) \times 100$
$= (186.6/198.3) \times 100 = 94$ %



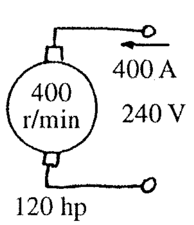
b. Shunt field loss = 20 % × 11.7 = 2340 W
$I_f = 2340/230 \text{ V} = 10$ A

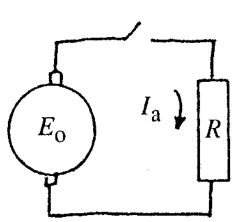
c. I_a^2R 1055 = 50 % × 11.7 = 5850 W
$R_a = 5850 \text{ W}/852^2 = 8\ \text{m}\Omega$
note that $I_a = 862 - I_f = (862 - 10) = 852$ A
$E_o = 250 - (852 \times 0.008) = 223$ V

d. $\frac{n_2}{n_1} = \frac{1100}{435} = 2.5$ I_2 should be less than $\frac{10}{2.5} = 4$ A

n does not follow *I* owing to saturation.

5-14





a. $I_{a(max)} = 400 \times 1.25 = 500$ A; $R = 240/500 = 0.48\ \Omega$

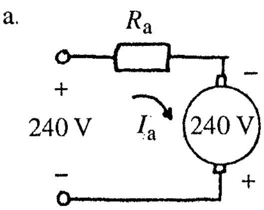
b. at 200 r/min $E_o = \frac{240}{2} = 120$ V

breaking power $= \frac{120^2}{0.48} = 30$ kW

breaking power @ 50 r/min $= \frac{(240/8)^2}{0.48} = 1.9$ kW

breaking power @ 0 r/min = 0

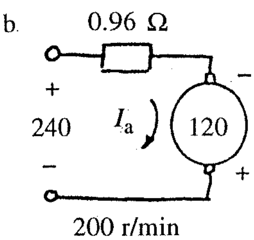
5-15 a.



At the instant of plugging the voltages and polarities are as shown. To limit I_a to 500 A,

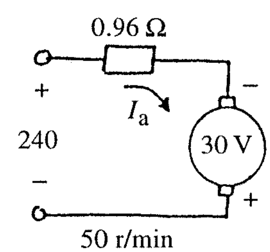
$R_a = \frac{480}{500} = 0.96\ \Omega$

b.



$I_a = (120 + 240)/0.96 = 375$ A
(at 200 r/min)

Breaking power = 375 × 120
= 45 kW



$I_a = (240 + 30)/0.96 = 281$ A
$P = 281 \times 30 = 8430$ W
at 0 r/min $P = 0$
because $E_o = 0$

c. Brake power = 45 kW, $I^2R_a = 375^2 \times 0.96 = 135$ kW

5-16 a. Mass $= \frac{\pi d^2 l}{4} \times \text{density} = \frac{\pi \times (0.559)^2}{4} \times 0.235 \times 7900$
$= 455.6$ kg

$J = \frac{mr^2}{2} = \frac{455.6}{2} \times \left(\frac{0.559}{2}\right)^2 = 17.8\ \text{kg·m}^2$ (eq. 3-10)

b. $E_K = 5.48 \times 10^{-3} Jn^2 = 5.48 \times 10^{-3} \times 17.8 \times (1200)^2$
$= 140$ kJ

c. $E_K = 5.48 \times 10^{-3} \times (17.8 \times 2) \times 600^2 = 70$ kJ

5-17 A decrease of 50 % in I_f does not produce a 50 % decrease in the flux, owing to saturation. Hence the speed does not double

5-18 As a shunt field heats up, its resistance increases, I_f decreases, ϕ decreases and the speed rises.

In a series motor, its resistance increases and so the *IR* drop increases, which reduces the effective voltage applied to the armature; hence the speed falls.

INDUSTRIAL APPLICATION – CHAPTER 5

5-19 Decrease in magnetism when temperature increases from

$22\ °C$ to $40\ °C = 3\ \% \times \dfrac{(40-22)°C}{100\ °C} = 0.0054$

$\therefore \dfrac{\varphi_{40}}{\phi_{22}} = 1 - 0.0054 = 0.9946$

but $E_0 = Z\,n\,\phi/60$ (4.1)

hence $n = \dfrac{60\,E_0}{Z\,\phi}$, so speed is inversely proportional to the flux ϕ.

Thus, the speed at 40 °C $= 2500 \times \dfrac{1}{0.9946} = 2514$ r/min.

5-20 (a) Number of coils = number of commutator bars = 40.
Conductors per coil = 2 × 5 = 10
Z = conductors on armature = 10 × 40 = 400

(b) Armature IR drop = 14.5 A × 0.34 Ω = 4.93 V
Cemf = 90 – 4.93 = 85.1 V

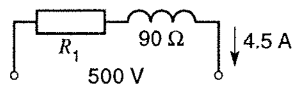
(c) $E_0 = Zn\phi/60$

$85.1 = \dfrac{400 \times 2900 \times \phi}{60}$

$\phi = 0.044 = 4.4$ mWb

5-21 Power output = 20 × 746 = 14 920 W
Power input = 14 920/0.88 = 16 954 W
Losses in motor = 16 954 – 14 920 = 2034 W
$P = 1280\,V_a\,(t_2 - t_1)$ (3.20)
$2034 = 1280\,V_a\,(35 - 30)$ $\therefore V_a = 0.318\ m^3/s$
$0.318\ m^3/s = 0.318 \times 1.308 \times 27\ ft^3/s = 11.23\ ft^3/s$
$= 11.23 \times 60 = 674\ ft^3/min$
(see Appendix AXO for conversion factors)

5-22 R of field = 90 Ω



Total resistance of R_1 + field $= \dfrac{500\ V}{4.5\ A} = 111\ \Omega$

hence $R_1 = 111 - 90 = 21\ \Omega$
Power of resistor $R_1 = 4.5^2 \times 21 = 425$ W.

5-23 5 hp field power = 0.68 A × 150 V = 102 W

field power/rated power $= \dfrac{102}{5 \times 746} = 0.0273$ pu

500 hp field power = 4.3 A × 300 V = 1290 W

field power/rated power $= \dfrac{1290}{500 \times 746} = 0.00346$ pu

Conclusion: A large dc motor has relatively much lower field power requirements.

CHAPTER 6

6-8 180°C

6-9 $P_o = 160\ (\div 1.34) = 119.4$ kW
$P_i = 119.4 + 12 = 131.4$ kW
$I_L = 131\,400 / 240 = 547$ A

6-10 $P_i = \dfrac{115 \text{ V} \times 120 \text{ A}}{0.81} = 17.04 \text{ kW} = 17.04 \times 1.34 = 22.8$ hp

6-11 $P_i = \dfrac{250}{1.34} \times \dfrac{1}{0.92} = 202.8$ kW

$I = \dfrac{202\,800}{230} = 882$ A

6-12 a. Temp rise = (208 – 180) = 28° C
b. Yes, too hot by (208 – 120) = 88° C (Fig. 6-7)

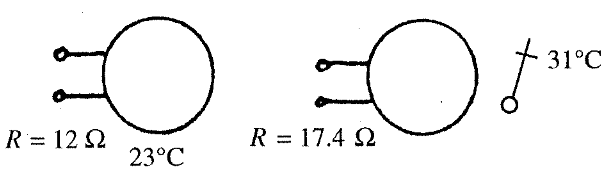
6-13 The losses are then a significant portion of the output power.

6-14 1 hp = 1 ÷ 1.34 = 0.746 kW. The output is 0,746/10 kW of the rated power. Hence the losses are
$(0.0746)^2 \times 595 + 830 = 833$ W
$\eta = P_o/P_i = 0.746/(0.746 + 0.833) = 47.2$ %

6-15 Lifting force = 9,8 m = 9,8 × 1500 = 14.7 kW (Eq. 3-1)
$P = Fd/t = 14\,700 \times 20/30 = 9{,}8$ kW
$P_{motor} = 9.8/0.94 = \underline{10.4}$ kW $= 10.4 \times 1.34 = \underline{14}$ hp

6-16 40° C ambient, temperature should < 155 °C
30° C ambient, temperature should < 145 °C
14° C ambient, temperature should < 129 °C
Note that with embedded thermocouples, the temperature rise should be < (155 – 40) < 115° C [Fig. 6-7]

6-17



a. $t_2 = \dfrac{R_2}{R_1}(234 + t_1) - 234$

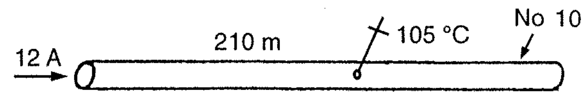
$= \dfrac{17.4}{12}(234 + 23) - 234 = 139$ °C

b. Temperature rise = (139 – 31) = 108 °C

c. Class *F* temperature rise by resistance is allowed to be 105 °C. The motor is running hot. The maker could not reduce the power output because the ratings are staderdized as to power output and frame size. He will have to reduce the losses by a slight redesign.

6-18 8 years at 30°C; 4 years at 40°C; 2 years at 50°C; 1 year at 60°C we assume that the temperature of the motor increases by as much as the increase in the ambient temperature.

6-19



No 10 wire has a cross section of 5.27 mm^2

a. $J = 12/5.27 = 2.28$ A/mm^2 (Table AX3 in appendix)

b. $R = 4.36 \times (210/1000) = 0.9156\ \Omega$.
mass = 46.9 × (0.210) = 9.849 kg
I^2R loss $= 12^2 \times 0.9156 = 131.8$ W

specific loss $= \dfrac{131.8}{9.849} = 13.4$ W/kg

6-20 a. $P_{120\,°C} = 26\,(1 + 0.00439 \times 120) = 39.7$ nΩ·m
density of aluminum = 2703 kg/m^3
From Eq, (6-3)

$$P_c = 1000\, J^2 \rho / \zeta$$
$$= 1000 \times (2)^2 \times 39.7/2703$$
$$= 58.7 \text{ W/kg}$$

b. cmils = 1 (× 1.97) (× 1000) = 1970

$\therefore \dfrac{\text{circular mils}}{\text{ampere}} = \dfrac{1970}{2} = 985$ cmil/A

6-21 Let the rated efficiency be η and the rated losse = p. The temperature rise may be considered to be proportional to the losses.

original losses = p; new losses $= \dfrac{105}{80} p = 1.31\, p$.

$\left.\begin{aligned} \eta &= \frac{P_o}{P_i} \\ \eta &= \frac{20}{20 + p} \end{aligned}\right\}$ original $\quad \left.\eta = \dfrac{x}{x + 1.31\,p}\right\}$ overload

because the efficiencies are about the same,

$\dfrac{20}{20 + p} = \dfrac{x}{x + 1.31\,p} \quad 20\,x + 26.2\,p = 20\,x + px \quad \therefore x = 26.2$

The motor can deliver 26.2 kW or 35 hp at the new temperature rise.

6-22 Class A = 105 °C; Class F = 155 °C; (50° higher)
∴ new life = 2 years $(\times 2)^5$ = 64 years.

6-23 Increase in temperature above normal is (200 – 120) = 80°C. Life is reduced by half for every 10°C increase in temperature. The life is shortened by a factor of $2^8 = 256$ ∴ 3 h is equivalent to having run the motor for 3 × 256 = 768 h. Service life is reduced (statistically) by 768 h, or about 32 days of continuous operation.

INDUSTRIAL APPLICATION – CHAPTER 6

6-24 $\rho_{25} = 15.88\ (1 + 0.00427 \times 25)$ (6.2)

$= 17.58\ \text{n}\Omega\cdot\text{m}$

$$R = \rho \frac{L}{A} = \frac{17.58 \times 10^{-9} L}{67.4 \times 10^{-6}} = 0.135$$

$\therefore L = 518$ m

From AX3 $m = \frac{518}{1000} \times 600$ kg/km = 310 kg.

6-25 $\rho_{70} = \rho_0\ (1 + 0.00427 \times 70)$

$= 15.88 \times 1.3 = 20.64\ \text{n}\Omega\cdot\text{m}$

A for No 4 wire = 21.1 mm^2 = 21.1×10^{-6} m^2

$$R = \rho \frac{L}{A} = \frac{20.64 \times 10^{-9} \times (27 \times 2)}{21.1 \times 10^{-6}} = 0.0528\ \Omega$$

$= 52.8\ \text{m}\Omega$

6-26 A diameter of 0.04 in corresponds to 40 mils. The closest wire having the diameter is No 18 (see AX3).

From AX3 length of wire $= \frac{56\ \Omega}{21.4 \times 10^{-3}\ \Omega/\text{m}} = 2617$ m

Total mass of 4 poles $= \frac{2617}{1000} \times 7.31$ kg/km = 19.1 kg

weight per pole = 19.1 ÷ 4 = 4.78 kg.

6-27 From problem 6-25, we know $\rho_{70} = 20.64\ \text{n}\Omega\cdot\text{m}$

Length of cable = 420 ÷ 3.28 = 128 m × 2 = 256 m.

A = 13.5 mm^2 = 13.3×10^{-6}m^2

$$R = \rho \frac{L}{A} = \frac{20.64 \times 10^{-9} \times 256}{13.3 \times 10^{-6}} = 0.397\ \Omega$$

(a) $\rho = I^2R = 48^2 \times 0.397 = 915$ W

(b) $E = IR = 48 \times 0.397 = 19.0$ V

$\therefore$ voltage at load end = 243 – 19 = 224 V.

6-28 If the No 6 cable carried 60 A when the temperature is 70 °C, the IR drop would be (from Problem 6-27)

$90.0\ \text{V} \times \frac{60}{48} = 23.8$ V.

To reduce the IR drop to 10 V, the conductor size must be increased by a factor of 2.38. The minimum wire size is therefore 2.38 × 13.3 mm^2 = 31.65 mm^2.

From AX3, the closest wire size is No 2 wire having A = 33.6 mm^2. hence use No 2 gauge.

6-29 $\rho_{105} = 15.88\ (1 + 0.00427 \times 105) = 23\ \text{n}\Omega\cdot\text{m}$

$L = 30 \div 3.28 = 9.15$ m

$A = 4" \times 1/4" \times 6.4516 \times 100 = 645.16$ mm^2

$$R = \rho \frac{L}{A} = \frac{23 \times 10^{-9} \times 9.15}{645.16 \times 10^{-6}} = 0.000326\ \Omega$$

IR drop = 2500 × 0.000326 = 0.81 V

Power loss per meter $= \frac{0.81 \times 2500}{9.15} = 223$ W

6-30 For copper 1/0.00427 = 234 } see AX2
For aluminum 1/0.00439 = 228 }

$\therefore t_2 = R_2/R_1\ (228 + t_1) - 228$

6-31 circumference $= \pi d = \pi \times 63 = 198$ mm

peripheral speed $= 3000 \times \frac{198}{1000} = 594$ m/min

594 m/min = 594 × 3.28 ft/min = 1948 ft/min

1948 ft/min = $\underbrace{1948 \div 1.97 \div 100 \times 2.237}_{\text{see AXO}}$ = 22 mi/h

6-32 (a) 0.0016 Ω·inch = 0.0016 × 2.54 ÷ 100
= $40.64 \times 10^{-6}\ \Omega\cdot\text{m}$

$$R = \rho \frac{L}{A} = \frac{40.64 \times 10^{-6} \times \left(\frac{3}{4} \times \frac{2.54}{100}\right)}{\frac{5}{16} \times \frac{5}{8} \times \left(\frac{2.54}{100}\right)^2}$$

$= 0.00614\ \Omega$

(b) IR drop = 15 A × 0.00614 Ω = 0.092 V

(c) Total drop = 1.2 + 0.092 = 1.29 V

(d) Power loss (electrical) = 1.29 × 15 × 2 brushes
= 38.7 W

(e) Frictional force = applied force × coefficent
= 1.5 lbf × 0.2 × 1 brushes = 0.3 lbf
and 0.3 lbf = 0.3 × 4.448 = 1.33 N

(f) Energy in 1 revolution = frictional force × circumference = 1.33 × 2 × 0.198 m = 0.528 J

(g) Time to complete 1 revolution $= \frac{60}{3000} = 0.02$ s

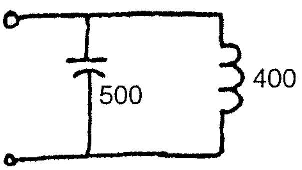
Power required to overcome friction

P = energy/time = 0.528/0.02 = 26.4 W

(h) % brush loss $= \frac{26.4 + 38.7}{1.5 \times 746} \times 100 = 5.8$ %.

CHAPTER 7

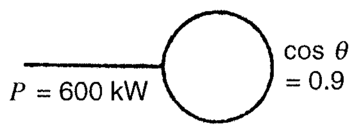
7-2



$S = 500 - 400 = 100$ kVA The apparent power is 100 kVA, and we know that the net reactive power is 100 kVA

7-6 $\cos\theta = \cos 50 = 0.6427 = 64.3\ \%$

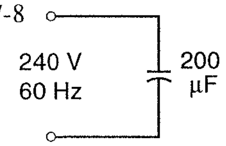
7-7



$S = P/\cos\theta = 600/0.9 = 667$ kVA

$Q = \sqrt{667^2 - 600^2} = 291$ kvar

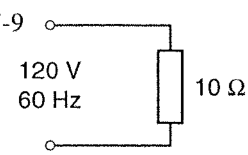
7-8



$$X_c = \frac{1}{2\pi fc} = \frac{10^6}{2\pi \times 60 \times 200} = 13.26\ \Omega$$

$$Q = \frac{E^2}{X_c} = \frac{240^2}{13.26} = 4.34 \text{ kvar}$$

7-9



a. $P = \frac{E^2}{R} = \frac{120^2}{10} = 1440$ W ← note

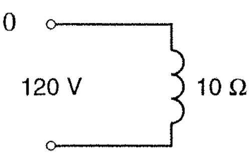
b. $S = EI = 120 \times 12 = 1440$ VA ←

c. Peak power $= 120\sqrt{2} = 12\sqrt{2} = 2880$ W

d. each pulse lasts for 1/120 s

(Note that apparent power S is always expressed in volt-amperes even though we know that only active power (watts) are being consumed).

7-10



a. $Q = \frac{E^2}{X_L} = \frac{120^2}{10} = 1440$ var

b. $S = EI = 120 \times 12 = 1440$ VA

c. Referring to Fig. 7-7c, the peak power occurs exaclly between the zero-power

7-10 Crossing points. Peak power occurs ∴ at 45°, 135°, 225°, etc. At these instants (45° say)

$e = 120\sqrt{2}\sin 45 = 120$ V

$i = 12\sqrt{2}\sin(45 - 90) = -12$ A

∴ peak power = 1440 W (<u>not</u> var, <u>not</u> VA)

d. 1440 W

e. each pulse lasts for 90° or 1/240 s.

7-11 a. *A* <u>looks</u> like a power source because current flows out of the positive terminal. This is confirmed by the fact that the phasor diagram shows *E* and *I* in phase. *A* is therefore an active power source.

b. *D* <u>looks</u> like a power source (*I* flows out of (+) terminal). However *I* is 180° out of phase with *E*. ∴ *C* is the active power source.

c. *G* <u>looks</u> like a power source (*I* flows out of (+) terminal). It is <u>not</u> a reactive power source because *I* <u>leads</u> *E*.

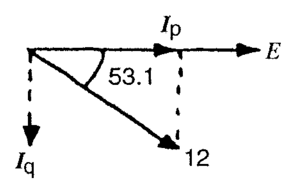
It is sometimes easier to look at the element which looks as if it is the load – in this case divice *F*. It is not an inductive load, because the current leads the voltage. Hence *F* must be an inductive source. We shall use this reasoning in the next three examples.

d. *H* <u>appears</u> to be the load. It would be inductive because *E* and *I* are 90° out of phase. It <u>is</u> the load because *I* lags behind *E*. Consequently, *I* is the reactive source.

e. *L* <u>appears</u> to be the load. It is not the load because *E* and *I* are 180° out of phase. ∴ *L* is the reactive source.

f. *N* appears to be the load. It <u>is</u> the load because *I* lags 90° behaind *E*. ∴*M* is a reactive source.

7-12



arc cos θ = arc cos 0.6 = 53.1°

$I_p = 12\cos 53.1 = 7.2$ A

$I_q = 12\sin 53.1 = 9.6$ A

also $I_q = \sqrt{12^2 - 7.2^2} = 9.6$ A

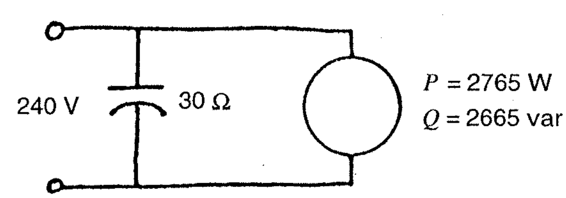
7-13 $P = 2765$ W

$\cos\theta = 2765/3840 = 0.72$

$S = 240 \times 16 = 3840$ VA

$Q = \sqrt{3840^2 - 2765^2} = 2665$ var

7-14



a. 2765 W

b. $Q_c = 240^2/30 = 1920$ var

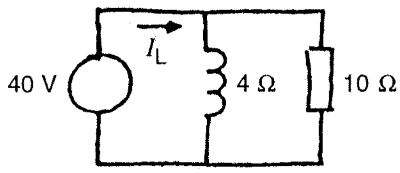
$Q_L = (2665 - 1920) = 745$ var

c. $S = \sqrt{2765^2 - 745^2} = 2864$ VA

d. $I = S/E = 2864/240 = 11.9$ A

e. $\cos\theta = P/S = 2765/2864 = 0.965 = 96.5\ \%$

7-15 a



$P = 40^2/10 = 160$ W

$Q = 40^2/4 = 400$ var

$S = \sqrt{160^2 + 400^2}$

$= 430.8$ VA

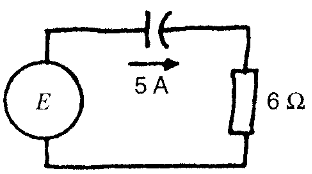
7-15 $I_L = S/E = 480.8/40 = 10.77$ A

$Z = E/I_L = 40/10.77 = 3.71\ \Omega$

b. $Q = I^2 X_c = 5^2 \times 2 = -50$ var

$P = I^2R = 5^2 \times 6 = 150$ W

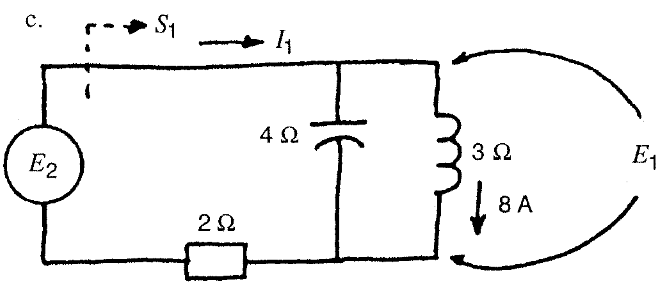
$S = \sqrt{150^2 + (-50)^2} = 158.1$ VA



$E = S/I = 158.1/5 = 31.62$ V

$Z = E/I = 31.62/5 = 6.32\ \Omega$

c.



$Q_L = 8^2 \times 3 = +192$ var

$Q_c = E^2/X_c = 24^2/4 = -144$ var

$Q_L + Q_c = 192 - 144 = 48$ var

$I_1 = 48/E_1 = 2$ A

$P = I^2R = 2^2 \times 2 = 8$ W

$S_1 = \sqrt{48^2 + 8^2} = 48.66$ var

$E_2 = S_1/I_1 = 48.66/2 = 24.33$ V

$E_1 = 8 \times 3 = 24$ V

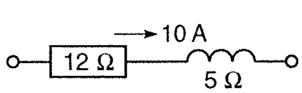
$\therefore Z = \dfrac{24.33}{2} = 12.16\ \Omega$

7-16 $S = 400$ kVA   a. $P = 400 \times 0.8 = 320$ kW

$\cos\theta = 0.8$ b. $Q = \sqrt{400^2 - 320^2} = 240$ kvar

c. To produce the magnetic field.

7-17



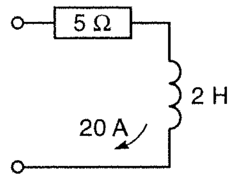
a. $P = 10^2 \times 12 = 1200$ W

b. $Q = 10^2 \times 5 = 500$ var

c. $S = \sqrt{1200^2 + 500^2} = 1300$ VA

d. $\cos\theta = 1200/1300 = 0.923$

7-18



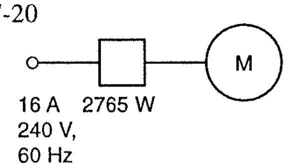
a. $P = 20^2 \times 5 = 2$ kW

b. no reactive power is absorbed because the the current is dc.

7-19 $P = 1200$ $\cos\theta = 0.8$ $\therefore S = 1200/0.8 = 1500$ VA

$Q = \sqrt{1500^2 - 1200^2} = 900$ var

7-20



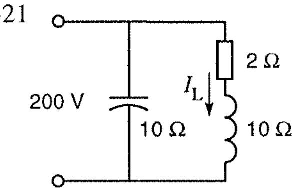
a. 2765 W

b. $Q_L = 2665 - 500 = 2165$ var

$S = \sqrt{2165^2 + 2765^2} = 3512$ VA

c. $\cos\theta = \dfrac{2765}{3512} = 0.787$

7-21



$Z_{coil} = \sqrt{2^2 + 10^2} = 10.2\ \Omega$

$I_L = 200/10.2 = 19.61$ A

a. $I^2X_L = 19.61^2 \times 10 = +3845$ var

b. $Q_c = 200^2/10 = -4000$ var

c. $P = 19.61^2 \times 2 = 769$ W

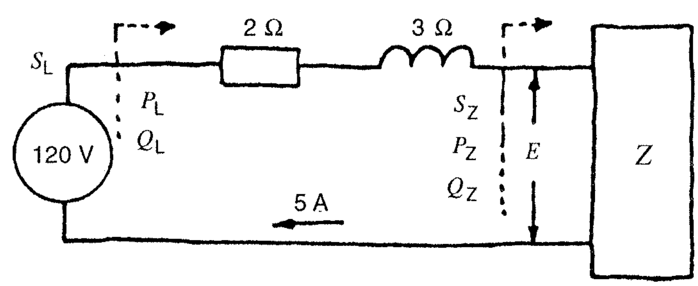
d. $Q_{line} = -4000 \times 3845 = -155$ var

$P_{line} = 769$ W

$S_{line} = \sqrt{769^2 + (-155)^2} = 784.5$ VA

$S = 784.5$ VA

7-22



$S_L = 120 \times 5 = 60$ VA $P_L = 0.6 \times 600 = 360$ W

$Q_L = \sqrt{600^2 - 360^2} = +480$ var

(positive because the power factor is lagging).

$P_{resistor} = 5^2 \times 2 = 50$ W $\therefore P_Z = 360 - 50 = 310$ W

$Q_{induct} = 5^2 \times 3 = 75$ var

$Q_Z = 480 - 75 = 405$ var

The 120 V source supplies 480 var, and 75 var is absorbed by the inductor; the remainder must be absorbed by Z.

7-22 cont'd

$S_Z = \sqrt{310^2 + 405^2} = 510$ VA

a. $E = S_Z/I = 510/5 = \underline{102\text{ V}}$

b. $Z = E/I = 102/5 = \underline{20.4\ \Omega}$

also, $\cos\theta = 310/510 = 0.607 = \cos 52.56°$

$\therefore\ Z = 20.4\angle{-52.56°} = 20.4\cos(-52.56) + j\sin(-52.56)$
$= 12.4 - j\,16.2$

7-23 a. $I_p = 5\cos 30 = 4.33$ A in phase with E; $I_q = 5\sin 30 = 2.5$ A 90° behind E

$\therefore$ A is both an active load and reactive load

$P = 519.6$ W, $Q = 300$ var, both flowing from B to A

b. $I_p = 5\cos 150 = -4.33$ A 180° out of phase with E; $I_q = 5\sin 150 = 2.5$ A 90° behind E

D appears to be the load, owing to direction of I and the polarity of E. It is a reactive load, but an active source.

$P = 519.6$ W flowing from D to C

$Q = 300$ var, flowing from C to D.

INDUSTRIAL APPLICATION – CHAPTER 7

7-24 $I = \dfrac{30\text{ kvar}}{480\text{ V}} = 62.5$ A $\therefore X_c = X_c = E/I = 480/62.5 = 7.68\ \Omega$

$C = 10^6/(2\pi \times 60 \times 7.68) = 345\ \mu$F

7-25 (a) $E_{peak} = 460\sqrt{2} = 650$ V

(b) $W = \frac{1}{2}CE^2 = \frac{1}{2} \times 345 \times 10^{-6} \times 650^2 = 72.9$ J

7-26 A capacitor discharges according to the equation $E = E_o e^{-t/T}$ wherein $T = RC$ and $t = 1$ min $= 60$ s, $E_o = 650$ and $E = 50$

$50 = 650\, e^{-60/T}$ i.e. $1 = 13\, e^{-60/T}$

Taking the natural log we get

$$0 = 2.565 - \frac{60}{T} \quad \therefore T = \frac{60}{2.565} = 23.4 \text{ s}$$

$$R \times 345 \times 10^{-6} = 23.4 \quad R = 67\,800$$

$$P = \frac{E^2}{R} = \frac{480^2}{67\,800} = 3.4 \text{ W}$$

In practice, a lower resistance would be used, say 63 kΩ, with a power rating of 5 W.

7-27 (a) $S = \sqrt{3^2 + 2^2} = 3.605$ MVA

$I = \dfrac{3.605 \times 10^6}{12\,500} = 288$ A

(b) P (line) $= I^2R = 288^2 \times 2.4 = 0.199$ MW

Q (line) $= I^2X = 288^2 \times 12 = 0.995$ Mvar

(c) P (load) $= 3$ MW $- 0.199$ MW $= 2.80$ MW

Q (load) $= 2$ Mvar $- 0.995$ Mvar $= 1.00$ Mvar

S (load) $= \sqrt{2.8^2 + 1^2} = 2.97$ MVA

(d) E (load) $= \dfrac{2.97 \times 10^6}{288\text{ A}} = 10\,300$ V $= 10.3$ kV

7-28 (a) $P_o = 2 \times 746 = 1492$ W

$P_i = 1492/0.755 = 1976$ W

$S = 1976/\cos\theta = 1976/0.74 = 2670$ VA

(b) $Q_{motor} = \sqrt{2670^2 - 1976^2} = 1796$ var

$X_c = 1/2\pi fC = 10^6/2\pi \times 60 \times 40 = 66.3\ \Omega$

$Q_{capacitor} = 230^2/66.3 = 798$ var

Q (line) net $= 1796 - 798 = 998$ var

P (line) $= 1976$ W

S (line) $= \sqrt{1976^2 - 998^2} = 2214$ VA

I (line) $= 2214/230 = 9.63$ A

(c) No. The active power is the same.

7-29 (a) $S = \sqrt{3^2 + 4^2} = 5$ kVA

$I = \dfrac{5000}{240} = 20.83$ A

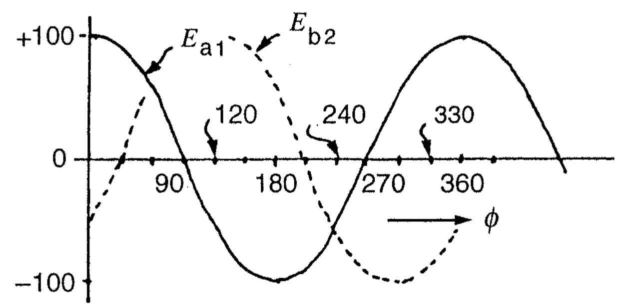
(b) $I = \dfrac{4000}{240} = 16.7$ A

This problem shows that adding a capacitor to a line does not always reduce the line current.

CHAPTER 8

8-1 $E_L = 2400\sqrt{3} = 4157$ V

8-2



a.

Angle	E_{a1}	E_{1a}
0	+ 100	− 100
90	0	0
120	− 50	+ 50
240	− 50	+ 50
330	+ 86.6	− 86.6

Note an angle of 120° gives the same value as an angle of 30°. Also, 330° is equivalent to 60°

The values can also be calculated from

$E_{1a} = -100 \cos \phi$;

thus, at 240° $E_{1a} = -100 \cos 240 = +50$ V

b. The polarity is given by the sign in culumn 2 above. At 0° terminal 1 is (−) with respect to terminal a

c.

angle	0	90	120	240	330
E_{b2}	− 50	+ 86.6	+ 100	− 50	− 86.6
E_{2b}	+ 50	− 86.6	− 100	+ 50	+ 86.6

The values can be read off by inspection. The equation for E_{2b} is: $E_{2b} = -100 \sin(\phi - 30)$. Thus, at 240° $E_{2b} = -100 \sin(240 - 30) = +50$ V

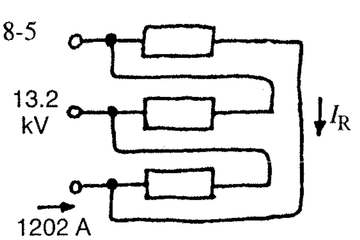
8-3 yes

8-4 a. $E_{LN} = 620/\sqrt{3} = 358$ V

b. $I = 358/15 = 23.87$ A

c. $P = 3\,EI = 3 \times 23.87 \times 356 = 25.8$ kW

8-5



a. $I_R = 120^2/\sqrt{3} = 694$ A

b. $E_R = 13.2$ kV

c. 13.2 kV × 694 = 9.16 MW

d. 9.16 × 3 = 27.5 MW

e. $R = 13\,200/694 = 19\ \Omega$

8-6 a. The phase sequence is a-b-c

b. by reversing the rotation or (as far as the load is concerned) by interchanging leads a-b and 1-2.

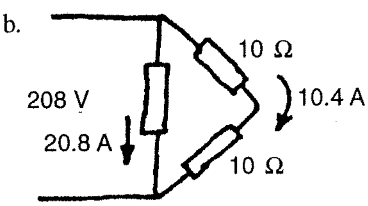
8-7 $S = EI\sqrt{3} = 600 \times 25 \times \sqrt{3} = 26$ kVA

8-8 120 V

8-9 a. $I_R = 208/10 = 20.8$ A

$\therefore P = 3 \times E_R I_R = 3 \times 208 \times 20.8 = 13$ kW

b.



If a fuse blows, it is as if one line were disconnected. The circuit is then a simple single-phase circuit, as shown

Total $P = (208 \times 20.8) + (208 \times 10.4) = 6.5$ kW

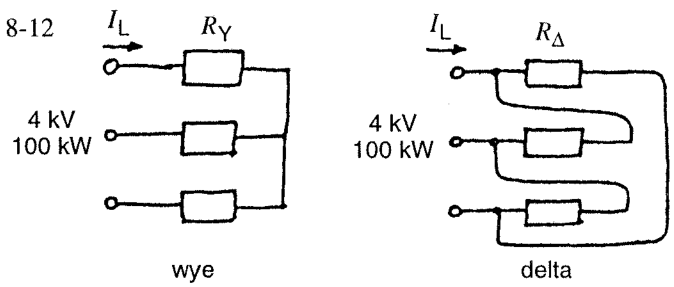
8-10 Single-phase, because only 2 lines are active

8-11 a. $I = \dfrac{P}{E\sqrt{3}} = \dfrac{15\,000}{208\sqrt{3}} = 41.6$ A

b. 41.6 A

c. $R = E/I = \dfrac{208}{\sqrt{3} \times 41.6} = 2.89\ \Omega$

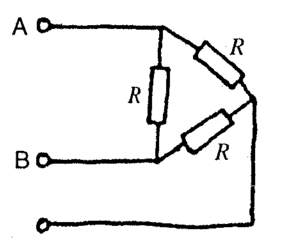
8-12



In both cases $I_L = \dfrac{100\,000}{4000\sqrt{3}} = 14.43$ A

a. $R_Y = \dfrac{4000}{\sqrt{3} \times 14.43} = 160\ \Omega$ b. $R_\Delta = \dfrac{4000}{(14.43/\sqrt{3})} = 480\ \Omega$

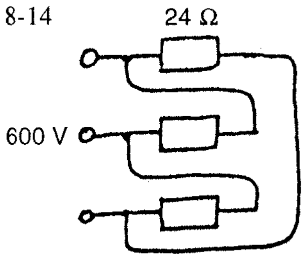
8-13



If we measure the resistance between terminals A and B, we are taking the R of a series-parallel circuit. Let R be the resistance per winding. Then we have

$$R_{AB} = \frac{R \times 2R}{3R} = \frac{2}{3}R = 0.6 \quad \therefore R = 0.9\ \Omega$$

8-14



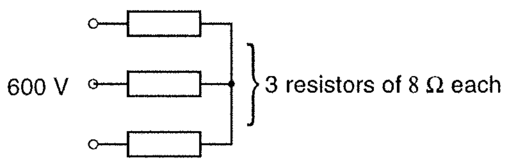
$I_R = 600/24 = 25$ A

Power dissipated per resistor $= 600$ V $\times$ 25 A $= 15$ kW

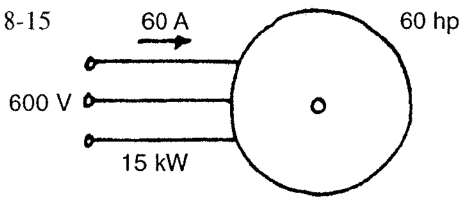
If resistors are connecter in Y, they must each also dissipate 15 kW. The voltage across each resistor $= 600/\sqrt{3} = 346.4$ V.

$\therefore 15\,000 = \dfrac{346.4^2}{R} \quad \therefore R = 8\ \Omega$ (see below)

8-14



8-15



$P_o = 60/1.34$
$= 44.78$ kW

$P_i = 50$ kW

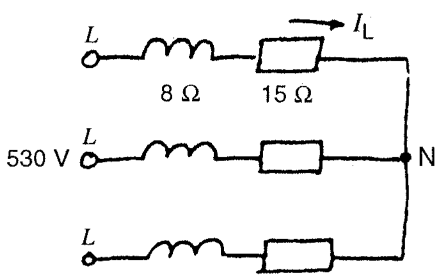
a. $\eta = \dfrac{P_o}{P_i} = \dfrac{44.78}{50} = 0.895 = 89.5\ \%$

b. $S = EI\sqrt{3} = 600 \times 60 \times \sqrt{3} = 62.3$ kVA

c. $Q = \sqrt{60.3^2 - 50^2} = 37.2$ kvar

d. $\cos\theta = 50/62.3 = 80.2\ \%$

8-16 a.



a. Z per phase $= \sqrt{8^2 + 15^2} = 17\ \Omega$

$E_{LN} = 530/\sqrt{3} = 306$ V

$I_L = E_{LN}/Z = 306/17 = 18$ A

Q per phase $= 18^2 \times 8 = 2592$ var

P per phase $= 18^2 \times 15 = 4860$ W

S per phase $= \sqrt{4860^2 + 2592^2} = 5508$ VA

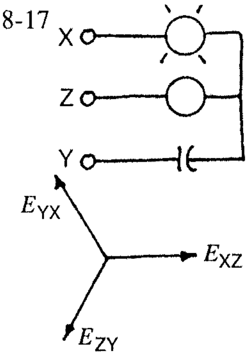
$\therefore Q$ total $= 2592 \times 3 = 7776$ var $= 7.78$ kvar

P total $= 4860 \times 3 = 14\,580$ W $= 14.6$ kW

S total $= 5508 \times 3 = 16\,524$ VA $= 16.5$ kVA

b. $E_R = 18 \times 15 = 270$ V

8-17



a. the segment is given by the rule "bright-dim-capacitor" the sequence is XZY, meaning XZYXZYXZY

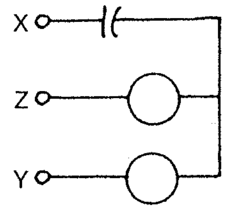
b.

8-18 $X_c = \dfrac{1}{2\pi fc} = \dfrac{10^6}{2\pi \times 60 \times 10} = 265\ \Omega$

a. $I = E_{LN}/265 = \dfrac{2300}{\sqrt{3} \times 265} = 5$ A

b. $Q = 2300 \times 5 \times \sqrt{3} = 19.9$ kvar

8-19

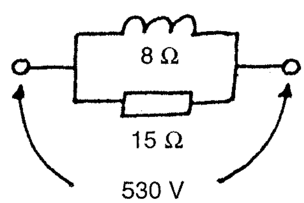


The sequence is still XZY or XZYXZYXZY... the sequence is also given by ZYX; ∴ the lamp connected to teminal Z will be brighter.

8-20 The voltage across the resistors falls to $1/\sqrt{3}$ of its original value. Each resistor will absorb $(1/\sqrt{3})2$ of its original power. $\therefore P = 60/3 = 20$ kW.

8-21 a. Same solution as Problem 8-16: $I = 18$ A

b.



On a per-phase basis:

$Q = 530^2/8 = 35.1$ kvar

$P = 530^2/15 = 18.7$ kW

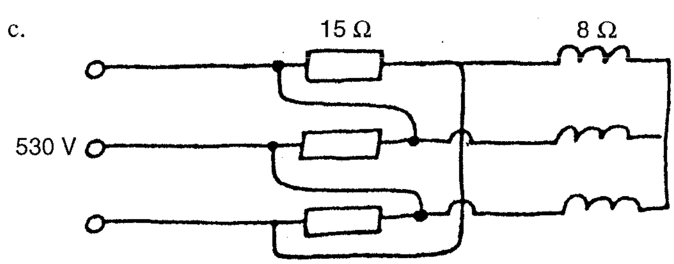
For the 3 phases $P = 18.7 \times 3 = 56.1$ kW

$Q = 35.1 \times 3 = 105.3$ kvar

$S = \sqrt{56.1^2 + 105.3^2} = 119.3$ kVA

$I_L = S/E\sqrt{3} = 119\,300/530\sqrt{3} = 130$ A

c.



Taking matters on a per-phase basis we find:

$P = 530^2/15 = 18.7$ kW $P_{tot} = 56.1$ kW

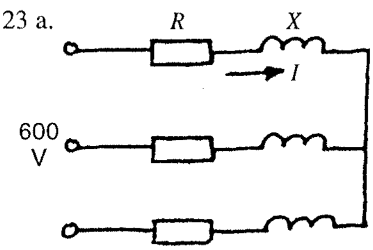
$Q = (530/\sqrt{3})^2/8 = 11.7$ kvar $Q_{tot} = 35.1$ kvar

$S_{tot} = \sqrt{56.1^2 + 35.1^2} = 66.17$ kVA

$I = \dfrac{66\,170}{530\sqrt{3}} = 72.1$ A

8-22 The frenquency has the effect of increasing X_c in the ratio 6/5. The line current drops to $5/6 \times 22 = 18.3$ A.

8-23 a.



$I = 60$ A

$3I^2R = 50$ kW

$\therefore R = \dfrac{50\,000}{3 \times 60^2} = 4.63\ \Omega$

also $3I^2X = 37.2$ kvar $\therefore X = \dfrac{37\,200}{3 \times 60^2} = 3.44\ \Omega$

8-23 b. We already found that $\cos\theta = 80.2$ %

$\therefore$ the phase angle = arc cos 0.802 = 36.7°

8-24 a. $I = \dfrac{600\,000}{2400 \times \sqrt{3}} = 144$ A $\therefore Z = \dfrac{2400}{\sqrt{3} \times 144} = 9.6\ \Omega$

b. $P = 600 \times 0.8 = 480$ kW = 160 kW per phase

$Q = 600 \times 0.6 = 360$ kvar = 120 kvar per phase

$I^2X = 120\,000 \quad \therefore X = \dfrac{120\,000}{144^2} = 5.79\ \Omega$

$I^2R = 160\,000 \qquad R = \dfrac{160\,000}{144^2} = 7.72\ \Omega$

8-25 a. $S = \sqrt{3}\,EI = \sqrt{3} \times 220 \times 16 = 6.1$ kVA

b. $\cos\theta = \dfrac{P}{S} = \dfrac{3.5 + 1.5}{6.1} = .82$ or 82 %

8-26 a. $S = \sqrt{3}\,EI = \sqrt{3} \times 600 \times 25 = 26$ kVA

$P = S\cos\theta = 26 \times 0.82 = 21.3$ kW

b. $P_o = \eta P_i = 0.85 \times 21.3 = 18.1$ kW

c. 21.3 kW × 3 h = 63.9 kW·h

8-27 a. $P = 35 - 20 = 15$ kW

$Q = \sqrt{3} \times (30 - (-20)) = 95.3$ kvar

$S = \sqrt{15^2 + 95.3^2} = 96.5$ kVA

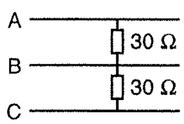
$\cos\theta = \dfrac{P}{S} = \dfrac{15}{96.5} = .155$ or 15.5 %

b. $S = \sqrt{3}\,EI$

$I = \dfrac{96\,500}{\sqrt{3} \times 630} = 88.4$ A

INDUSTRIAL APPLICATION – CHAPTER 8

8-28 $I_A = I_B = \dfrac{480\ \text{V}}{20\ \Omega} = 24\ \text{A} \qquad I_C = 0$

8-29 

$I_A = 480/30 = 16$ A
$I_C = 480/30 = 16$ A
$I_B = 16\sqrt{3} = 27.7$ A

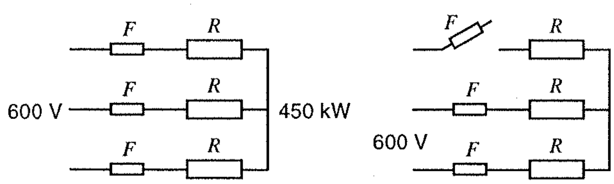
8-30 $P = \left(\dfrac{470}{460}\right)^2 \times 150 = 156.6$ kW. (The power varies as the square of the voltage)

E (line to-neutral) $= 480/\sqrt{3} = 277$ V

$I_A = I_B = I_C = 277/5 = 55.4$ A

If one line is disconnected, the remai-ning two resistors are in series across the 480 V line. The current in each becomes 480/10 Ω = 48 A.

8-32 Suppose the resistors are connected in wye.



Full 3 ϕ power = 200 kW $= \dfrac{(600/\sqrt{3})^2}{R} \times 3 = \dfrac{600^2}{R}$

Single-phase power $= \dfrac{600^2}{2R}$

Hence the single-phase power is equal to 1/2 of the 3 ϕ power or $1/2 \times 200 = 100$ kW. The heater develops 100 kW.

8-33 The quantity of steam is proportional to the thermal power which in turn varies as the square of the voltages.

Thus steam produced $= 1300 \times \left(\dfrac{612}{575}\right)^2 = 1359$ lb/h

8-34 (a) $P = \dfrac{40 \times 746}{0.936} = 31.88$ kW

(b) $S = \dfrac{31.88}{0.83} = 38.41$ kVA

(c) $I = \dfrac{38.41 \times 1000}{460\sqrt{3}} = 48.2$ A

8-35 (a) $S = \dfrac{1600 \times 746}{0.96 \times 0.90} = 1381$ kVA

$I_L = \dfrac{1381 \times 1000}{2400\sqrt{3}} = 332$ A

(b) $P = \dfrac{1600 \times 746}{0.96} = 1243$ kW

$Q = \sqrt{1381^2 - 1243^2} = 602$ kvar

(c) $\theta = \arccos \dfrac{1243}{1381} = 25.8°$

CHAPTER 9

9-1 a. $I_m = \frac{E_g}{X_L} = \frac{120}{60} = 2$ A

b. $I_{m(peak)} = \sqrt{2}\, I_m = \sqrt{2} \times 2 = 2.83$ A

c. $U_{(peak)} = NI_{m(peak)} = 500 \times 2.83 = 1415$ A

d. $\phi_{max} = \frac{E_g}{4.44\, fN} = \frac{120}{4.44 \times 60 \times 500} = 0.9$ mWb

9-2 $U = 1415 \times 40/120 = 472$ A

$\phi_{max} = 0.9 \times 40/120 = 0.3$ mWb

9-4 a. $\frac{E_1}{E_2} = \frac{N_1}{N_2} \quad \therefore E_2 = \frac{600 \times 300}{500} = 360$ V

b. $I_2 = \frac{E_2}{Z} = \frac{360}{12} = 30$ A

c. $\frac{I_1}{I_2} = \frac{N_2}{N_1} \quad \therefore I_1 = \frac{300 \times 30}{500} = 18$ A

d. $P_1 = E_1 I_1 = 600 \times 18 = 10.8$ kW

e. $P_2 = E_2 I_2 = 360 \times 30 = 10.8$ kW

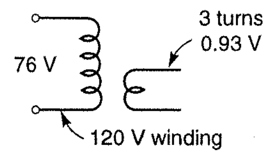
9-5 $Z_x = a^2 Z = (500/300)^2 \times 12 = 33.3\ \Omega$

9-6 $I_c = aI = 1/100 \times 2 = 0.02$ A

$V_c = X_c I_c = 20\,000 \times 0.02 = 400$ V

INDUSTRIAL APPLICATION – CHAPTER 9

9-7



0.93 V = 3 turns

$\therefore$ 1 V = $\frac{3}{0.93}$ = 3.226 turns

76 V = 76 × 3.226 = 245 turns.

The 120 V winding has therefore 245 turns.

The 480 V winding has 245 × $\frac{480}{120}$ = 980 turns.

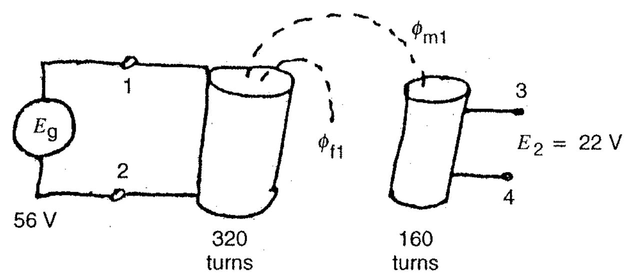
9-8 (a) $Z = 42$ V/1.24 A = 33.87 Ω

(b) $X_L = \sqrt{33.87^2 - 14.7^2} = 30.5\ \Omega$

$L = 30.5/(2\pi \times 60) = 0.0809$ H = 80.9 mH

(c) $\theta = \arctan \frac{X_L}{R} = \arctan \frac{30.5}{14.7} = 64.3°$

9-9



$E = 4.44\, fN_1\phi$

$56 = 4.44 \times 60 \times 320 \times \phi \rightarrow \therefore \phi = 0.000657$ Wb

also on secondary side = 0.657 mWb

$22 = 4.44 \times 60 \times 160 \times \phi_{m1} \rightarrow \phi_{m1} = 0.516$ mWb

consequently, $\phi_{f1} = \phi - \phi_{m1}$

$= (0.657 - 0.516) = 0.141$ mWb

9-10 Ratio of capacitances = $\frac{300\ \mu F}{40\ \mu F} = 7.5$

Hence ideal transformer turns ratio = $\sqrt{7.5} = 2.7386$

Ratios available = $\frac{330\text{ V}}{120\text{ V}} = 2.75$

and = $\frac{450}{60} = 7.5$

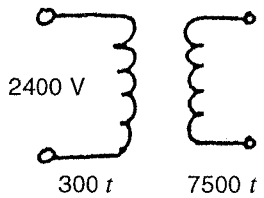
and = $\frac{480}{150} = 3.2$

The 330 V/130 V transformer is the most appropriate choice. The 40 μF capacitor must be connected to the 330 V winding.

CHAPTER 10

10-11 $E_2 = \frac{240}{1200} \times 600 = 120$ V

10-12



$$HV = \frac{7500}{300} \times 2400 = 60\ 000 \text{ V} = 60 \text{ kV}$$

10-13 a. $E_2 = 6900 \times \frac{24}{1500} = 110.4$ V

b. $I_2 = 110.4/5 = 22.08$ A

I_1 (primary) $= 22.08 \times 24/1500 = 0.353$ A

10-14 $E_1 = 220$ V, $E_2 = 110$ V, $I_2 = 110/5 = 22$ A

$I_1 = I_2/2 = 11$ A, $P = 11 \times 220 = 2.42$ kW

10-15 $I_1 = \frac{3000 \times 1000}{60\ 000} = 50$ A, $I_2 = \frac{3000 \times 1000}{2400} = 1250$ A

10-16 $E = 4.44\, fN\phi$

$600 = 4.44 \times 60 \times 1200 \times \phi \quad \therefore \phi = 1.88$ mWb

10-18 a. If the coupling were perfect, the voltmeter would read:

$$E_2 = E_1 \times \frac{N_2}{N_1} = 120 \times \frac{600}{200} = 360 \text{ V}$$

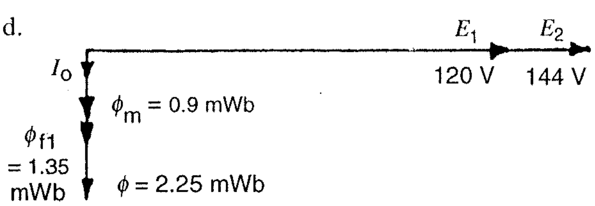
However, only 40 % of the flux enters the secondary.

$$\therefore E_2 = 40\ \% \times 360 = 144 \text{ V}$$

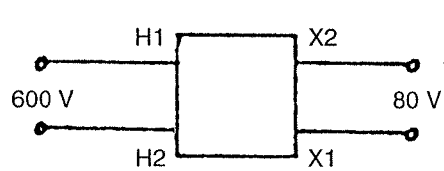
b. $120 = 4.44 \times 60 \times 200 \times \phi \quad \therefore \phi = 2.25$ mWb

c. $\phi_m = 40\ \% \times \phi = 0.4 \times 2.25 = 0.9$ mWb

d.

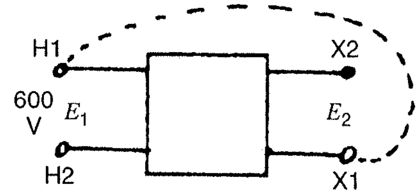


10-19



a. zero

10-19 b.



H1, X1 have the same instantaneous polarity; $\therefore$ E_1 and E_2 subtract.

$E_{H2-X2} = 600 - 80 = 520$ V

c. additive polatity (see Fig. 10-10)

10-20 a. A short-circuit; the line circuit-breakers or fuses will trip.

b. No, because both polarities are changed.

10-23 Z_{np} on 60 kV side $= \frac{E^2}{S} = \frac{60\ 000^2}{3000\ 000} = 1200\ \Omega$

Z_{np} on 2400 kV side $= \frac{E^2}{S} = \frac{2400^2}{3 \times 10^6} = 1.92\ \Omega$

a. $Z_p = 1200 \times 0.06 = 72\ \Omega$

b. $Z_s = 1.92 \times 0.06 = 0.115\ \Omega$

10-24 a. 2184 V yields 120 V (according to the table)

$\therefore$ 2300 V yields $\frac{2300}{2184} \times 120 = 126.4$ V

10-24 b. $I_2 = \frac{12\ 000}{126.4} = 95$ A; $I_1 = \frac{12\ 000}{2300} = 5.22$ A

10-25 a. Losses $= \frac{0.7}{100} \times 66.7 \times 10^6 = 466.9$ kW

10-25 b. The losses are the same because E and I are the same; however, $P_o = 66.7 \times 0.8 = 53.36$ MW

$P_i = 53.36 + 0.4669 = 53.827$ MW

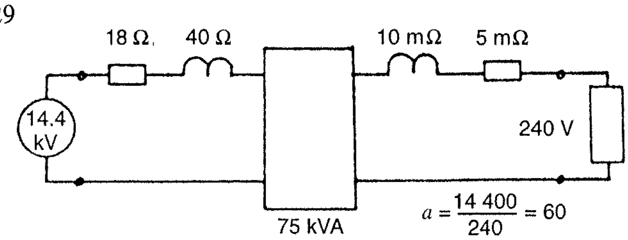
efficiency $\eta = \frac{P_o}{P_i} = \frac{53.36}{53.827} = 99.1$ %

10-26 Oil cannot withstand a higher temperature.

10-27 $E = 4.44 fN\phi \quad 600 = 4.44 \times 50 \times 300 \times \phi \quad \therefore \phi = 9$ mWb

10-28 There is more leakage flux as the coupling is reduced. This increases the kvars needed to create the field. Thus, for a given load current Q increases. Because $Q = I^2X_f$, X_f must rise with reduced coupling. Hence the transformer impedance increases.

10-29



a. R referred to primary $= 18 + a^2R_s = 18 + 60^2 \times 0.005$
$= 36\ \Omega$

X referred to primary $= 40 + a^2X_s = 40 + 60^2 \times 0.01$
$= 76\ \Omega$

$Z_p = \sqrt{36^2 + 76^2} = 84.1\ \Omega$

b. $Z_{nominal} = \dfrac{E_p^2}{S_{nominal}} = \dfrac{14\,400^2}{75\,000} = 2765\ \Omega$

$\therefore$ percent impedance $= \dfrac{84.1}{2765} \times 100 = 3.04\ \%$

c. Z referred to secondary $= \dfrac{Z_p}{a^2} = \dfrac{84.1}{60^2} = 23.36\ \text{m}\Omega$

d. 3.04 % (Note that the nominal impedance is

$\dfrac{240^2}{75\,000} = 0.768\ \Omega \quad \therefore \dfrac{23.36 \times 10^{-3}}{0.768} \times 100 = 3.04\ \%$)

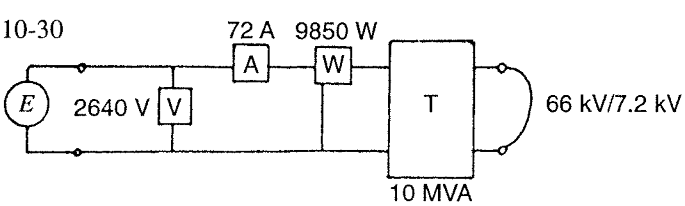
e. I_N on primary side $= \dfrac{75\,000}{14\,400} = 5.208$ A

Total I^2R loss $= 5.208^2 \times 36 = 976$ W

Note That we could have found the copper losses by adding the primary and secondary losses, found independently; the same result is obtained.

f. percent $R = (36/2765) \times 100 = 1.3\ \%$
percent $X = (76/2765) \times 100 = 2.75\ \%$

10-30



a. $I^2R_p = W \quad 72^2 \times R_p = 9850 \qquad \therefore R_p = 1.9\ \Omega$
$Z_p = E/I = 2640/72 = 36.67\ \Omega$

$\therefore X_p = \sqrt{Z_p^2 - R_p^2} = \sqrt{36.67^2 - 1.9^2} = 36.6\ \Omega$

b. $Z_{np} = \dfrac{66\,000^2}{10 \times 10^6} = 435.6\ \Omega$

c. percent impedance $= \dfrac{36.67}{435.6} \times 100 = 8.4\ \%$

10-31 Full load primary current $= \dfrac{10 \times 10^6}{66\,000\ \text{V}} = 151.5$ A

I^2R loss $= 151.5^2 \times 1.9 = 43.62$ kW

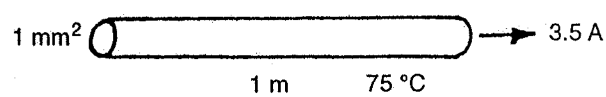
iron loss = 35 kW   Total loss = 35 + 43.62 = 78.62 kW

$P_o = S \cos\theta = 8.5$ MW = 8 500 kW

$\therefore \eta = \dfrac{P_o}{P_i} \times 100 = \dfrac{8500}{8578.62} = 99.08\ \%$

10-32 Assume a conductor having a cross section

a. Of 1 mm² and a length of 1 m, carrying a current of 3.5 A. This immediataly gives us the required current density. The loss per kilogram is independent of the conductor shape



$\rho_{75} = \rho_0\,(1 + \alpha_0\, t)$ see TABLE AX2 in appendix
$= 15.88\,(1 + 0.0427 \times 75) = 20.96\ \text{n}\Omega\cdot\text{m}$

$R = \dfrac{\rho l}{A} = \dfrac{20.96 \times 10^{-9}}{10^{-6}} \times 1 = 20.96\ \text{m}\Omega$

loss $= I^2R = 3.5^2 \times 20.96 \times 10^{-3} = 0.25676$ W

mass of conductor $= 8890 \times 1\ \text{mm}^2 \times 1$ m
$= 8.89 \times 10^{-3}$ kg

$\dfrac{\text{power loss}}{\text{mass}} = \dfrac{0.25676\ \text{W}}{8.89 \times 10^{-3}\ \text{kg}} = 28.9$ W/kg

b. For aluminum, using the same calculations, we find:

$\rho_{75°C} = 34.56\ \text{n}\Omega\cdot\text{m} \qquad R = 34.56\ \text{m}\Omega$

loss = 0.423 W   mass $= 2.703 \times 10^{-3}$ kg

Power loss per unit mass $= \dfrac{0.423}{2.703 \times 10^{-3}} = 156$ W/kg

10-33 Wind the primary and secondary coils on top of each other.

INDUSTRIAL APPLICATION – CHAPTER 10

10-34 Current in the HV and LV windings are respectively

$\frac{200\,000}{14\,400} = 13.89$ A and $\frac{200\,000}{277} = 722$ A

I^2R loss in HV winding = $13.89^2 \times 62 = 11.96$ kW

The I^2R loss in the LV winding will be about the same:

$722^2 \times R = 11\,960 \quad \therefore R = 0.023\ \Omega$

10-35 The current density J should be about the same in both windings. No 11 wire = 4.17 mm²

In HV winding $J = \frac{13.89\text{ A}}{4.17} = 3.33$ A/mm²

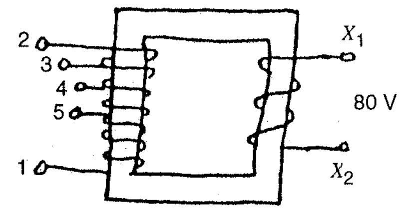
Cross section of secondary wire = $\frac{722}{3.33} = 217$ mm²

A rectangular conductor would be used, both to save space and to ensure better heat transfer through the body of the LV coil.

10-36 10 kVA transformer: $\frac{10\,000}{118} = 85$ W/kg

100 kVA transformer: $\frac{100\,000}{445} = 225$ W/kg

10-37



Voltage between 3 and 4 when 120 V is applied to $X_1 X_2 = 2292 - 2184 = 108$ V by proportion, 80 V across $X_1 X_2$ will give $\frac{80}{120} \times 108 = 72$ V between 3 and 4.

Rated primary current = $\frac{40\,000}{2400} = 16.7$ A

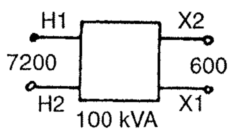
The maximum load current would be 16.7 A if a load were connected between terminals 3 and 4. Such a connection would only be made in an experimental or research setup.

CHAPTER 11

11-5 Primary – 1 turn; secondary: $\frac{1500}{5} = 300$ turns

11-6 Nominal primary voltage (drop) = $S/I = \frac{10\ \text{VA}}{50\ \text{A}} = 0.2$ V

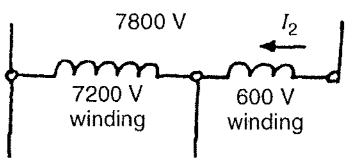
11-7



I_1 on 7200 V side = $\frac{100\ 000}{7200}$
= 13.9 A

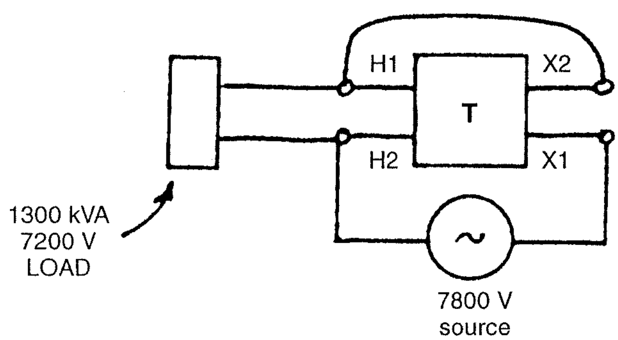
I_2 on 600 V side = $\frac{100\ 000}{600}$
= 166.7 A

We can load the transformer until I_2 = 166.7 A

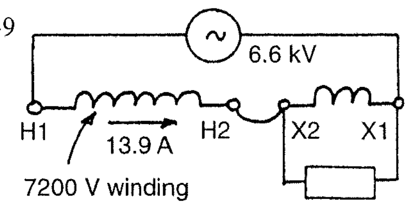


∴ The input to the transformer can be 166.7 × 7800 = 1300 kVA. The load is also 1300 kVA – 13 times greater than the nameplate rating of the transformer.

11-8 The primary and secondary voltages must add; therefore H1 – X2 or H2 – X1 must be connected together.

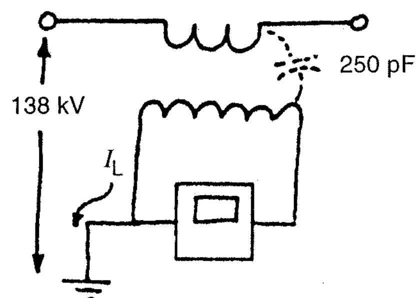


11-9



input = EI
= 13.9 × 6.6 kV
= 92 kVA
= LOAD CAPACITY

11-10



$$X_c = \frac{1}{2\pi f C} = \frac{1 \times 10^{12}}{2\pi \times 60 \times 250} = 10.6\ \text{M}\Omega$$

$$I_L = \frac{138\ 000}{10.6 \times 10^6} \times 1000 = 13\ \text{mA}$$

Note: a current of 13 mA is a strong current if it were to pass through a person's body.

11-11 Secondary current = $600 \times \frac{5}{1000} = 3$ A

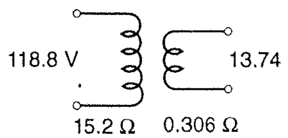
a. Voltage across the ammeter = voltage across the secondary winding = 3 × 0.15 = 0.45 V

b. Primary voltage = $0.45 \times \frac{5}{1000} = 2.25$ mV.
Because the primary winding is connected in series with the line, it effectively produces a voltage drop of 2.25 mV.

c. New ratio is $\frac{1000}{4}$ = 250 A/5A.
This is obvious because the core "sees" the 4-turn coil as a 4-turn primary winding.

NDUSTRIAL APPLICATION – CHAPTER 11

11-12



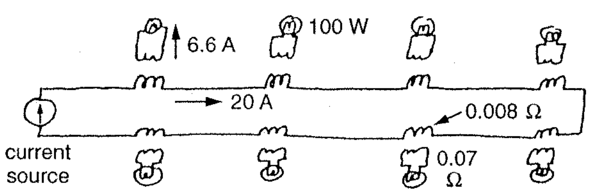
Turns ratio = 118.8/13.74
= 8.646

If 120 V is applied to primary, the secondary voltage would be 120/8.646 = 13.88 V. The 13.88 V at no load is higher than the 12.8 V shown on the nameplate. The reason is that when the transformer is loaded, the internal voltage drop due to the resistance and leakage reactance of the windings, will cause the secondary voltage to fall to about 12.8 V at full load.

11-13 In an ideal transformer, the I^2R losses in the primary and secondary should be about the same. Based on the 120 V winding resistance, the resistance of the secondary should be $15.2\ \Omega \times \left(\frac{1}{8.646}\right)^2 = 0.203\ \Omega$.

The actual value is 0.306 Ω. Consequently, we are led to the conclusion that the LV winding is wound on top of the HV winding, because that way the mean length per turn is greater.

11-14



(a) Voltage across each lamp = $\frac{100\text{ W}}{6.6\text{ A}} = 15.15$ V

(b) Power on the secondary side =

$100\text{ W} + 6.6^2 \times 0.07\ \Omega = 103$ W

Power delivered by the primary =

$103\text{ W} + 20^2 \times 0.008 = 106.2$ W.

Hence voltage across primary terminals =

106.2/20 A = 5.31 V

(c) Length of wire = (140 + 1) 50 = 7050 m [No 14]

Resistance of 105°C = $\frac{7050}{1000} \times 11.0\ \Omega/\text{km} = 77.6\ \Omega$

IR drop at 20 A = 77.6 × 20 = 1552 V

Voltage across 140 lamps = 140 × 5.31 = 743 V

Minimum voltage source = 743 + 1552 = 2295 V, say 2300 V.

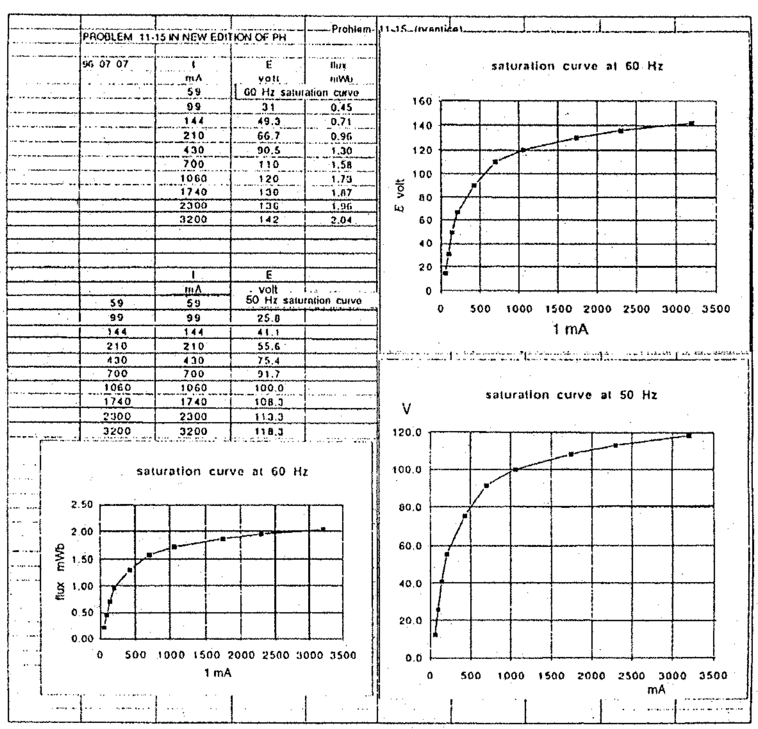
11-15 (a) The saturation curve is plotted below for 60 Hz. Volt versus I_o.

(c) From $E = 4.44\ fN\phi$ $\quad E = 4.44 \times 60 \times 260\ \phi$

Hence $\phi = 0.0144\ E$ where E is in volts and ϕ in mWb.

(b) At 50 Hz for the same I_o, the flux will be the same but the induced voltage is only 50/60 of its 60 Hz value.

(c) At 60 Hz, saturation sets in when E is about 120 V and ϕ is about 1.75 mWb. Note that the transformer is heavily saturated at 50 Hz and 120 V.



PROBLEM 11-15 IN NEW EDITION OF PH

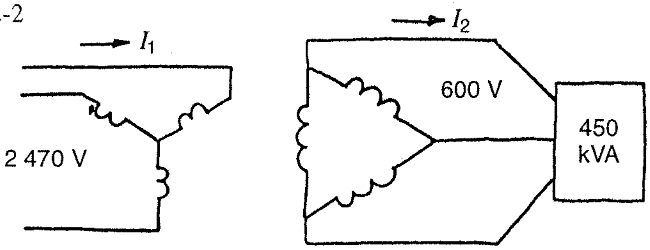
96 07 07

I mA	E volt	flux mWb
59	60 Hz saturation curve	
99	31	0.45
144	49.3	0.71
210	66.7	0.96
430	90.5	1.30
700	110	1.58
1060	120	1.73
1740	130	1.87
2300	136	1.96
3200	142	2.04

	I mA	E volt
59	59	50 Hz saturation curve
99	99	25.8
144	144	41.1
210	210	55.6
430	430	75.4
700	700	91.7
1060	1060	100.0
1740	1740	108.3
2300	2300	113.3
3200	3200	118.3

CHAPTER 12

12-2

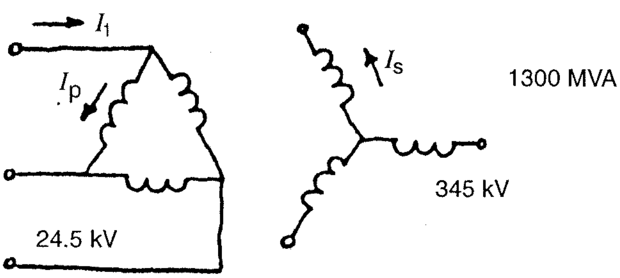


a. $I_1 = \dfrac{450\ 000}{12\ 470\ \sqrt{3}} = 20.8\ \text{A} \qquad I_2 = \dfrac{450\ 000}{600\ \sqrt{3}} = 433\ \text{A}$

b. $I_p = 20.8\ \text{A} \qquad I_s = \dfrac{I_2}{\sqrt{3}} = \dfrac{433}{1.73} = 250\ \text{A}$

12-3 $I_1 = \dfrac{36 \times 10^6}{13.8 \times 1000\ \sqrt{3}} = 1506\ \text{A}; \quad I_2 = \dfrac{36 \times 10^6}{320\ \sqrt{3}} = 65\ \text{kA}$

12-4



$I_1 = \dfrac{1300 \times 10^6}{24.5 \times 10^3\ \sqrt{3}} = 30\ 635\ \text{A} \quad \therefore\ I_p = \dfrac{30\ 635}{\sqrt{3}} = 17.7\ \text{kA}$

$I_s = \dfrac{1300 \times 10^6}{345\ 000\ \sqrt{3}} = 2175\text{A}$

12-5 In the FA mode the capacity is 48 MVA. The corresponding rated line current $= \dfrac{48 \times 10^6}{225\ \sqrt{3}\ \text{kV}} = 123$ A.

a. Current in secondary lines $= 150 \times \dfrac{225}{26.4} = 1278$ A.

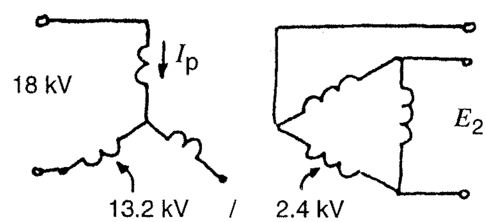
b. Yes, because the rated current in the FA mode is 123 A.

12-6 a. in delta-delta

b. $I_1 = 600\ 000/600\ \sqrt{3} = 577\ \text{A}; \quad I_2 = 577/12 = 48.1\ \text{A}$

c. $I_p = 577/\sqrt{3} = 333\ \text{A}; \quad I_s = 333/12 = 27.8\ \text{A}$

12-7



a. The rated current in the primary windings is:

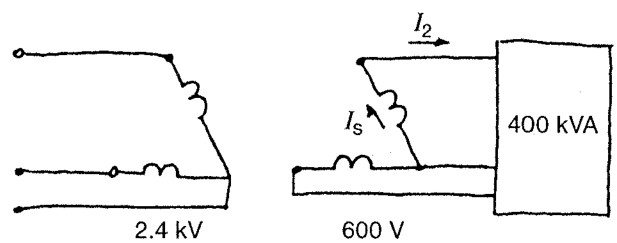
$$I_p = \frac{100\ 000}{13\ 200} = 7.57\ \text{A}$$

This current must not be exceeded when the transformers are connected as shown above. The max. load is:

$$S = EI\sqrt{3} = 18\ 000 \times 7.57 \times \sqrt{3} = 236\ \text{kVA}$$

b. $E_2 = 2.4 \times \dfrac{18}{\sqrt{3}} \times \dfrac{1}{13.2} = 1.89\ \text{kV}$

12-8



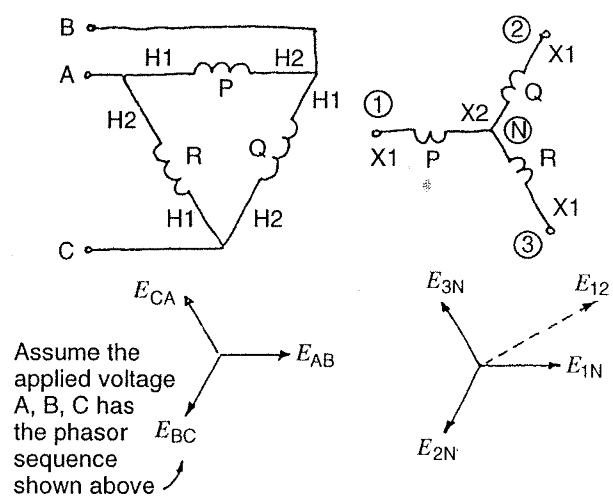
$I_2 = 400 \times 10^3/600\ \sqrt{3} = 385\ \text{A}$

Nominal value of $I_s = \dfrac{250\ 000}{600} = 417$ A

a. The transformers are not overloaded.

b. The max load is $417 \times 600\ \sqrt{3} = 433$ kVA.

12-9



Then E_{1N} must be in phase with E_{AB}, owing to the polarity marks. Similarly, E_{34} is in phase with E_{CA}

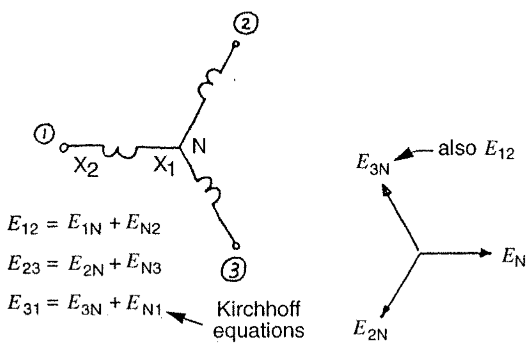
$$E_{1N} = E_{2N} = E_{3N} = 600/\sqrt{3} = 347 \text{ V.}$$

We also have:

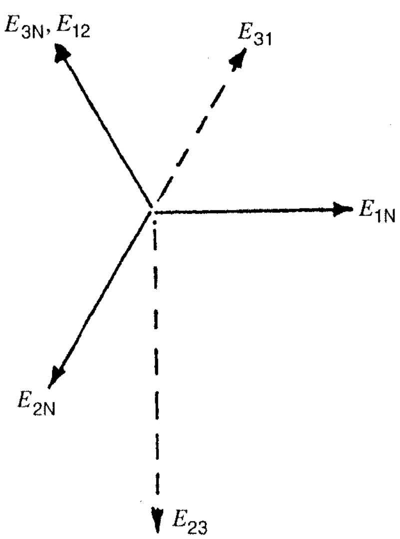
$$E_{12} = E_{1N} + E_{N2};\ E_{23} = E_{2N} + E_{N3};\ E_{31} = E_{3N} + E_{N1}$$

all ok with the connections reversed, E_{N1} is in phase with E_{AB}, because E_{X1-X2} is in phase with E_{H1-H2} of the same transf.

12-9



12-9 E_{12} is equal to and in phase with E_{3N}



The other phasors are found by adding according to Kirchhoff's equations. We find that:

$E_{12} = 347$ V, leading E_{23} by 150°

$E_{31} = 347$ V, lagging behind E_{12} by 60°

$E_{23} = 600$ V.

Thus, reversing one connection produces a totally unbalanced system.

NDUSTRIAL APPLICATION – CHAPTER 12

12-10 The rated line current on the 3-ph 4000 V line, based on the transformer rating, is:

$$I = \frac{150\ 000 \times 3}{4000\ \sqrt{3}} = 64.95 \text{ A}$$

At no-load, the line current = 0.02 × 64.95 = 1.3 A.

12-11 Hours of no-load operation per year = 365 × 24 × 0.5 = 4380 h.

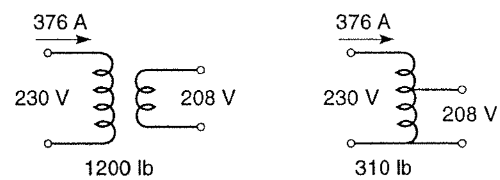
The copper I^2R losses are negligible at no-load. The core loss (iron losses) = 0.003 × 300 kVA = 0.9 kW.

Energy loss during one year = 0.9 × 4380 = 3942 kWh

Cost per year = 3942 × 4.5 × 0.01 = $177.

There are hundreds of thousands of such transformers installed in North America. Hence the no-load losses amount to millions of dollars.

12-12



The rated line current on the 230 V side is:

$$I = \frac{150\ 000}{230\ \sqrt{3}} = 376 \text{ A.}$$

Assuming a wye-wye connection, the line-to-neutral voltage $= \frac{230}{\sqrt{3}} = 133$ V.

The line to-neutral voltage on the secondary side =

$$\frac{208}{\sqrt{3}} = 120 \text{ V.}$$

In the standard transformer, the full 133 V winding carries the 376 A current.

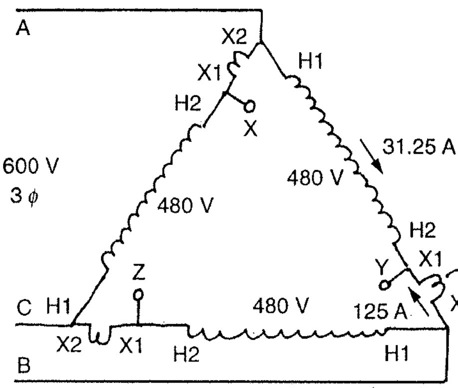
In the autotransformer, only the portion (133 – 120) = 13 V carries the 376 A current.

Consequently, the relative rating of the 3-phase autotransformer is only

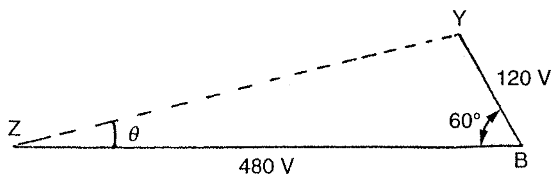
$$\frac{13 \text{ V}}{230 \text{ V}} = 0.0565$$

of the standard transformer rating. In other words, the autotransformer has an equivalent rating of 0.0565 × 150 kVA = 8.5 kVA. That is why there is such a large difference in the weight of the two transformers.

12-13



(a) The transformers are connected as shown above.
(b) The phasor diagram enables us to calculate the output voltage.



$E_{YZ}{}^2 = 120^2 + 480^2 - 120 \times 480 \cos 60° = 216\ 000$
$E_{YZ} = 465$ V

12-13 (c) From the figure, the phase shift is θ and is found by the sine law $\frac{120}{\sin\theta} = \frac{120}{\sin 60}$ $\therefore \sin\theta = 0.223$
and $\theta = 12.9°$

The 465 volt output is shifted by 12.9° from the 600 V, 3-phase input.

12-14 The rated current in 480 V winding and the 120 V windirng are: $\frac{150\ 000}{480} = 31.25$ A and $\frac{150\ 000}{120} = 125$ A

Looking at the autotransformer figure, these currents must be in phase, but flow in opposite directions (see portion AYB of 3-ph diagram). Hence current out of terminal Y = 125 + 31.25 = 156.25 A. The output terminals XYZ is $S = 465 \times 156.25 \times \sqrt{3} = 126$ kVA. The output must equal the 600 V, 3-ph input. The 600 V line currents are therefore $I = \frac{126\ 000}{600\sqrt{3}} = 121$ A. Note that the installed capacity of the standard transformers is only 3 × 15 = 45 kVA

12-15 We can use the information obtained in Problem 12-14. The 3 transformers will be connected as autotransformers. Together, they can deliver

$$\frac{5 \text{ kVA}}{15 \text{ kVA}} \times 126 \text{ kVA} = 42 \text{ kVA}$$

The power drawn by the motor is only $465 \times 42 \times \sqrt{3}$ = 33.8 kVA.

CHAPTER 13

13-7 No; the efficiency and power factor are lower than if a 10 hp motor were used.

13-10 a. $n = 120\,f/p = 120 \times 60/20 = 360$ r/min
b. no c. 20

13-12 $I = 600\,P_h/E = 600 \times 150/575 = 156$ A
starting current $\approx 6 \times 156 \approx 936$ A
no-load current $\approx 0.35 \times 156 \approx 55$ A

13-15 a. $n_s = 120\,f/p = 120 \times 60/12 = 600$ r/min
b. slip $= 0.06 \times 600 = 36$ r/min
$n = 600 - 36 = 564$ r/min

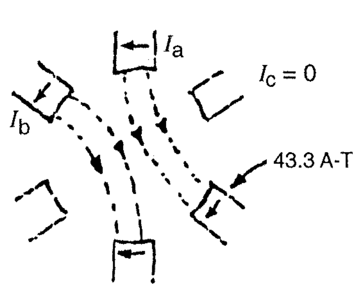
13-16 $E_{cc} = 4$ V $\quad n_s = 120\,f/p = 120 \times 60/6 = 1200$ r/min
a. $s = (1200 - 300)/1200 = 0.75$
$E = 0.75 \times 4 = 3$ V $\quad f = 0.75 \times 60 = 45$ Hz
b. $s = (1200 - 1000)/1200 = 0.167$
$E = 0.167 \times 4 = 0.67$ V $\quad f = 0.167 \times 60 = 10$ Hz
c. $s = (1200 - 1500)/1200 = -0.25$
$E = 0.25 \times 4 = 1$ V $\quad f = 0.25 \times 60 = 15$ Hz

13-17 a. $I = 600\,P_h/E = 600 \times \dfrac{75 \times 1.34}{4000} = 15$ A
$I_{LR} \approx 6 \times 15 = 90$ A; $I_{\text{no-load}} \approx 0.35 \times 15 \approx 5.25$ A
b. Full load speed $= 0.98 \times 900 = 882$ r/min
$P = nT/9.55 \quad 75\,000 = 882\,T/9.55 \quad T = 812$ N·m

13-18 $S = \dfrac{75 \times 746}{0.91 \times 0.83} = 74\,076$ VA; $I = \dfrac{S}{E\sqrt{3}} = \dfrac{74\,076}{4400 \times 1.73}$
$= 97.2$ A

13-19 $n_s = 1200 \quad f = 60$ Hz $\quad E_{dc} = 240$ V
a. $f = 30$ Hz $\quad E = 120$ V (with $s = 0.5$)
b. $s = (1200 - 900)/1200 = 0.25$
$E = 0.25 \times 240 = 60$ V; $\quad f = 0.25 \times 60 = 15$ Hz
c. $s = [1200 - (-3600)]/1200 = 4$
$E = 4 \times 240 = 960$ V; $\quad f = 4 \times 60 = 240$ Hz

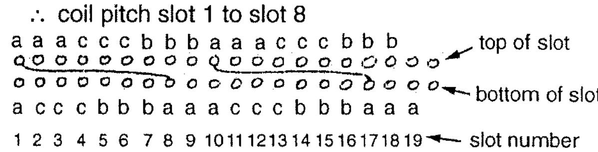
13-20 a. $I_c = 0$; $I_a = 10 \cos 150 = -8.66$ A; $I_b = +8.66$ A



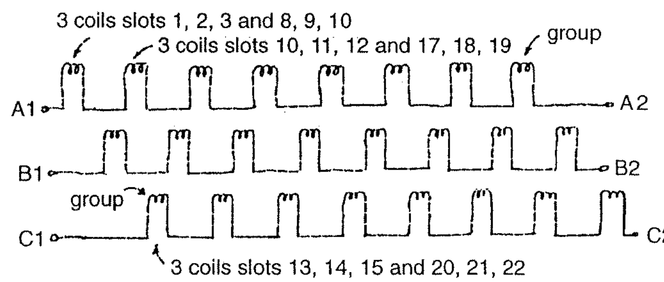
b. mmf of the windings $= 8.66\text{ A} \times 2 \times 3$ turns $= 86.6$ A (see text on section 13.3)
c. The flux is exactly between the positions corresponding to instants 3 and 4.

13-21 900 r/min corresponds to an 8-poles motor.
groups per phase = 8; coils per phase = 72/3 = 24;
coils/group = 24/8 = 3; full pitch = 72/8 = 9
i.e. slot 1 to slot 10; coil pitch $\approx 80\,\% \times 9 \approx 7.2$
∴ coil pitch slot 1 to slot 8.

∴ coil pitch slot 1 to slot 8



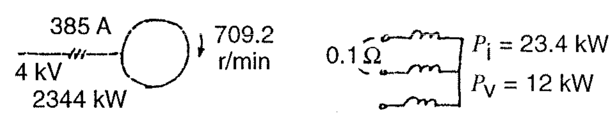
a a a is one coil group for phase A: note coil pitch from slot 1 to slot 8. The next coil in the group goes from slot 2 to slot 9. Note that slot 5, for example, has one coil side belonging to phase B (bottom of slot) while top of slot has a coil side of phase C. The coils of phase A are connected as follows:



The coils of phases B and C are arranged into 8 groups as shown above.

13-22 a. speed = 1800 r/min dia. = 250 mm
circumference $= \pi D = \pi \times 250 = 785.4$ mm
peripheral speed $= 1800 \times 785.4/60 = 23.56$ m/s
b. $e = Blv = 0.7 \times 200/1000 \times 23.56 = 3.3$ V
c. pole pitch $= \pi D/p = 785.4/4 = 196.35$ mm

13-23



a. $S = EI\sqrt{3} = 4000 \times 385\sqrt{3} = 2667$ kVA
$\cos\theta = 2344/2667 = 87.88$ %
b. $P_r = 2344000 - 23\,400 - 3 \times 385^2 \times 0.1/2 = 2298$ kW

c. Although the synchronous speed is not specified, the slip must be low. The possible values of n_s are 600, 720, 900 r/min. ∴ 720 is the one to use.

$s = (720 - 709.2)/720 = 0.015$

$P_{jr} = sP_r = 0.015 \times 2298 = 34.5$ kW

d. $P_m = 2298 - 34.5 = 2263.5$ kW

$P_L = 2263.5 - 12 = 2251.5$ kW

$P_L = nT_L/9.55 \quad \therefore 2251.5 = 709.2\ T_L/9.55$

$T_L = 30.32$ kN·m

efficiency $= P_L/P_C = 2251.5/2344 = 0.960$ or 96.0 %

13-24 a. increase d. decrease
b. decrease (slight) e. increase
c. slight decrease f. increase

13-26 $e = BLv = 0.5 \times 0.1 \times 30 = 1.5$ V

$I = e/R = 1.5/0.001 = 1500$ A

$F = BlI = 0.5 \times 0.1 \times 1500 = 75\ N = 16.9$ lbf.

This is a rough calculation because we assume the current has had time to build up to 1500 A while the conductor is still in the magnetic field of 0.5 teslas.

13-27 By Newton's third law of motion the force on the magnet is also 20 *N*.

13-28 $s = (600 - 594)/600 = 0.01$

$P_L = 5000$ hp $= 5000/1.34 = 3731$ kW

neglecting windage and friction losses P_v, we have

$P_m = P_L = 3731$ kW; $P_m = (1 - s)\ P_r$

$\therefore 3731 = (1 - 0.01)\ P_r \quad \therefore P_r = 3769$ kW

$P_{jr} = P_r - P_m = (3769 - 3731) = 38$ kW. (answer)

If we assume that $P_v \cong 1$ % of P_L, or 37 kW, we have:

$P_m = P_L + P_v = 3731 + 37 = 3768$ kW

again: $P_m = (1 - s)\ P_r$

$3768 = 0.99\ P_r \quad \therefore P_r = 3806$ kW

$P_{jr} = (3806 - 3768) = 38$ kW. We see that the rotor I^2R losses are not affected appreciably by the magnitude of P_v. We conclude that the value of P_{jr} is very close to 38 kW.

13-29 a. Stator R/ph $= 0.112/2 = 56$ mΩ @ 70 °C

$R_t = R_o\ (1 + \alpha t)$

$56 = R_o\ (1 + 17 \times 0.00427) \quad \therefore R_o = 52.2$ mΩ

$R_{75} = 52.2\ (1 + 0.00427 \times 75) = 68.9$ mΩ

Rotor R/ph at 75 °C is: $= \dfrac{7.3}{2} = \dfrac{68.9}{56} = 4.49$ mΩ

b. $s = (600 - 200)/600 = 0.67$

$E = 0.67 \times 1600 = 1067$ V; $f = 0.67 \times 60 = 40$ Hz

at 594 r/min $s = 0.01 \quad f = 0.6$ Hz; $E = 16$ V

c. S at no-load $= EI\sqrt{3} = 6000 \times 100 \times 1.73 = 1039$ kVA

$P_{\text{no-load}} = 91$ kW $Q = \sqrt{1039^2 - 91^2} = 1035$ kvar

d. $P_{js} = 3\ I^2R = 3 \times 100^2 \times 68.9/1000 = 2.07$ kW

e. $P_r = 91 - 39 - 2.07 = 50$ kW. Note that this active power is very nearly equal to P_v; in effect, P_{jr} is negligible.

13-30 a. at locked rotor $S = EI\sqrt{3} = 6000 \times 1800 \times 1.73$
$= 18\ 706$ kVA

$P = 2207$ kW $Q = \sqrt{18\ 706^2 - 2207^2} = 18\ 575$ kvar

b. $P_{js} = 3\ I^2R = 3 \times 1800^2 \times 68.9/1000 = 670$ kW

c. Assuming the iron losses are still 39 kW, we have:

$P_r = 2207 - 670 - 39 = 1498$ kW

d. $P_m = P_L = 0$ because the motor is locked.

e. $T_m = 9.55\ P_r/n_s = 9.55 \times 1498 \times 1000/600$
$= 23.84$ kN·m.

13-30 The full load torque is $P = nT/9.55$

$3731 = 594\ T/\ 9.55 \quad \therefore T = 60$ kN·m

$\dfrac{\text{locked-rotor torque}}{\text{full-load torque}} = \dfrac{23.84}{60} = 0.4$ or 40 %

This low torque is normal for big machines.

13-31 a. $s = (600 - 450)/600 = 0.25$

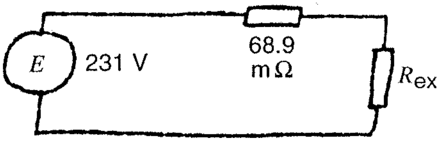
$E = 0.25 \times 1600 = 400$ V; E/phase $= 400/1.73 = 231$ V

b. $T = 9.55\ P_r/n_s$

$20\ 000 = 9.55 \times P_r/600 \quad \therefore P_r = 1256$ kW

$P_{jr} = sP_r = 0.25 \times 1256 = 314$ kW

P_{jr}/phase $= 314/3 = 105$ kW



$E^2/R = P \quad 231^2/R = 105\ 000 \quad R = 0.508 = 508$ mΩ

external rotor resistance $R_{ex} = (508 - 68.9) = 0.439$ Ω

c. rotor current $= 231/0.508 = 455$ A

13-32 $v = 200$ km/h $= 200\ 000/3600 = 55.55$ m/s; $f = 105$ Hz

$n_s = 2\ wf \quad 55.55 = 2\ w \times 105 \quad \therefore w = 264.5$ mm

13-33 a. The speed will increase very slightly but this will not affect the power drawn by the compressor.

b. The torque will be the same because the pressure of the compressor is not affected by the voltage.

c. The speed will increase slightly (to calculate the new speed, use Eq. 14-1)

d. The active power drawn by the motor will be about the same because the compressor load is unchanged. The reactive power increases somewhat, because a higher voltage produces a larger flux in the motor. Consequently, the apparent power will increase slightly. However, it will not increase by as much as the voltage does (2760/2300 = 1.2 or 20 %). The full-load current will therefore decrease slightly.

e. The power factor will decrease slightly because Q increases, whereas P does not.

The efficiency will be about the same. In effect, the increase in the iron losses is offset by the reduced copper losses in both the rotor and the stator.

f. The locked rotor torque increases as $(E_1/E_2)^2$ or $1.2^2 = 1.44$.

g. The L.R. current is proportional to the voltage; it increases by 20 %.

h. The breakdown torque increases by 20 %.

i. Because the efficiency is about the same, the losses are the same; ∴ the temperature rise is about the same. Actually, the iron in the stator will get hotter but the windings (including the rotor) will run cooler. The average temperature will be the same.

j. The flux per pole increases in proportion to the voltage: increase is 20 %.

k. The exciting current increases by more than 20 % because of saturation. Probable increase is about 30 %.

l. The iron losses increase as the square of the flux density (see sec 2-29, 2-30) approximately.

13-34 $v_s = 2\,wf \quad 12 = 2\,w \times 60 \quad \therefore w = 0.1 = 100$ mm

$F = P_r/v_s \quad \therefore 10\,000 = P_r/12 \quad \therefore I^2R = P_r = 120$ kW

13-39 Synchronous speed of stator $= \dfrac{120\,f}{P} = \dfrac{120 \times 5}{2}$

$= 3000$ r/min

Synchronous speed of rotor $= \dfrac{120 \times 11}{2} = 660$ r/min

Subsynchronous speed = 3000 – 660 = 2340 r/min

Supersynchronous speed = 3000 + 660 = 3660 r/min

The 11 Hz source absorbsactivepower (see Fig. 13-35).

13-40 The rotor delivers active power, as does the stator (see Fig. 13-38).

13-41 Synchronous speed of stator $= \dfrac{120\,f}{P} = \dfrac{120 \times 60}{4}$

$= 1800$ r/min

Slip speed = 18000 – 2367 = – 567 r/min

Slip $= \dfrac{-567}{1800} = -0.315$

a) Slip frequency = sf = – 315 × 60 Hz = – 18.9 Hz. Because the slip frenquency is negative, the phase sequence of the rotor voltage is negative.

b) The motor is running a supersynchronous speed. Consequently, the rotor is absorbng active power (see Fig, 13-36).

Approximate power P_r delivered from stator:

$P_r = 460$ kW

Power delivered to the 18.4 Hz source:

$sP_r = -0.315 \times 460 = -145$ kW.

Since the power is negative, the 18.9 Hz source delivers power to the rotor.

Total mechanical power delivered the the shaft of the motor: $P_m = 460$ kW + 145 kW = 605 kW.

INDUSTRIAL APPLICATION – CHAPTER 13

13-35 (a) Trimming the end rings increases the rotor resistance. Thus, for a given slip the current in the rotor bars will be less, which reduces the torque. To develop the same torque as before, the motor will have to run at a lower speed.

(b) The starting torque will increase. Compare for example, Figs. 13-18(a) and 13-18(b).

(c) The rotor will be hotter, because the rotor current for a given torque will be the same, but the rotor resistance is greater. Also, the speed is lower which reduces the cooling effect of the fan. Conseqently, the motor temperature will be slightly higher.

13-36 (a) The number of coils equals the number of slots = 90

(b) coils per phase = 90 ÷ 3 = 30

(c) number of poles = number of groups = 6

∴ coils per group = 30 ÷ 6 = 5

(d) The pole pitch = circumference ÷ poles = ($\pi \times 20$) ÷ 6 = 10.47 inches = 10.47 × 25.4 = 266 mm. The coil pitch could be equal to the pole pitch, but usually it is less. A full coil pitch means that the coil sides fall in slots 1 and 16. A more realistic coil pitch would be 80 % of the pole pitch. This would put coil sides in slots 1 and 13, giving a coil pitch of 0.80 × 266 = 212.8 mm.

(e) Area of one pole = 266 × (16 × 25.4) = 108 102

(f) $\phi = 108\ 102 \times 10^{-6} \times 0.54 = 0.0584$ Wb
$= 58.4$ mWb [$\phi = 8$ A]

13-37 This a 6-pole motor whose synchronous speed is 1200 r/min. The voltage induced in the rotor is 320 V when the flux cuts the rotor windings at 1200 r/min, at standstill. The line-to-neutral voltage is $320/\sqrt{3}$ = 184.75 V when the motor runs at no-load, the slip must be enaugh to generate 0.6 V, which is the voltage drop in the brushes. The slip speed must therefore be

$$\frac{0.6}{184.75} \times 1200 = 3.9 \text{ r/min}$$

The no-load speed is therefore 1200 – 3.9 = 1196 r/min

13-38 Motor torque $= 9.55\ P/n$ (3.5)
$= 9.55 \times (60 \times 7.46)/1760$
$= 2437$ N·m

$$\text{radius of rotor} = \frac{11}{2} \times \frac{25.4}{1000} = 0.1397 \text{ m}$$

Tangential force of 117 rotor bars = 243 N·m ÷ 0.1397 m = 1739 N.

Average force on each rotor bar = 1739 ÷ 117 = 14.87 N.

CHAPTER 14

14-10 The new torques are $(208/440)^2 = 0.22$ or 22 % of their original values. Reduced by 78 %

14-11 a. L.R. current is 520/595 = 90 % of its original value.
b. L.R. torque is $(520/575)^2 = 82$ % of its original value
c. no-load current drops to slightly less than 90 % of its original value.
d. no-load speed decreases very slightly
e. full load current is higher
f. full load power factor is about the same
g. full load efficiency is about the same

14-12 a. Even without a gearbox 2.25 kW (or 2.25 × 1.34 = 3 hp) are still needed

b. The closest synchronous speed to 125 r/min is given by:

$n_s = 120\, f/p \quad 125 = 120 \times 60/p \quad \therefore p = 57.6$ poles

but, assuming a slip of, say, 5 %, the actual synchronous speed should be about 125 × 1.05 = 131 r/min. The corresponding number of poles is:

$p = 120 \times 60/131 \approx 55$ poles. The number of poles must be even; we can use either 54 or 56 poles.

14-13 30 hp = 30 ÷ 1.34 = 22.39 kW. Neglecting that the motor runs slightly below synchonous speed, the approximate torque at full-load is:

$T = 9.55\, P/n = 9.55 \times 22\,390/900 = 237$ N·m

or 237 ÷ 1.356 = 175 ft·lb.

Scaling off the values in Fig. 14-5, we find:

LR torque = 2.5 × 175 = 438 ft·lb
Pull-up torque = 1.6 × 175 = 280 ft·lb
breakdown torque = 1.8 × 175 = 315 ft·lb

The corresponding speeds are zero, 675, 765 r/min also scaled off from the graph, with a max possible error of ± 2 %.

14-14 $P_L = 300$ hp $= 300 \div 1.34 = 223.9$ kW

$s = (600 - 590)/600 = 0.0167$

Because $P_m \approx P_L$ (Fig. 13-15), we have

$$P_m = P_r (1 - s) \qquad \text{(Eq. 13-8)}$$

$223.9 = P_r (1 - 0.0167) \quad \therefore P_r = 227.7$ kW

P_{jr} = rotor losses $= sP_r = 0.0167 \times 227.7 = 3.8$ kW

a. $s_x = s_n (E_n/E_x)^2 = 0.0167\,(2300/1944)^2 = 0.0233$
speed = 600 (1 – 0.0233) = 586 r/min

b. $P_L = 300 \times (586/590) = 298$ hp $= 222.4$ kW

14-14 c. $222.4 = P_r (1 - 0.0233) \quad \therefore P_r = 227.7$ kW

$P_{jr} = sP_r = 0.0233 \times 227.7 = 5.3$ kW

Note that the rotor losses increase by a factor of 5.3/3.8 = 1.4. This raises the rotor temperature considerably.

14-15 The motor obviously has 8 poles.

a. The approx. freq. at 2100 r/min is:

$$f = np/120 = 8 \times 2100/120 = 140 \text{ Hz}$$

The actual frequency will be 2 to 3 % lower owing to slip.

b. I per resistor = 520/1.73 × 5 = 60 A.

$P = EI\sqrt{3} = 520 \times 60 \times 1.73 = 54$ kW

c. $X_c = 1/2\,\pi f c = 1/2\,\pi \times 140 \times 100 \times 10^{-6} = 11.37\ \Omega$

I per capacitor $= \dfrac{520}{\sqrt{3} \times 11.37} = 26.4$ A

$Q = 520 \times 26.4 \times 1.73 = 23.8$ kvar

d. $S = \sqrt{P^2 + Q^2} = \sqrt{54^2 + 23.8^2} = 59$ kVA

$I = 59\,000/520 \times 1.73 = 65.6$ A

e. 54 kW = 54 × 1.34 = 72.4 hp. Assuming the generator efficiency is about 90 %, the engine power must be 72.4/0.9 ≈ 90 hp. The 100 hp engine is the one to use.

14-16 a. $P_L = 30\,000$ hp $= 22\,388$ kW

$P_i = 22\,388/0.981 = 22\,822$ kW

$S = P_i/\cos\theta = 22\,822/0.9 = 25\,357$ kVA

$I = 25\,357/13.2 \times 1.73 = 1109$ A

b. Losses = (22 822 – 22 388) = 434 kW

c. $P_m = P_L + P_v = 22\,388 + 62 = 22\,450$ kW

$s = (1800 + 1792.8)/1800 = 0.004$

$22\,450 = (1 - s)\,P_r \quad \therefore P_r = 22\,540$ kW

$P_{jr} = sP_r = 0.004 \times 22\,540 = 90.2$ kW

d. *LR* current = 4.7 × 1109 = 5212 A
FL torque = $9.55\,P/n = 9.55 \times 22\,388/1792.8$ = 119 kN·m
LR torque = 0.7 × 119 = 83.5 kN·m

e. compressor shaft torque = 119 × 1792.8/4930 = 43.3 kN·m

14-17 350 gal (U.S.) = 350 × 3.785 = 1325 L ≡ 1325 kg

Energy dissipated per minute = 434 000 × 60 = 26.04 MJ

Using Eq. 3-17 and referring to Example 3-14:

$$Q = mc\Delta t$$
$$26.04 \times 10^6 = 1325 \times 4180\,\Delta t$$
$$\therefore \Delta t = 4.7\ °C$$

The water temperature increases by 4.7 °C as it moves through the heat exchanger.

14-18 Torque = 0.25 × 119 = 29.8 kN·m

Total J = 130 000 + 18 000 = 148 000 lb·ft²

= 148 000 ÷ 23.73 = 6237 kg·m²

$\Delta n = 9.55\ T\Delta t/J$ (Eq. 3-14)

$1800 = 9.55 \times 29\,800 \times \Delta t/6237$

a. ∴ Δt = 39.4 s

b. Energy stored in rotating parts = loss in rotor

$E_k = 5.48 \times 10^{-3}\ J n^2 = 5.48 \times 10^{-3} \times 6237 \times 1800^2$

= 110.7 MJ = 110.7 (× 1000)(÷ 1.055)

= 105 000 Btu

14-19 a. line E = 380 × (60/50) = 456 V (a 440 V line would be acceptable).

speed ≈ 1450 × (60/50) = 1740 r/min.

b. The motor current can be as high as before, but the motor voltage is 20 % higher. The apparent power input is 20 % greater and because the efficiency and power factor will be about the same, the output power will also be 20 % greater. The power is therefore 1.2 × 10 × 1.34 ≈ 16 hp.

14-20 A design D motor could be used.

a. Design D accelerates faster between zero and 1200 r/min (67 % n_s) because its torque is always greater during this interval. However, D accelerates more slowly than B after the speed exceeds 72 % n_s or 1300 r/min.

b. The rotors have about the same size and because the energy dissipated is the same in both cases (= $E_k = 5.48 \times 10^{-3}\ J\ n^2$) the temperatures will be about the same.

14-21 a. s = (1800 − 1760)/1800 = 0.0222

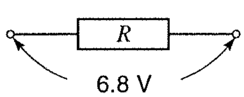
$P_L = 150 \div 1.34 = 112$ kW ≈ P_m

$112 = P_r(1 - 0.0222)$ ∴ P_r = 114.5 kW

$P_{jr} = sP_r = 0.0222 \times 114.5 = 2.545$ kW = 2545 W

Voltage induced in rotor = sE_{oc} = 0.0222 × 530 = 11.8 V

volts/phase = 11.8/√3 = 6.8 V



$3E^2/R = 2545$ ∴ $R = 3 \times 6.8^2/2545 = 54.5$ mΩ

14–21 b. 40 hp = 40 ÷ 1.34 = 29.85 kW

new torque $T_x = 9.55\ P/n = 9.55 \times 29\,850/600$

= 475 N·m

normal torque $T_n = 9.55 \times 112\,000/1760$

= 608 N·m

$E_n = 2.3$; $E_x = 2.4$; $s_n = 0.0222$; $s_x = 1200/1800 = 0.67$

$s_x = s_n\,(T_x/T_n)\,(R_x/R_n)\,(E_n/E_x)^2$

$0.67 = 0.0222\,(475/608)\,(R_x/0.0545)\,(2.3/2.4)^2$

$= 0.2925\,R_x$ ∴ $R_x = 2.28\ \Omega$

The external resistor to be added = 2.28 − 0.0545 = 2.23 Ω

14–22 a.1 The nominal torque T is given by Eq, 3-5:

$P = nT/955$

$150 \times 746 = 1165 \times T/9.55$

T = 917 N·m

a.2 The starting torque = 1.2 × 917 = 1100 N·m

a.3 Although the torque during the plugging period may be larger or smaller than the starting torque, the difference does not usually amount to more than ± 10 %. Consequently, we can usually make the assumption that the plugging torque is equal to the starting torque.

a.4 The plugging torque = 1100 N·m

b. The moment of inertia may be calculated from Eq. 3-14: $\Delta n = 9.55\ T\Delta t/J$

The change in speed is (1200 − 0) = 1200 r/min. It takes place in Δt = 1.3 s.

Consequently,

$1200 = 9.55 \times 1100 \times 1.3/J$

J = 11.4 kg·m²

14-23 The kinetic energy stored in the rotor is:

$E_k = 5.48 \times 10^{-3}\ J\,n^2$ Eq 3-8

$= 5.48 \times 10^{-3} \times 11.4 \times 1200^2$

= 90 kJ

The energy dissipated in the rotor during the plugging interval is 3 times E_k.

Energy dissipated as heat = 3 × 90 = 270 kJ

14-24 a. Mass of flywheel = vol × density = $\pi d^2/4\ l\,\rho$

$= \dfrac{\pi \times 31.5^2}{4} \times 7.875\ (\div 1000)(\div 61.02) \times 7900$

= 795 kg (steel and iron have the same density)

$J = \dfrac{mr^2}{4} = \dfrac{795}{2} \times \left(\dfrac{31.5}{2 \times 12 \times 3.28}\right)^2 = 63.6$ kg·m²

= 63.6 × 23.73 = 1509 lb·ft²

b. According to Fig. 14-5, the rated torque occurs at 90 % n_s or 0.9 × 900 = 810 r/min.

$T = 9.55\ P/n = \dfrac{9.55}{810} \times \dfrac{40}{1.34} \times 1000 = 352$ N·m

Full load T = 352 ÷ 1.356 = 260 ft·lb

c. LR torque is 270 % FL torque: 2.7 × 260 = 702 ft·lb

d.

speed	0	180	360	540	720	810
% torque	270	250	230	205	160	100
ft·lb	702	650	598	533	416	260
N·m	952	881	811	723	564	352

The torque-speed curve can be drawn from the table.

14-25 a. avge torque = (952 + 881)/2 = 916 N·m

b. $\Delta n = 9.55\ T\Delta t/J$

$180 = 9.55 \times 916\ \Delta t/63.6$

$\Delta t = 1.31$ s

c. $E_k = 5.48 \times 10^{-3}\ Jn^2 = 5.48 \times 10^{-3} \times 63.6 \times 180^2$

= 11.3 kJ

d. Avge torque between zero and 540 r/min is:

$T = (952 + 723)/2 = 837$ N·m

(Note that the curve is almost a straight line between 0 and 540 r/min $\quad\therefore$ Torque = 837 N·m)

Load torque = 300 N·m. Net torque available for acceleration = (837 – 300) = 537 N·m

$\Delta n = 9.55\ T\Delta t/J \qquad 540 = 9.55 \times 537\ \Delta t/63.6$

$\Delta t = 6.7$ s

14-26 a. One rev. of the gear wheel covers a distance of $\pi \times 573 = 1800$ mm = 1.8 m.

9 mi/h = 9 ÷ 2.237 = 4 m/s

$\therefore$ speed $= \dfrac{4}{1.8} = 2.235$ r/s = 134 r/min.

b. Ratio = 1470/134 = 10.96 or about 11:1

c. The total power of the 4 motors is:

$P = 78 \times 4 \times 1.34 = 418$ hp

$I = 600\ P_h/E$ (Eq. 13-5)

$I = 418 \times 600/700 = 358$ A

d. mass of train $= \dfrac{78\ 500}{2.204} + 240 \times 60 \approx 50\ 000$ kg

e. Energy to cover the vertical distance is:

$w = Fd$

$F = 9.8$ m (Eq. 3-1)

$F = 9.8 \times 50\ 000 = 490$ kN

$W = 490 \times (3089 - 1604) = 728$ MJ

f. If all the power of the motors were available to raise the train and its passengers through the vertical height (without losses) the time would be

$t = W/P = 728 \times 10^6/78 \times 10^3 \times 4 = 2333$ s

= 2333 ÷ 60 = 39 min.

g. Electrical energy consumed going uphill

= 728/0.8 = 910 MJ

Energy recovered going downhill

= 728 × 0.8 = 582 MJ

Net energy consumed = 910 – 582 = 328 MJ

308 MJ = 328 ÷ 3.6 = 91 kW·h

INDUSTRIAL APPLICATION – CHAPTER 14

14-27 Motor A must be greased at intervals of 2200 ÷ 24 = 91.67 days. This is equivalent to 365 ÷ 91.67 = 3.98 or 4 times per year.

Motor B operating time per year = 6 × 365 = 2190 hours. Greasing should be made at intervals of 10 000 ÷ 2190 = 4.5 years, say once every 4 years.

14-28 Power drawn by motor $= \dfrac{40 \times 746}{0.936} = 31.88$ k

Running time = 12 h × 5 days × 52 wk × 3 year = 9360 h

Energy consumed = 9360 × 31.88 = 298 397 kW.

Cost of energy = 298 397 × 0.06 = 17 904 $ say, 17 900 $.

14-29 Power drawn by standard motor $= \dfrac{40 \times 746}{0.902} = 33.08$ kW

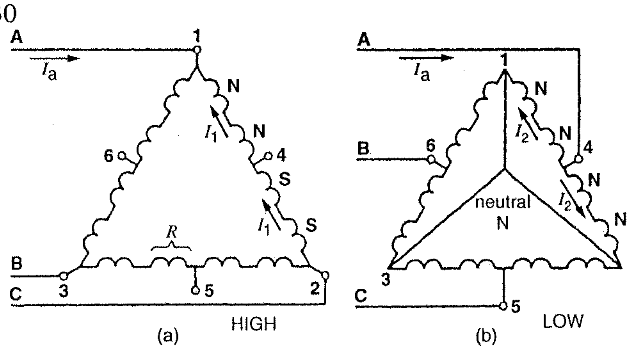
Power of high efficiency motor = 31.88 kW

Power saving = 33.08 – 31.88 = 1.2 kW

Energy saving in 3 year period = 1.2 kW × 9360 h = 11 232 kW·h

Cost saving = 11 232 × 0.06 = $ 674 say $ 670

14-30



Let resistance of one pole be R. The resistance between terminals 1 and 2 in Fig (a) is $\dfrac{8\,R \times 4\,R}{12\,R} = 12\ \Omega$

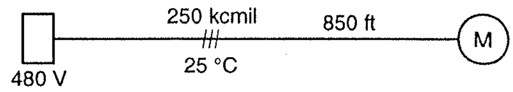
Hence $R = 4.5\ \Omega$

In Fig (b) resistance between 4 and neutral $= \dfrac{4.5 \times 2}{2}$

= 4.5 Ω = resistance between 6 and N.

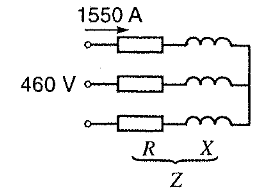
Therefore resistance between 4 and 6 in (b) = 9 Ω

14-31 (a)



Under LR conditions

$$Z = \frac{460/\sqrt{3}}{1550} = 0.171\ \Omega$$



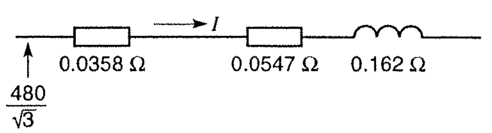
$R = 0.171 \times 0.32 = 0.0547\ \Omega$

$X = \sqrt{0.171^2 - 0.0547^2} = 0.162\ \Omega$

Resistance of one line of 250 kcmil @ 25 °C = R_L

$R_L = 0.138 \times \dfrac{850}{3.28} \times \dfrac{1}{1000} = 0.0358\ \Omega$ (see AX3)

14-31 (b)



$$Z_{TOTAL} = \sqrt{(0.0358 + 0.0547)^2 + 0.162^2} = 0.1855\ \Omega$$

$$I_{LR} = \frac{480}{\sqrt{3} \times 0.1855} = 1493\ \text{A}$$

(c) starting torque varies as the square of the locked-rotor current.

$$T = 1205 \times \left(\frac{1493}{1550}\right)^2 = 1118\ \text{ft·lbf}$$

(d) % torque $= \dfrac{1118}{1205} = 92.8$ %

14-32 No-load current = 71/183 = 0.39 pu

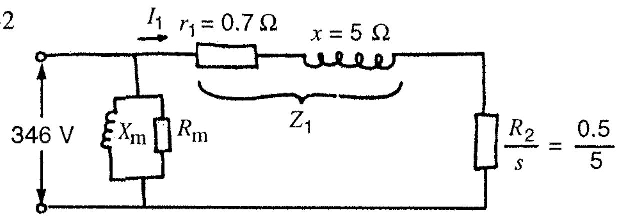
Locked-rotor current = 1550/183 = 8.47 pu

Breakdown torque = 2552/886 = 2.88 pu

Locked-rotor torque = 1205/886 = 1.36 pu

CHAPTER 15

15-2



a. $Z_1 = \sqrt{R_1^2 + x^2} = \sqrt{0.7^2 + 5^2} = 5.05\ \Omega$

$\alpha = \arctan x/r_1 = \arctan (5/0.7) = 82°$

b. $s_b = R_2/Z_1 = 0.5/5.05 = 0.099$

$n_b = n_s (1 - s_b) = 900 (1 - 0.099) = 811$ r/min

c. $\cos \alpha/2 = \cos 41° = 0.755$

$$I_1 = I_b = \frac{E_L}{2\, Z_1 \cos \alpha/2}$$

$$= \frac{346}{2 \times 5.05 \times 0.755} = 45.4 \text{ A}$$

alternative solution:
from circuit diagram when $r_2/s = Z_1 = 5.05\ \Omega$

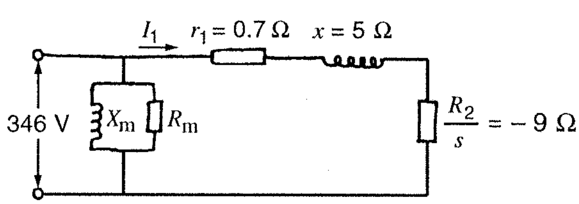
$$I_1 = I_b = \frac{346}{\sqrt{(5.05 + 0.7)^2 + 5^2}} = 45.4 \text{ A}$$

d. $P_r = I_b^2\, Z_1 = 45.4^2 \times 5.05 = 10\ 409$ W

$$T_b = \frac{9.55\, P_r}{n_s} = \frac{9.55 \times 10\ 409}{900} = 110.5 \text{ N·m}$$

Total torque = 110.5 × 3 phases = 332 N·m

15-3 a.



yes, the machine acts as a generator

$s = (n_s - n)/n_s = (900 - 950)/900 = -0.0556$

$R_2/s = 0.5/-0.0556 = -9\ \Omega$

$R_n = R_2/s + r_1 = -9 + 0.7 = -8.3\ \Omega$

$Z = \sqrt{-8.3^2 + 5^2} = 9.7\ \Omega$

$I_1 = E/Z = 346/9.7 = 35.7$ A

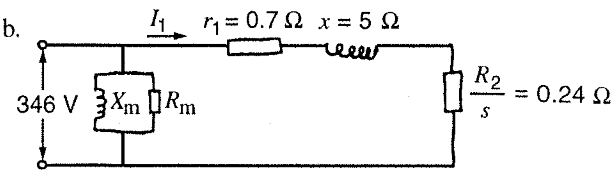
$P_r = I_1^2 \times R_2/s = 35.7^2 \times (-9) = -11\ 470$ W

(negative power indicates that the machine acts as a generator)

$$T_m = \frac{9.55\, P_r}{n_s} = \frac{9.55 \times 11\ 470}{900} = 122 \times 3 \text{ phases}$$

= 366 N·m

15-3 b.



no, it acts as a brake

$s = (900 - (-950))/900 = 2.06$

$R_2/s = 0.5/2.06 = 0.24\ \Omega$

$R_n = 0.24 + 0.7 = 0.94\ \Omega$

$Z = \sqrt{0.94^2 + 5^2} = 5.1\ \Omega$

$I_1 = E/Z = 346/5.1 = 67.8$ A

$P_r = I_1^2 \times R_2/s = 67.8^2 \times 0.24 = 1103$ W

$$T_m = \frac{9.55\, P_r}{n_s} = \frac{9.55 \times 1103}{900} = 11.7 \times 3 \text{ phases} = 33 \text{ N·m}$$

15-4 $S_{NL} = E_{NL}\, I_{NL} \sqrt{3} = 550 \times 12 \times \sqrt{3} = 11\ 432$ VA

$$Q_{NL} = \sqrt{S_{NL}^2 - P_{NL}^2} = \sqrt{11\ 432^2 - 1500^2} = 11\ 333 \text{ var}$$

$$X_m = \frac{E_{NL}^2}{Q_{NL}} = \frac{550^2}{11\ 333} = 26.7\ \Omega$$

$$R_m = \frac{E_{NL}^2}{P_{NL}} = \frac{550^2}{500} = 202\ \Omega$$

15-5 $r_1 = 0.8/2 = 0.4\ \Omega$

$S_{LR} = E_{LR}\, I_{LR} \sqrt{3} = 90 \times 30 \times \sqrt{3} = 4677$ VA

$Q_{LR} = \sqrt{4677^2 - 2430^2} = 3996$ var

$$x = \frac{Q_{LR}}{3 I_{LR}^2} = \frac{3996}{3 \times 30^2} = 1.48\ \Omega$$

$$r_1 + r_2 = \frac{P_{LR}}{3 I_{LR}^2} = \frac{2430}{3 \times 30^2} = 0.9\ \Omega$$

$r_2 = 0.9 - 0.4 = 0.5\ \Omega$

$Z = \sqrt{0.9^2 - 1.48^2} = 1.73\ \Omega$

$$I_{LR} = \frac{550}{\sqrt{3}} \times \frac{1}{1.73} = 183.5 \text{ A}$$

$P_r = I_{LR}^2\, r_2 = 183.5^2 \times 0.5 = 16\ 836$ W

Since the frequency is 60 Hz and the rated speed is 1780 r/min, it follows that the synchronous speed must be 1800 r/min

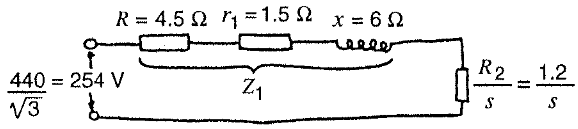
$$T_{LR} = \frac{9.55\, P_r}{n_s} = \frac{9.55 \times 16\ 836}{1800} = 89.3 \times 3 \text{ phases}$$

= 268 N·m

15-6 $T_b = \left(\frac{6200}{6900}\right)^2 \times 47 = 37.9\ \text{kN·m}$

$$T_{LR} = \left(\frac{6200}{6900}\right)^2 \times 3 = 2.4\ \text{kN·m}$$

15-7



At starting:

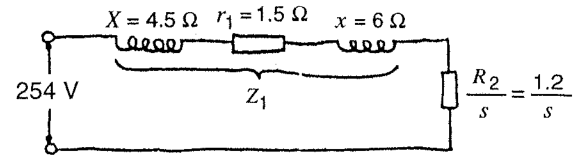
$$s = (1800 - 0)/1800 = 1$$
$$r_2/s = r_2 = 1.2\ \Omega$$
$$Z_{LR} = \sqrt{(4.5 + 1.5 + 1.2)^2 + 6^2} = 9.4\ \Omega$$
$$I_{LR} = E_{LN}/Z_{LR} = 254/9.4 = 27\ \text{A}$$
$$P_r = I_{LR}^2\, r_2 = 27^2 \times 1.2 = 875\ \text{W}$$

$$T_{LR} = \frac{9.55\ P_r}{n_s} = \frac{9.55 \times 875}{1800} = 4.64 \times 3 \text{ phases} = 13.9\ \text{N·m}$$

At breakdown:

$$\frac{r_2}{s} = Z_1 = \sqrt{(4.5 + 1.5)^2 + 6^2} = 8.5\ \Omega$$
$$I_b = \frac{254}{\sqrt{(4.5 + 1.5 + 8.5)^2 + 6^2}} = 16.2\ \text{A}$$
$$P_r = I_b^2\, Z_1 = 16.2^2 \times 8.5 = 2231\ \text{W}$$
$$T_b = \frac{9.55 \times 2231}{1800} = 11.84 \times 3 \text{ phases} = 35.5\ \text{N·m}$$

15-8



At starting:

$$r_2/s = 1.2/1 = 1.2\ \Omega$$
$$Z_{LR} = \sqrt{(1.5 + 1.2)^2 + (4.5 + 6)^2} = 10.8\ \Omega$$
$$I_{LR} = E_{LN}/Z_{LR} = 254/10.8 = 23.5\ \text{A}$$
$$P_r = I_{LR}^2\, r_2 = 23.5^2 \times 1.2 = 663\ \text{W}$$

$$T_{LR} = \frac{9.55\ P_r}{n_s} = \frac{9.55 \times 663}{1800} = 3.5 \times 3 \text{ phases} = 10.5\ \text{N·m}$$

At breakdown: using an alternate solution to the one used in problem 15-7, we have:

$$Z_1 = \sqrt{1.5 + (4.5 + 6)^2} = 10.6\ \Omega$$
$$\alpha = \tan^{-1}(10.5/1.5) = 82°$$
$$\cos \alpha/2 = \cos 41° = 0.755$$
$$I_b = \frac{E}{2\, Z_1 \cos \alpha/2} = \frac{254}{2 \times 10.6 \times 0.755} = 15.87\ \text{A}$$
$$P_r = I_b^2\, Z_1 \quad (\text{at breakdown } r_2/s = Z_1)$$
$$= 15.87^2 \times 10.6 = 2670\ \text{W}$$
$$T_b = \frac{9.55 \times 2670}{1800} = 14.2 \times 3 \text{ phases} = 42.6\ \text{N·m}$$

INDUSTRIAL APPLICATION – CHAPTER 15

15-9 (a) Leakage inductance $= x/2\pi f = \dfrac{6\ \Omega}{2\ \pi \times 60}$
$= 0.0159\ \text{H} = 15.9\ \text{mH}$

Magnetizing inductance $= 110/2\ \pi \times 60 = 292$ mH

(b) X (leakage) at 50 Hz $= 50/60 \times 6\ \Omega = 5\ \Omega$

X_m at 50 Hz $= 50/60 \times 110 = 91.7\ \Omega$

(c) To obtain the same magnetizing current at 50 Hz, the voltage must be $50/60 \times 254 = 212$ V.

15-10 (a) Synchronous speed at 80 Hz $= \dfrac{80}{60} \times 1800$
$= 2400$ r/min

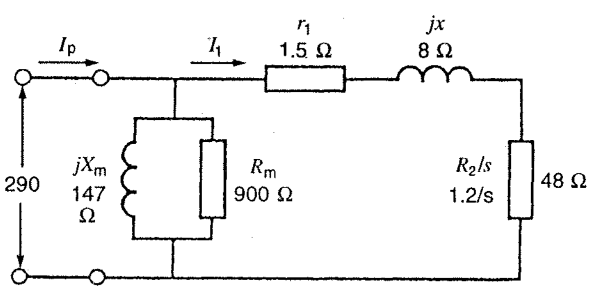
slip $= (2400 - 2340)/2400 = 0.025$

X leakage $= 6 \times (80/60) = 8\ \Omega$

$X_m = 110 \times (80/60) = 147\ \Omega$

line-to-neutral voltage $= \dfrac{513}{\sqrt{3}} = 290$ V.

The equivalent circuit is



$R_2/s = 1.2/0.025 = 48\ \Omega$

15-10 (b) $Z = \sqrt{8^2 + (1.5 + 48)^2} = 50.14\ \Omega$

$I_1 = 290/50.14 = 5.78$ A

Power to rotor $P_r = 5.78^2 \times 48 \times 3$ phases $= 4817$ W

$$T = \frac{9.55\ P_r}{n_s} = \frac{9.55 \times 4817}{2400} = 19.2\ \text{N·m} \qquad [13.9]$$

Power of motor $= \dfrac{nT}{9.55} = \dfrac{2340 \times 19.2}{9.55} = 4696$ W
$= 4696/746 = 6.3$ hp

CHAPTER 16

16-3 a. $f = pn/120$ $\quad 60 = p \times 350/120 \quad \therefore p = 20.57$
fractional poles are impossible; we use 20 poles

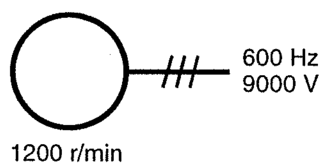
b. real speed is $n = 120\ f/p = 1200 \times 60/20 = 360$ r/min.

16-4 excitation must be increased

16-6 $f = pn/120 \quad 110 = p \times 1100/120 \quad \therefore p = 12$

16-7 $400 = p \times 12\ 000/120 \quad \therefore p = 4$

16-8



a. decrease
b. decrease
c. increase

16-9 a. $E = \dfrac{1000}{1200} \times 9\ \text{kV} = 7500\ \text{V}; \quad f = \dfrac{1000}{1200} \times 60 = 50\ \text{Hz}$

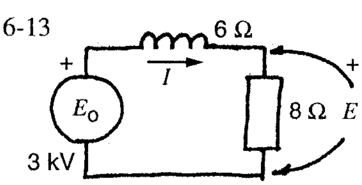
b. $E = \dfrac{5}{1200} \times 9000 = 37.5\ \text{V}; \quad f = \dfrac{5}{1200} \times 60 = 0.25\ \text{Hz}$

16-12 a. 24.2 kV line voltage $= \dfrac{24.2}{\sqrt{3}} = 14$ kV line-neutral

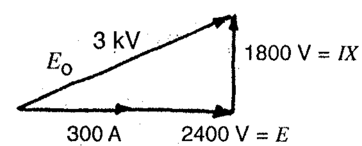
$I_x = 150$ A

b. 12.1 kV corresponds to 7 kV; $I_x = 50$ A

16-13



$Z = \sqrt{6^2 + 8^2} = 10\ \Omega$
$I = 3000/10 = 300$ A
$E = IR = 300 \times 8 = 2400$ V
$IX = 6 \times 300 = 1800$ V

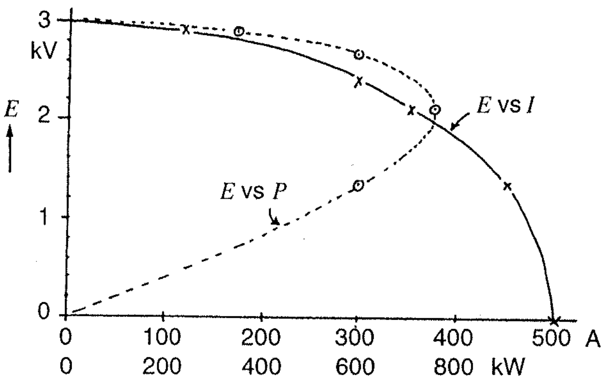


$P = EI = 2400 \times 300$
$= 720$ kW

16-14

R	8	∞	24	12	6	3	0
Z	10	∞	24.7	13.4	8.48	6.71	6
I	300	0	121	223	353	447	500
E	2400	3000	2910	2683	2121	1341	0
P	720	0	353	600	750	600	0

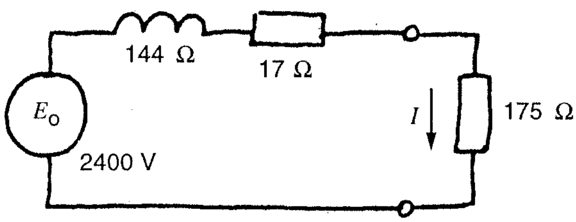
The other calculations are similar



16-15 $f = pn/120 \quad 60 = p \times 200/120 \quad \therefore p = 36$

1 pole pitch = $\pi \times 9250/36 = 807$ mm

16-16



a. $Z_s = \sqrt{144^2 + 17^2} = 145\ \Omega$

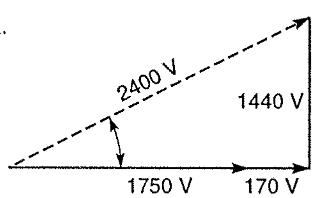
b. $R_{tot} = 17 + 175 = 192\ \Omega$ c. $X_{tot} = 144\ \Omega$

d. $Z_{tot} = \sqrt{144^2 + 192^2} = 240\ \Omega \quad I = 2400/240 = 10$ A

e. $E = 10 \times 175 = 1750$ V f. $E_{line} = 1750\sqrt{3} = 3031$ V

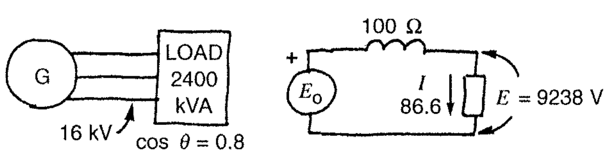
g. $p = I^2R = 10^2 \times 192 \times 3 = 57.6$ kW (3 phases)

h.



θ = arc cos 1920/2400 = 36.9°

16-17

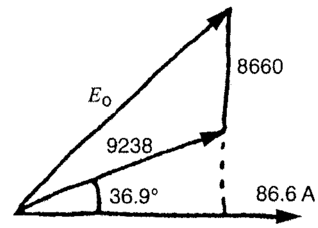


We solve the problem using only one phase

$$E_{LN} = 16/\sqrt{3} = 9238 \text{ V}$$

$$I = \frac{2400}{16\sqrt{3}} = 86.6 \text{ A}$$

θ = arc cos 0.8 = 36.9°



$IX_s = 86.6 \times 100 = 8660$

$E_o = 9238 \cos 36.9$

$+ j\ 8660$

$+ j \sin 36.9 \times 9238$

$$E_o = \sqrt{(9238 \cos 36{,}9)^2 + (9238 \sin 36{,}9° + 8660)^2}$$
$$= 16\ 000 \text{ V}$$

16-18 $E_o = \dfrac{1.14 \times 15}{\sqrt{3}} = \dfrac{17.1}{\sqrt{3}} = 9873$ V $\quad E = \dfrac{14}{\sqrt{3}} = 8083$

$$P = \frac{E_o E}{X} \sin\delta \qquad \frac{420 \times 10^6}{3} = \frac{8083 \times 9873}{0.4} \sin\delta$$

(a) $\therefore \delta = 44.56°$ (b) $\alpha = \dfrac{2\,\delta}{p} = \dfrac{2 \times 44.56}{36} = 2.475°$

(c) 360° is equal ot $\pi \times 9250$ mm = 29 060 mm

$\therefore$ 2.475° corresponds to $\dfrac{2.475}{360} \times 29\ 060 = 200$ mm

200 mm = 200/25.4 = 7.87 in.

16-19 a. $Z_n = \dfrac{E_n^2}{S_n} = \dfrac{15\ 000^2}{500 \times 10^6} = 0.45\ \Omega$ (line-to-neutral)

b. $E_{LN} = 15\ 000/\sqrt{3} = 8660$ V; $X_s = \dfrac{8660}{21\ 000} = 0.412\ \Omega$

c. X_s (p.u.) = 0.412/0.45 = 0.916

d. Short circuit ratio = 1/0.916 = 1.09

16-20 $P_o = 500$ MW; $P_i = 500/0.984 = 508{,}13$ MW

a. Total losses = 8130 kW

b. copper losses = 2400 × 300 = 720 kW

c. Power developed by turbine = 508.13 – 0.72
= 507.41 MW

$P = nT/9.55$

$507.4 \times 10^6 = 200\ T/9.55 \quad \therefore T = 24.23$ MN·m

d. $P = 1280\ V_a\,(t_2 - t_1)$ [Eq. 3-20]

$8130 \times 1000 = 1280 \times 280\ (t_2 - t_1)$

$\therefore (t_2 - t_1) = 22.7$°C

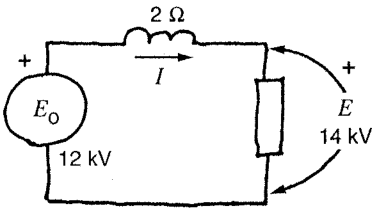
16-21 $U = 21.5 \times 500 = 10\ 750$ amp-turns

gap = 1.3 in = 1.3 × 25.4 (÷ 1000) = 0.033 m

$H = U/l = 10\ 750/0.033 = 0.3256 \times 10^6$ A/m [Eq.2-18]

$B = \mu_0 H = 4\pi \times 10^{-7} \times 0.3256 \times 10^6 = 0.409\ T$ [Eq. 2-20]

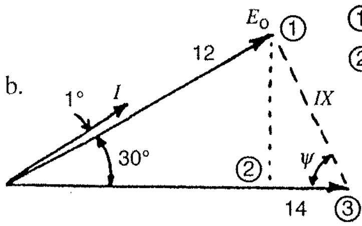
16-22



$$P = \frac{E_O\,E}{X_s}\sin\delta$$
$$= \frac{12 \times 14}{2}\sin 30$$
$$= 42\ \text{MW}$$

a. $42 \times 3 = 126$ MW

b.



①−② = 12 sin 30 = 6

②−③ = 14 − 12 cos 30
= 3.607

$IX = \sqrt{3.607^2 + 6^2}$
= 7 kV = 7000 V

I = 3500 A

ψ = arc sin 6/7 = 59°

16-22 b. because I is at 90° to IX, $I = 3500\ \angle\underline{+31°}$

c. $\cos\theta = P/S = 42 \times 10^6/14\,000 \times 3500 = 0.857$ leading

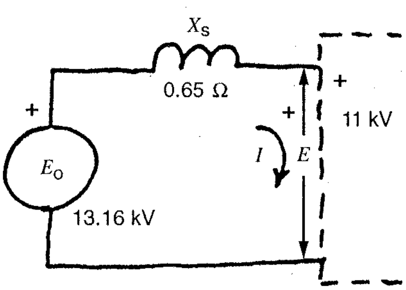
16-23 $Z_n = E_n^2/S_n = 19\,000^2/722 \times 10^6 = 0.5\ \Omega$

$X_s = 1.3 \times 0.5 = 0.65\ \Omega \quad E_o = 1.2 \times 19/\sqrt{3} = 13.16$ kV

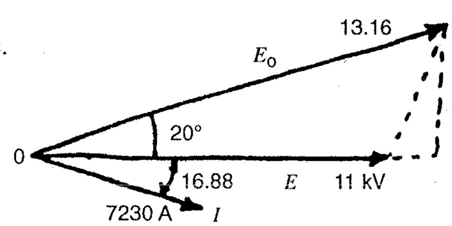
$E = 19/\sqrt{3} = 11$ kV

a. $P = \dfrac{E\,E_o}{X_s}\sin\delta = \dfrac{11 \times 13.16}{0.65}\sin 20 = 76.17\ \text{MW} \times 3$
$= 228.5$ MW

16-23 b.



c.



This problem is similar to Problem 19-22. However, this time we will use another method of solution:

$E_o = 13.16\ \angle\underline{+20}, \qquad E = 11\ \angle\underline{0}$

$-E_o + j\,IX_s + E = 0 \qquad \therefore\ I = j\,(E - E_o)/X_s$

$I = j\,(11 - 13.16\cos 20 - j\,13.16\sin 20)/0.65$

$= 6.92 - 2.1\,j = 7230\ \angle\underline{-16.88°}$ A

16-24 The active power is zero, $\therefore\ \delta = 0$ and E_o and E are in phase. The voltage across X_s is $E_o - E = 2160$ V
$\therefore\ I = 2160/0.65 = 3323$ A. Because $E_o > E$ the alternator delivers Q to the infinite bus:

$$Q = EI\sqrt{3} = 11 \times 3.323 \times \sqrt{3} = 63.3\ \text{Mvar}$$

16-25 Total $J = 54 \times 10^6\ (\div 23.73) + 4140\,000$
$= 6.41 \times 10^6\ \text{kg·m}^2$

$T = 24.23$ MN·m

$$\Delta_n = \frac{9.55\,T\Delta t}{J} = \frac{9.55 \times 24.23 \times 1}{6.41} = 36\ \text{r/min}\quad \text{[Eq. 3-14]}$$

a. speed = 200 + 36 = 236 r/min

b. average gain in speed during the interval = 18 r/min

distance covered = 18 r/min × 1 s = $18 \times \dfrac{1}{60}$
= 0.3 rev. = 108°

The poles advance by 108 mechanical degrees in one second. The acceleration is therefore very rapid.

Electrical degrees = $108 \times \dfrac{36}{2} = 1944°$.

16-26 a. $p = \dfrac{120\,f}{n} = \dfrac{120 \times 400}{1200} = 40$

b. 180 slots gives 180 coils

c. $\dfrac{180}{3} = 60$ coils/phase

40 poles gives 40 groups/phase

$\dfrac{60}{40} = 1.5$ coils/phase group

d. pole pitch = $\dfrac{180}{40} = 4.5 = \dfrac{4.5}{180} \times \pi \times 22 = 1.73$ in

e. $R = \dfrac{115}{31} = 3.7\ \Omega$

$P = 115 \times 31 = 3565$ W

INDUSTRIAL APPLICATION – CHAPTER 16

16-27 (a) Active power output = 33.8 × 0.8 = 27 kW

Power needed to drive generator = 27/0.834
= 32.4 kW
= 32 400 + 746 hp
= 43.5 hp

(b) The maximum temperature is 120 °C [see Section 6.9 and Fig. 6-7].

16-28 (a) The generator can deliver 220 MW at unity power factor and 220 × 0.9 = 198 MW at 90 % power factor.

(b) $Q = \sqrt{220^2 - 198^2} = 96$ Mvar

(c) short-circuit ratio = 1/1.27 = 0.787

(d) rated current $= \dfrac{220 \times 10^6}{13\ 800 \times \sqrt{3}} = 9204$ V

line-to-neutral voltage $= \dfrac{13\ 800}{\sqrt{3}} = 7967$ V

Nominal line-to-neutral impedance $= \dfrac{7967 \text{ V}}{9204 \text{ A}}$
$= 0.8656\ \Omega$

$X_S = 0.8656 \times 1.27 = 1.1\ \Omega$

(e) $P_o = 220$ MW
$P_i = 220/0.9875 = 222.785$ MW
Losses = (222.785 – 220) × 1000 = 2785 kW.

16-29 (a) $P = \dfrac{145 \times 10^6}{746} = 194\ 370$ hp

(b) $E_k = 5.48 \times 10^{-3}\ Jn^2$
$= 5.48 \times 10^{-3} \times 525\ 000 \times 500^2$
= 719 250 000 J = 719 MJ

(c) E_k at 890 r/min $= 719 \times \left(\dfrac{890}{500}\right)^2 = 2279$ MJ

(d) Active power at rated load = 198 MW

$$\text{Torque} = \frac{9.55 \times 198 \times 10^6}{500} = 3.78 \times 10^6 \text{ N·m}$$

but $\Delta n = \dfrac{9.55\ T\Delta t}{J}$ [3.14]

$$890 - 500 = \frac{9.55 \times 3.78 \times 10^6\ \Delta t}{525\ 000}$$

$\Delta t = 5.67$ s

The generator reaches its maximum allowable speed in less than 6 seconds. To prevent this dangerous situation, the wicket gates must be closed as soon as possible.

16-30 Total power for excitation = 2980 A × 258 V = 768.8 kW

poles = 120 f/n = 120 × 50/500 = 12

power dissipated per pole $= \dfrac{768.8}{12} = 64.1$ kW

water flow = 5.9 Liters/s = 5.9 kg/s

heat supplied to water in 1 second = 64 100 J

$Q = mc\ \Delta t$
$64\ 100 = 5.9 \times 4180\ \Delta t$
$\therefore \Delta t = 2.6$ °C

Temperature of water flowing out = 26 + 2.6 = 28.6 °C

$$\text{Resistivity} = \frac{1}{\text{conductivity}} = \frac{1}{5\ \mu\text{s/cm}} = \frac{\Omega\text{·cm}}{5 \times 10^{-6}}$$
$$= \frac{\Omega\ (\text{m}/100)}{5 \times 10^{-6}} = 2000\ \Omega\text{·m}$$

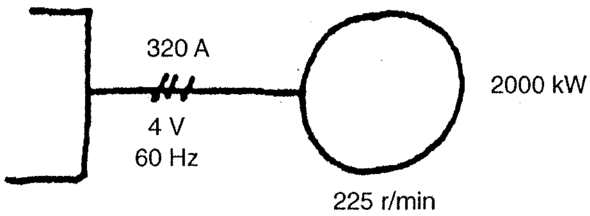
(Note that the resistivity of copper at 0 °C is 15.88×10^{-9} Ω·m)

CHAPTER 17

17-7 $P = 0.95 = 0.9 \times 2000 = 1800\text{ kW} \approx 1800 \times 1.34 \approx 2412$ hp because the efficiency is about 95 %, the output power is closer to $0.95 \times 2412 \approx 2300$ hp.

17-8 The apparent power will increase ∴ the current will increase and the motor will feed reactive power into the line.

17-9



a. $S = 4000 \times 320 \times \sqrt{3} = 2217$ kVA

b. $\cos\theta = \dfrac{2000}{2217} = 90.2$ %

c. $Q = \sqrt{2217^2 - 2000^2} = 956$ kvar

d. $n_s = 120\,f/p \quad \therefore p = \dfrac{120 \times 60}{225} = 32$ poles

17-10 The motor was under-excited (see Fig. 17-19).

17-11 a. $P_i = \dfrac{3000}{1.34 \times 0.97} = 2308$ kW according to the figure, $\cos\theta = 100$ %. $I = 2308/4\sqrt{3} = 333$ A

b. $I_{dc} = 21\,000/250 = 84$ A; $R = \dfrac{250}{84} = 3\ \Omega$

17-12 $n_s = \dfrac{120\,f}{p} = \dfrac{120 \times 16\,^2\!/_3}{4} = 500$ r/min

17-13 a. The speed is constant, hence the load does not "know" that the line voltage has dropped. ∴ the mechanical power is unchanged.

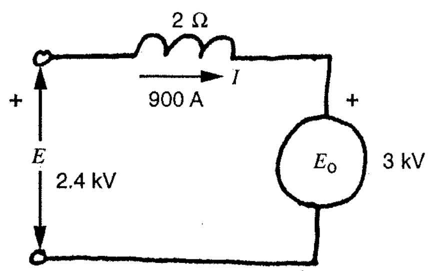
b. $P = (E_o E/X) \sin\delta$. P_1 E_o and X are the same but E has fallen; consequently $\sin\delta$ must increase, which means that δ increases.

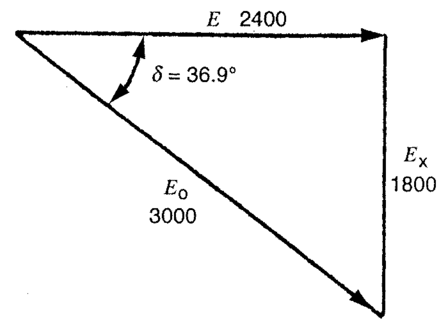
c. The poles fall slightly behind their former position, because α increases.

d. E is smaller than before; ∴ the motor appears overexcited, so the $\cos\theta$ is less than unity, and leading. P is the same, so S must be greater than before.

e. S is greater and E is smaller, and $I = S/E\sqrt{3}$ ∴ I must increase.

17-14 (a)





$E_x = IR = 900 \times 2 = 1800$ V in drawing the phasors to scale, remember E, E_x and E_o make a triangle with E_o lagging behind E. Draw E horizontally and scale off E_o and E_x. δ is found to be 36.9°.

b. $P = \dfrac{E_o E}{X} \sin\delta = \dfrac{3 \times 2.4}{2} \sin 36.9 = 2.16$ MW

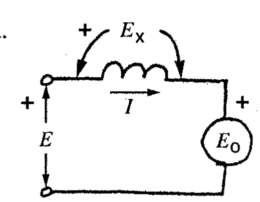
c. $P = EI\cos\theta \quad 2.16 \times 10^6 = 2400 \times 900 \cos\theta$ where θ is phase angle between E and I $\cos\theta = 1 \therefore \theta = 0°$ and I is in phase with E.

d. The motor draws no reactive power for the line.

17-15 a. $P = 0 \quad \therefore \delta = 0°$ and E, E_o are in phase. $E_x = 3000 - 2400 = 600$ V; $I = 600/2 = 300$ A.

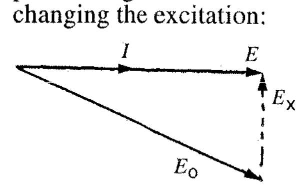
b. $Q = EI = 2400 \times 300 = 720$ kvar. Because $E_o > E$, the motor is over excited (for the no-load condition); it delivers reactive power.

17-16 a.



The active power is the same (see reason given in Problem 17-13)

phasor diagram before changing the excitation:

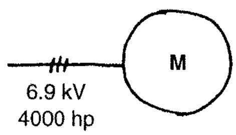


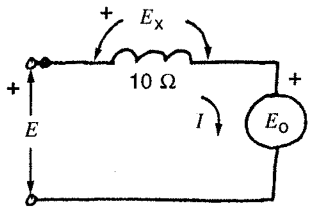
b. The power factor becomes leading and < 1.0. Because P is unchanged, S must increase ∴ I increases.

c. The motor feeds recative power into the line while drawing active power P.

17-16 d. $P = \frac{E_o E}{X} \sin \delta$. E_o increases, but E, P, X are the same as before. ∴ δ must decrease, and the poles move forward slightly.

17-17 a.

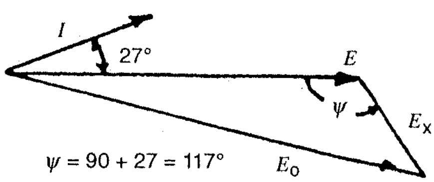




$P_o = 4000 \text{ hp} = 4000 \div 1.34 = 2985 \text{ kW}$
$P_i = 2985/0.97 = 3077 \text{ kW}$; $S = 3077/0.89 = 3457 \text{ kVA}$

b. $I = 3457/6.9\sqrt{3} = 289 \text{ A}$

c. $E = 6900/\sqrt{3} = 3984 \text{ V}$ $\cos\theta = 0.89$ ∴ $\theta = 27°$
I leads E by 27° $IX_s = E_x = 289 \times 10 = 2890 \text{ V}$



$E_o^2 = E^2 + E_x^2 - 2E_x \cos\psi$
$= 3984^2 + 2890^2 - 2 \times 3894 \times 2890 \cos 117°$
∴ $E_o = \sqrt{34\,678\,631} = 5889 \text{ V}$

d. $P = \frac{E_o E}{X} \sin\delta$ $\frac{3077 \times 1000}{3} = \frac{5889 \times 3984}{10} \sin\delta$

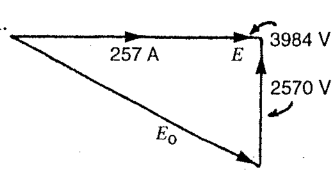
$\sin\delta = 0.437$ ∴ $\delta = 25.9°$; $\alpha = \frac{25.9}{18} = 1.44°$

e. $S = 289 \times 6900\sqrt{3} = 3454 \text{ kVA}$; $P_i = 3077 \text{ kW}$
$Q = \sqrt{3454^2 + 3077^2} = 1569 \text{ kvar}$

f. $P_{max} = \frac{3984 \times 5889}{10} \times 3 = 7038 \text{ kW input}$
assuming $\eta = 97\%$ $P_o = 7038 \times 1.34 \times 0.97 \approx 9150 \text{ hp}$

17-18 $P_i = 3077 \text{ kW}$ P_i per phase $= 1025.6 \text{ kW}$
$I = 1025600/3984 = 257 \text{ A}$ $E_x = 2570 \text{ V}$

a.



$E_o = \sqrt{3984^2 + 2570^2}$
$= 4741 \text{ V}$

b. $\delta = \arctan 2570/3984 = 32.8°$

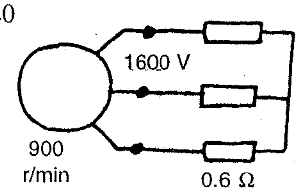
17-19 $Z_n = E_n/I_n = \frac{2300/\sqrt{3}}{80} = \frac{1328}{80} = 16.6\ \Omega$
(we always assume a wye connection)
a. $X_s = 0.88 \times 16.6 = 14.6\ \Omega$
$E_o = 1.2 \times 1328 = 1594 \text{ V}$

17-19 b. $P = E_o E/X_s = \frac{1594 \times 1328}{14.6} \times 3 = 435 \text{ kW} = 583 \text{ hp}$

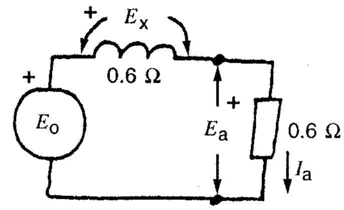
$T = 9.55\ p/n = \frac{9.55 \times 435}{450} = 9.23 \text{ kN·m}$
$= 9230/1.356 = 6807 \text{ ft·lb}$

c. E and E_o are at 90° when max power is developed.
∴ $E_x = \sqrt{1328^2 + 1594^2} = 2075 \text{ V}$
$I = E_x/X_s = 2075/14.6 = 142 \text{ A}$

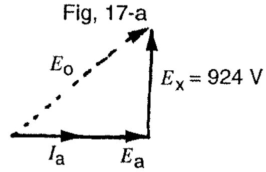
17-20



The line volatge is 1600 V at 900 r/min we neglect the stator R of 0.007 Ω. The equivalent circuit per phase at 900 r/min is given in Fig. 17-a



Fig, 17-a



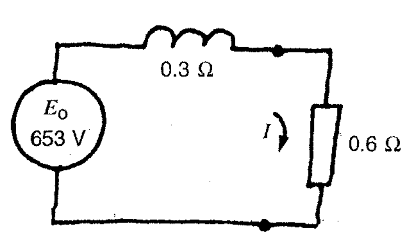
$E_a = \frac{1600}{\sqrt{3}} = 924 \text{ V}$
$I_a = 924/0.6 = 1540 \text{ A}$
$E_o = \sqrt{E_a^2 + E_x^2}$
$= \sqrt{924^2 + 924^2}$
$= 1307 \text{ V}$

a. braking power $P = 3\,I^2R = 3 \times 1540^2 \times 0.6 = 4269 \text{ kW}$

braking torque $T = \frac{9.55\ P}{n} = \frac{9.55 \times 4269}{900} = 45.3 \text{ kN·m}$

b. at 450 r/min E_o drops to $1307/2 = 653 \text{ V}$ also $f = 30 \text{ Hz}$ and so $X_s = 0.6 \div 2 = 0.3\ \Omega$. The circuit is given in Fig. 17-22b

$I = \frac{E_o}{Z} = \frac{653}{\sqrt{0.6^2 + 0.3^2}} = 973 \text{ V}$



17-20 cont'd

braking power = $3 \times 973^2 \times 0.6 = 1704$ kW

braking torque $T = \frac{9.55\,P}{n} = \frac{9.55 \times 1704}{450} = 36.2$ kN·m

c. $T_{avge} = \frac{45.3 + 36.2}{2} = 40.7$ kN·m

d. 1.7×10^6 lb·ft^2 = $1.7 \times 10^6 \div 23.73 = 71\,639$ kg·m^2

$$\Delta n = \frac{9.55\,T\Delta t}{J} \qquad \text{[Eq. 3-14]}$$

$$(900 - 450) = \frac{9.55 \times 40.7 \times 10^3\,\Delta t}{71\,639} \qquad \Delta t = 82.9 \text{ s}$$

INDUSTRIAL APPLICATION – CHAPTER 17

17-21 The power must be reduced by (46 – 40) = 6 %
The power is proportional to the current, and so the current should be limited to 94 % × 103 A = 96.8 A.

17-22 (a) Total mass = 6.10 + 7.50 + 3.97 = 17.57 *t*

(b) 465 L/min = $\frac{465}{3.785}$ gal/min = 123 gal/min

(c) 1370 kg·m^2 = 1370 × (2.205) lb (3.28) ft^2
= 32 500 lb·ft^2

(d) $P_i = 8800/0.978 = 8.998$ kW
stator losses = 8998 – 8800 = 198 kW
rotor excitation losses = 160 V × 387 A = 61.9 kW
Total losses = 198 + 61.9 = 260 kW

(e) Total efficiency = $\frac{8800}{8800 + 260} = 0.971 = 97.1$ %

(f) $S = \frac{P_i}{\cos\theta} = \frac{8998}{0.9} = 9998$ kVA

Q supplied by motor = $\sqrt{9998^2 - 8998^2} = 4358$ kvar

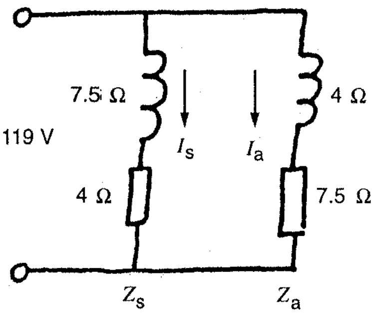
(g) Stator losses = (core loss + copper loss) = 198 kW
(see (d) above. Copper loss = 1/2 × 198 = 99 kW
rated current = 962 A. Let R = resistance/phase
$962^2 \times R \times 3 = 99\,000 \quad \therefore R = 0.03566\ \Omega$
Resistance between stator terminals, assuming a wye connection = 2 R = 0.0713 Ω

(h) Resistance of field circuit = 160 V/387 A = 0.413 Ω.

CHAPTER 18

18-8 a., c,: Series motor b.: capacitor-start
d.: shaded-pole e.: resistance split-phase
f.: capacitor run g.: synchronous h.: hysteresis

18-9 a.



$Z_s = \sqrt{4^2 + 7.5^2}$
$= 8.5\ \Omega$
$I_s = 119/8.5$
$= 14$ A
$P_s = 14^2 \times 4$
$= 784$ W
$Q_s = 14^2 \times 7.5$
$= 1470$ var

$S_s = 14 \times 119 = 1666$ VA
$\cos\theta_s = 784/1666 = 0.47 \quad \therefore \theta_s = 61.9°$
$Z_a = 8.5\ \Omega \quad I_a = 14$ A $\quad P_a = 14^2 \times 7.5 = 1470$ W
$\cos\theta_a = 1470/1666 = 0.88 \quad \therefore \theta_a = 28.1°$

b. $\theta_s - \theta_a = 61.9 - 28.1 = 33.8°$

c. $P_s + P_a = 784 + 1470 = 2254$ W
$Q_s + Q_a = 2254$ var
$\therefore S_{s+a} = \sqrt{2254^2 + 2254^2} = 3188$ VA
$I_L = 3188/119 = 26.8$ A

d. $\cos\theta_L = 2254/3188 = 0.707$

18-10 130 °F = (130 – 32) ÷ 1.8 = 54.4 °C
a. no b. 76 °F = (76 – 32) ÷ 1.8 = 24.4 °C
The temperature rise of the frame is 64 – 24.4 ≈ 40 °C. The motor is probably not too hot, depending on the type of construction.

18-11 $T_m > 4$ N·m until the switch opens, where-upon $T_m < 4$ N·m. When switch recloses at 300 r/min, $T_m > 4$ N·m and motor accelerates again. The speed will cycle continually between 300 and 1370 r/min until the circuit breaker trips.

18-12 a. $f = 50$ Hz b. There is no vibration (see Sec. 18.10)
c. 6 in·lb = 0.5 ft·lb = 0.5 × 1.356 = 0.678 N·m
$E_h = 6.28\ T = 6.28 \times 0.678 = 4.26\ J$

18-13 a. 6 W = (6/746) × 1000 = 8 mhp
b. $\cos\theta = 21/(0.33 \times 115) = 0.55$
c. $s = (3600 - 2600)/3600 = 0.28$
d. $I_{NL} = 0.26/0.33 = 0.79$ p.u.
$I_{LR} = 0.35/0.33 = 1.06$ p.u.

18-14 a. 6 N·m ÷ 1.356 = 4.42 ft·lb b. 6/1.35 = 4.44 p.u.

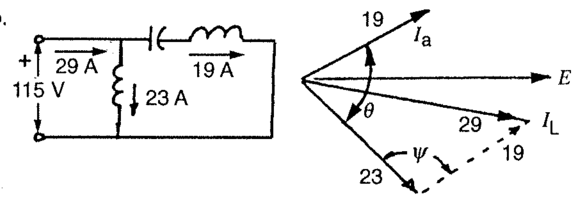
c. zero d. $\frac{3.4}{1.35} = 2.5$ p.u.

e. all torques reduced to $(100/115)^2 = 75.6$ % of their former value.

18-15 $X_c = 1/2\pi fc = 1/2\pi \times 60 \times 320 \times 10^{-6} = 8.29\ \Omega$

a. $I_a = 19$ A $\therefore E_c = 19 \times 8.29 = 157.5$ V

b.



$29^2 = 23^2 + 19^2 - 2 \times 23 \times 19 \cos \psi$

$\cos \psi = 0.056$ $\therefore \psi = 86.8°$ $\therefore \theta = 180 - 86.8 = 93.2°$

18-16 Component of I_L in phase with E

$I_p = 0.29 \cos 30 + 0.5 \cos 60 = 0.5$ A

I_q (in quadrature) $= 0.29 \sin 30 - 0.5 \sin 60 = -0.288$

a. $I_L = \sqrt{0.5^2 + 0.288^2} = 0.577$ A

b. $\theta = \arctan -0.288/0.5 = -29.9°$

$\cos \theta = 86.6$ % lagging

c. $P_a = EI_a \cos 30 = 120 \times 0.29 \cos 30 = 30.1$ W

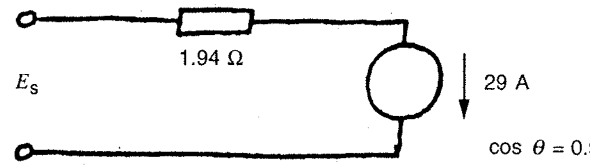
$P_s = EI_s \cos 60 = 120 \times 0.5 \times 0.5 = 30$ W

Each winding absorbs the same power despite their different voltages. The motor operates as a true 2-phase motor (at full load).

d. $P_o = \frac{30}{1000} \times \frac{1000}{1.34} = 224$ W $P_i = 60$ W

$\therefore \eta = \frac{22.4}{60} = 37$ %

18-17



a. Length = 600 × 2 (÷ 3.28) = 366 m. From Table AX3 (in appendix) $R = 0.366 \times 5.31 = 1.94\ \Omega$

b. instead of working from the 122 V service entrance voltage, assume the voltage is 115 V across the motor. Then $I_{LR} = 29$ A (Table 18 A)

$S_m = 29 \times 115 = 3335$ VA $P_m = 3335 \times 0.9 = 3001$ W

$\therefore Q_m = \sqrt{3335^2 - 3001^2} = 1453$ var

P_L in line $= 29^2 \times 1.94 = 1631$ W

at the service entrance, we have:

$P_s = 1631 + 3001 = 4632$ W $Q_s = 1453$ var

$\therefore S_s = \sqrt{4632^2 + 1453^2} = 4855$ VA

$\therefore E_s = 4855/29 = 167$ V

Because 167 V produces 115 V at the motor

$\therefore$ 122 V produces $115 \times 122/167 = 84$ V at the motor

The current is $29 \times 122/167 = 21.2$ A

c. The starting torque is $(84/115)^2 \times 6 = 32$ N·m

Note how drastically the torque is reduced.

INDUSTRIAL APPLICATION – CHAPTER 18

18-18 (a) *LR* torque = 30/9 = 3.33 pu

BD torque = 20/9 = 2.22 pu

LR current = 90/15 = 6 pu

(b) 9 lbf·ft = 9 × (4.448 N) × (m/3.28) = 12.2 N·m

(c) input active power = $\dfrac{3 \times 746}{0.79} = 2833$ W

input S = 2833/0.87 = 3256 VA

input $Q = \sqrt{3256^2 - 2833^2} = 1606$ var

desired $Q = \sqrt{3148^2 - 2833^2} = 1372$ var

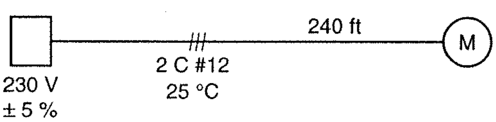
desired S = 2833/ 0.90 = 3148 VA

Q_c of capacitor = (1606 – 1372) = 234 var

$X_c = E^2/Q_c = 230^2/234 = 226\ \Omega$

$$C = \frac{10^6}{2\,\pi \times 60 \times 226} = 11.7\ \mu\text{F}$$

18-19



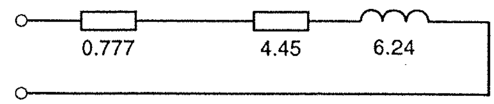
LR impedance of motor = 230 V/30 A = 7.67 Ω

effective *LR* resistance = 7.67 × 0.58 = 4.45 Ω

effective *LR* reactance = $\sqrt{7.67^2 - 4.45^2} = 6.24\ \Omega$

resistance of 240 ft, 2 conductors cable @ 25°C

$R_L = 5.31 \times \dfrac{240}{3.28} \times 2 = 777\ \text{m}\Omega = 0.777\ \Omega$ [AX3]



Z of motor + cable = $\sqrt{6.24^2 + (4.45 + 0.777)^2} = 8.14\ \Omega$

Lowest voltage = 95 % × 230 V = 218.5 V

(The *LR* torque is lowest when the voltage is low)

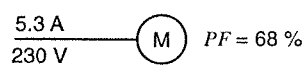
LR current under worst conditions = $\dfrac{218.5\ \text{V}}{8.14\ \Omega} = 26.84$ A

LR torque is proportional to the current^2.

$$LR \text{ torque} = 9.5 \times \left(\frac{26.84}{30}\right)^2 = 7.6\ \text{lbf·ft}$$

$$= 7.6 \times (4.448\ \text{N}) \times \left(\frac{\text{m}}{3.28}\right) = 10.3\ \text{N·m}$$

18-19 (b)



S = 230 × 5.3 = 1219 VA

P = 1219 × 0.68 = 829 W

$Q = \sqrt{1219^2 - 829^2} = 894$ var

desired S = 829/0.90 = 921 VA

desired $Q = \sqrt{921^2 - 829^2} = 401$ var

Capacitive vars needed = Q_c = (894 – 401) = 493 var

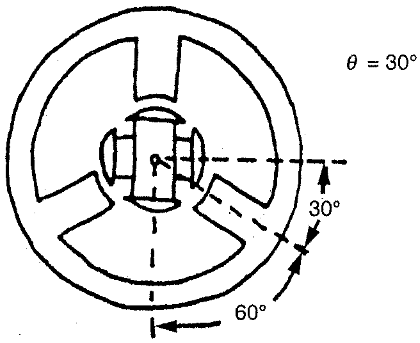
$X_c = E^2/Q_c = 230^2/493 = 107\ \Omega$

$C = 10^6/2\,\pi \times 60 \times 107 = 24.8\ \mu$F

CHAPTER 19

19-4 $8 \times \frac{360}{2.5} = 1152$ pulses

19-6



19-8 True

19-9 30° per pulse $\therefore \frac{360}{30} = 12$ pulses per revolution

$12 \times 20 = 240$ ms

19-10 7 pulses × 1.8° = 12.6°

360° advances lead screw by one thread, or $1/20 = 0.05"$

movement = $12.6/360 \times 0.05 = 0.00175"$

19-11 a. At 50 sps, $T = 2.2$ N·m

$$n = 500 \times \frac{7.5}{360} \times 60 = 625 \text{ r/min}$$

$$T = \frac{9.55\,P}{n} \quad \therefore \ P = \frac{625 \times 2.2}{9.55} = 144 \text{ W}$$

b. $T = 3$ N·m

$$n = \frac{200}{500} \times 625 = 250 \text{ r/min}$$

$$P = \frac{250 \times 3}{9.55} = 78.5 \text{ W}$$

19-12 a. The pull-in curve corresponds to the start-stop mode

$T_{max} = 30$ mN·m

b. step angle = 7.5°

$$n = 150 \times \frac{7.5}{360} \times 60 = 187.5 \text{ r/min}$$

$$P = \frac{nT}{9.55} = \frac{187.5 \times 0.03}{9.55}$$

$$= 0.59 \text{ W } (\times 1.34) = 0.79 \text{ mhp}$$

c. $W = Pt = 0.59 \times 3 = 1.77\ J$

9-13 – In modifying the time constant L/R

– By using the bilevel drive

19-14 $n = 350 \times \frac{7.5}{360} \times 60 = 437.5$ r/min

19-15 a. $T_0 = L/R = 0.0799/52.4 = 1.5$ ms

b. $3\,T_0 = 3 \times 1.5 = 4.5$ ms

c. $I = E/R = 12/52.4 = 0.23$ A

19-16 a. 360/50 = 7.2°

b. 7.2/2 = 3.6°

c. 3.6/2 = 1.8°

19-17 Because the rotor runs essentially at uniform speed, thus, the inertia effect is absent.

19-18 a. $n = \frac{10\,000}{200} \times 60 = 3000$ r/min

$$P = \frac{nT}{9.55} = \frac{3000 \times 2.2}{9.55}$$

$$= 0.691 \text{ kW } (\times 1.34) = 0.93 \text{ hp}$$

b. $T_0 = \frac{L}{R} = \frac{0.77 \times 10^{-3}}{60 \times 10^{-3}} = 13$ ms

c. Final current if voltage were maintained at:

$$65 \text{ V} = I_{Final} = \frac{E}{R} = \frac{65}{0.06} = 1083 \text{ A}$$

$$\text{Rate of current rise} = \frac{I_{Final}}{T_0} = \frac{1083}{0.013} = 83\,308 \text{ A/s}$$

$$t = \frac{13}{83\,308} = 0.16 \text{ ms}$$

INDUSTRIAL APPLICATION – CHAPTER 19

19-19 $74\ \text{oz·in} = \frac{74}{16}\ \text{lbf·in} = 4.625\ \text{lbf·in} = \frac{4.625}{8.851}$
$= 0.5227$ N·m [see AXO]
$11\ \text{oz·in} = \frac{11}{74} \times 0.5227 = 0.07769$ N·m

19-20 Desired $L/R = 400 \times 10^{-6} = \frac{33 \times 10^{-3}}{R}$
$\therefore R = 82.5\ \Omega$ we must add an external resistor whose value is $(82.5 - 26) = 56.5\ \Omega$

19-21 $T_{25\,°C} = 1.32\ \text{ms} = \frac{L}{R_{25\,°C}}$

$R_{100} = R_o(1 + \alpha \times 100) \qquad R_{25} = R_o(1 + \alpha \times 25)$

$\therefore \frac{R_{100}}{R_{25}} = \frac{1 + 0.00427 \times 100}{1 + 0.00427 \times 25} = 1.289$

Hence $T_{100\,°C} = \frac{T_{25°}}{1.289} = \frac{1.32}{1.289} = 1.02$ ms

19-22 (a) 48 steps per revolution = 48 pulses per rev.

$250\ \text{r/min} \equiv 48 \times 250\ \text{pulses/min} = \frac{48 \times 250}{60} = 200$ pulses per second

(b) The start/stop mode corresponds to the pull-in curves of Fig. 19-14d, bipolar mode. At 200 pulses per second the pull-in torque = 22 mN·m.

(c) $\Delta n = 250$ r/min $\qquad J = 2 \times 10^{-4}\ \text{g·m}^2 = 2 \times 10^{-7}\ \text{kg·m}^2$

$\Delta t = 1/200\ \text{s} = 0.005\ \text{s} \qquad \Delta n = \frac{9.55\, T \Delta t}{J}$ [3.14]

$250 = \frac{9.55\, T \times 0.005}{20 \times 10^{-7}} \qquad \therefore T = 0.01047 = 10.5$ mN·m

(d) The motor develops 22 mN·m of torque, of which 10.5 mN·m are needed to overcome inertia. The maximum friction torque must be less than (22 – 10.5), or 11.5 mN·m.

19-23 How many r/min does the motor make when the slew rate is 1200 pulses/second?

1200 pulses/s = 1200 × 1.8°/s = 2160°/s = 129 600°/min

$= \frac{129\,600}{360}$ r/min = 360 r/min.

Thus, direct coupling will never produce 500 r/min. To get 500 r/min we could use a gear having a ratio of

$\frac{360}{500} = 18:25$.

CHAPTER 20

20-4 Contact T: inside the thermal relay of Fig. 20-6
Coil A: part of the magnetic contactor (FIg. 20-7)

20-5 Nothing: the circuit of coils A and B remain open.

20-6 The motor runs only as long as we press the start button – otherwise it stops.

20-7 The fuses. The time lag of the thermal relays is much longer.

20-8 The thermal relays. The fuse will not even begin to melt with a 50 % overlead.

20-10 a. quadrant 1; b. quadrant 4

20-11 $n = 450$ and the corresponding torque is 100 N·m

$P = nT/9.55 = 450 \times 100/9.55 = 4712\ \text{W} = 4.7\ \text{W}$
$= 4.7 \times 1.34 = 6.3$ hp

20-12 A 4-pole 60 Hz motor runs at a no-load speed of 1800 r/min. To run at 225 r/min the voltage and frequency must be reduced in the ratio 225/1800 = 1/8. $E = 208/8 = 26$ V; $f = 7.5$ Hz.

20-13 a. $I = 40$ A; b. $I = 120$ A; c. There are two possibilities, corresponding to $n = 1950$ r/min and $n = 2850$ r/min
$I = 40$ A $\qquad I = 113$ A

20-14 a. 2 or 4
b. 1 or 3 (respectively, referring to answer a.)
c. 4 or 2 (respectively, referring to answer a.)
} see Fig. 20-36

20-15 Clockwise

20-16 (a) 60/40 = 1.5 from graph, trip time = 2 min.
(b) 240/40 = 6 trip time = 5 s.

20-17 (a) A_x close as before and jag contact is closed
(b) Pushing J energizes coil A and contact A_x closes. However, terminals 1, 2 are now open, and so A_x cannot "seal" the circuit.

20-18 The motor can be jagged $3 \times 10^6 \div 30 = 10^5$ times before the contacts need replacing (see Sec. 20.8).

10^5 min = 100 000/(60 × 8) = 208 working days.

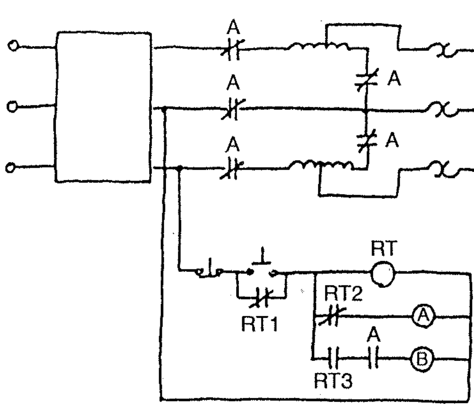
20-19 a. coil A is enegized; A_{x_1} closes; contacts C-F and A close; motor continues to run normally
b. coil A is de-energized; contacts 5-6 are shorted, but coil B is only energized after contactor A_{x_1} is in the open position because only then is contact A_{x_2} (in se-

ries with coil B) closed. The motor is plugged and the speed decreases. The speed continues to fall even if the stop button is released, owing to sealing contact B_{x_1}. (Note that if the operator pushes the start button during this plugging phase, the operation would not be affected because B_{x_2} in series with coil A is now open). When the speed is zero contacts C-F open, coil B is de-energized and the motor is disconnected from the line.

20-20 a. 1. coils RA and RT are energized; sealing contact RA closes; coil A is enegized; power contacts A close, placing resistors in series with the motor; 10 s later contact RT closes, energizing coil B. Power contacts B close, shorting the resistors.

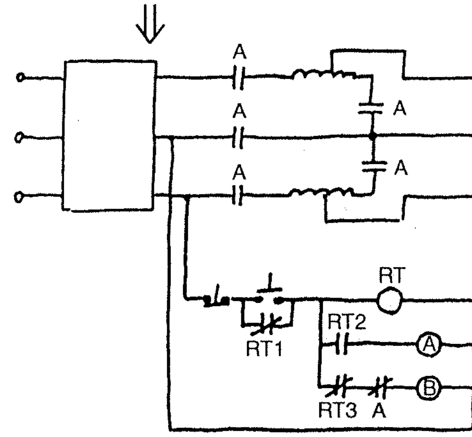
b. Coils RA snd RT are de-energized; contact RA opens, causing contactors A and B to drop out simultaneously.

20-21 (1) Coil RT is excited, causing sealing contact RT1 in parallel with the start button to close immediately; coil A operates for 5 s after which RT2 in series with coil A opens. Contact RT3 in series with coil B closes, but coil B is only energized after contactor A has dropped out; coil B is then energized and the motor is directly connected to the line.

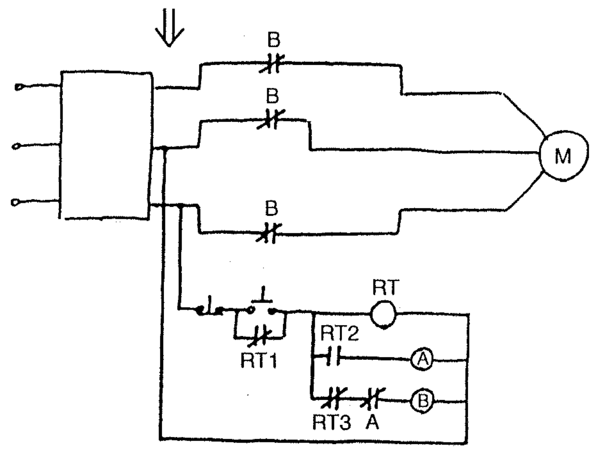


1. connections immediately after the start pushbutton was depressed

(2) connections immediately after contacts RT change state. Contactor A has dropped out but contactor B is not yet closed because contact A has just closed the circuit of coil B. The motor is disconnected from the line.



(3) contactor B is now closed and full voltage is applied to the motor. Capacitor A has opened both ends of the autotransformer windings and so it is inoperative



20-22 The ratio 240/120 = 2 which corresponds to a tripping time of 40 s, from a cold start. According to the caption, and because the motor has been running, the time is about 70 % × 40 = 28 s.

20-23 In solving this problem we use the power flow diagrams of Chapter 13. See also Fig. 14-16.

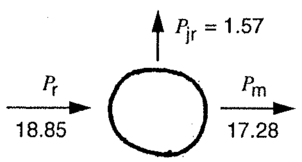
a. $n = +1650$; $T = +100$ N·m

$P_m = nT/9.55 = 1650 \times 100/9.55 = 17.28$ kW

$s = (n_s - n)/n_s = (1800 - 1650)/1800 = +0.083$

$P_m = (1 - s)P_r \quad \therefore 17.28 = (1 - 0.083)\, P_r$

$P_r = 18.85$ kW $\quad P_{jr} = (18.85 - 17.28) = 1.57$ kW



MOTOR

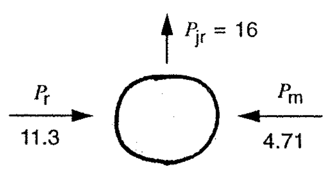
b. $n = -750$; $T = +60$

$P_m = 750 \times 60/9.55 = -4.71$ kW

$s = (n_s - n)/n_s = [1800 - (-750)]/1800 = +1.417$

$P_m = (1 - s)P_r \qquad -4.71 = (1 - 1.417)\, P_r$

$\therefore P_r = +11.3$ kW $\quad P_{jr} = 11.3 + 4.71 = 16$ kW



BRAKE

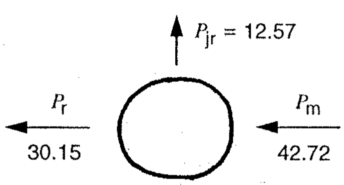
c. $n = +2550$; $T = -160$

$P_m = nT/9.55 = 2550 \times (-160)/9.55 = -42.72$ kW

$s = (n_s - n)/n_s = (1800 - 2550)/1800 = -0.417$

$P_m = (1 - s)P_r \qquad \therefore -42.72 = (1 - (-0.417))\, P_r$

$P_r = 30.15$ kW $\quad P_{jr} = 42.72 - 30.15 = 12.57$ kW



GENERATOR

20-24 a. 1.57 kW; b. 16 kW; c. 12.57 kW
(see calculations in 20-23 above)

20-25 a. To develop 100 N·m, the slip speed must be (1800 – 1650) = 150 r/min (see Fig, 20-39). The slip speed must also be 150 r/min when the motor develops 100 N·m at 1200 r/min. The synchronous speed is therefore

$$n_s = 1200 + 150 = 1350 \text{ r/min.}$$

The voltage and frequency must be reduced in the ratio 1350/1800 = 0.75. Consequently,

$$f = 0.75 \times 60 = 45 \text{ Hz; } E = 0.75 \times 460 = 345 \text{ V}$$

20-25 b. To develop 60 N·m, the slip speed must be

(1800 – 1725) = 75 r/min.

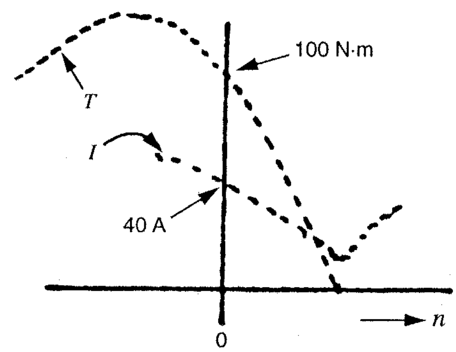
Using the same reasoning as in (a):

$$n_s = (2400 + 75) = 2475$$

$$f = \left(\frac{2475}{1800}\right) \times 60 = 82.5 \text{ Hz} \quad E = \left(\frac{2475}{1800}\right) \times 460 = 633 \text{ V}$$

20-26 The entire T-n and I-n curves at 60 Hz must be shifted to the left until the intersection with the Y axis yields I = 40 A and T = 100 N·m. This result is obtained at a slip speed of 150 r/min. Thus, n_s = 150 r/min and

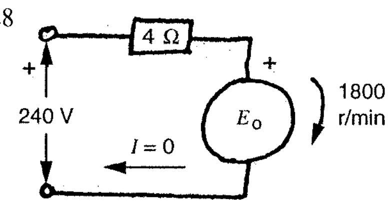
$$f = \left(\frac{150}{1800}\right) \times 60 = 5 \text{ Hz} \quad E = \left(\frac{150}{1800}\right) \times 460 = 38 \text{ V}$$



20-27 a. The speed cannot reverse instantaneously owing to inertia.

b. Yes, because the torque can change instantaneously.

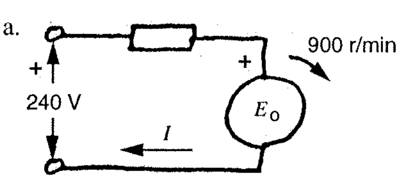
20-28



GIVEN

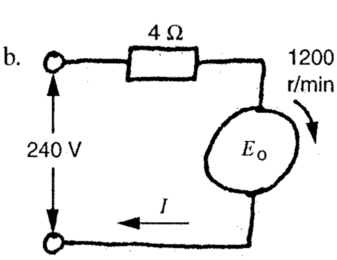
$E_o = 240$ V

a.

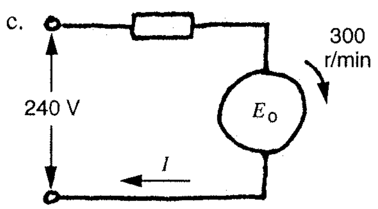


$$E_o = \frac{900}{1800} \times 240$$
$$= 120 \text{ V}$$
$$I = (240 - 120)/4$$
$$= 30 \text{ A}$$

b.



$$E_o = \frac{1200}{1800} \times 240 = 160 \text{ V}$$
$$I = (240 - 160)/4$$
$$= 20 \text{ A}$$
$$P_o = \frac{(160 \times 20)}{1000} \times 1.34$$
$$= 4.29 \text{ hp}$$

c. 

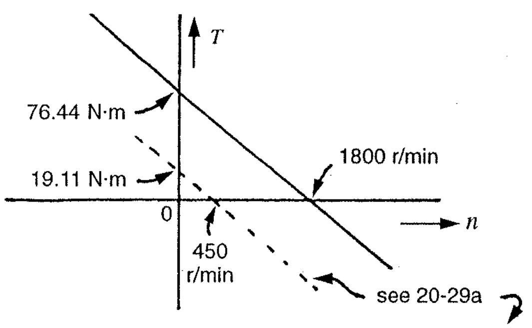
$E_o = \frac{300}{1800} \times 240$
$= 40$ V
$I = (240 - 40)/4$
$= 50$ A
$P_o = E_o I = 40 \times 50$
$= 2000$ W

$$T = \frac{9.55\,P_o}{n} = \frac{9.55 \times 2000}{300} = 63.7 \text{ N·m}$$

d. The starting current = 240/4 = 60 A. Because the torque depends directly upon the current when ϕ is fixed and because 50 A produces a torque of 63.7 N·m (see above)

we find that the starting torque is: $63.7 \times \frac{60}{50} = 76.44$ N·m

$\therefore T = 76.44/1.356 = 56.4$ ft·lb

e. 

20-29 a. The no-load speed is (60/240) × 1800 = 450 r/min.
The starting current is 60 V/4 Ω = 51 A.
The starting torque = 76.44 × (15/60) = 19.11 N·m .
See resulting *T-n* curve in 20-28e above.

b. The frequency of the current is the same as that of the voltage: $f = pn/120 = 4 \times 300/120 = 10$ Hz.

20-30 Rated torque $T_n = \frac{9.55\,P}{n} = \frac{9.55}{1765} \times \left(\frac{100}{1.34} \times 1000\right)$
$= 404$ N·m $= 404 \div 1.356 = 298$ ft·lb.

a. Breakdown torque = 2.8 p.u. = 2.8 × 298 = 834 ft·lb for curve (2) BDT = 1.2 × 298 = 358 ft·lb

b. 480 A/120 A = 4 p.u. From Fig. 20-23b, this corresponds to a speed of 800 r/min. But 800 r/min corresponds to a torque of 0.5 p.u. (Fig. 20-23a).

∴ Torque is 0.5 × 298 = 149 ft·lb.

20-31 a. $f = \frac{1200}{1800} \times 60 = 40$ Hz; $E = \frac{1200}{1800} \times 460 = 307$ V

b. 90 lb·ft² = 90 ÷ 23.73 = 3.79 kg·m²

$E_k = 5.48 \times 10^{-3} J n^2$ (Eq. 3-8)
$= 5.48 \times 10^{-3} \times 3.79 \times 1800^2 = 67.3$ kJ

c. $E_k = 5.48 \times 10^{-3} \times 3.79 \times 1200^2 = 29.9$ kJ

d. The kinetic energy "lost" = 67.3 – 29.9 = 37.4 kJ only a portion of this energy is returned to the line. The motor functions as an asynchronous generator as it drops in speed from 1800 to 1200 r/min. During this period the machine has losses P_r, P_{jr}, P_f and P_{js} (see Fig. 14-16). These losses multiplied by time are the energy losses that must be substracted from 37.4 kJ to give the energy actually returned to the 3-phase line.

20-32 a. All torques are 1/4 of their value because $T \alpha E^2$

b. The breakdown torque is
160/4 = 40 N·m = 40/1.356 = 29.5 ft·lb

20-33 $E = 460\sqrt{\frac{60}{160}} = 282$ V

INDUSTRIAL APPLICATION – CHAPTER 20

20-34 Multiple of current setting = $\frac{135}{82}$ = 1.65

On the single-phase curve, the time to trip lies between 60 s and 32 s.

20-35 Starting current at 200 V = 465 A

starting current at 155 V = $\frac{155}{200} \times 465 = 360$ A

multiple = $\frac{360}{82}$ = 4.39 (of 3-ph relay setting)

a) starting current (pu) = 360/82 = 4.39

starting torque $2.20 \times \left(\frac{360}{465}\right)^2 = 1.32$

Thus, the starting torque is only 32 % larger than the full-load torque.

b) With a relay multiple of 4.39 on a 3-phase line, the time to trip lies between 165 and 12 s, say 14 s. The time cannot be stated precisely, and there is no need to.

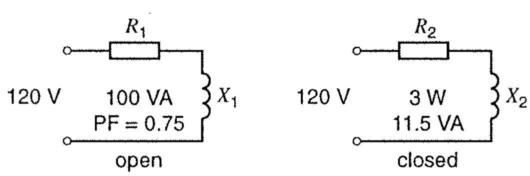
20-36 (a) $P = 3\,I^2R = 3 \times 71^2 \times 0.023 = 348$ W

The motor actually draws 71 A, and not the rated current of 82 A.

(b) single-phase copper loss = $135^2 \times 0.023 \times 2 = 8.38$ W

In comparing (a) and (b) it is obvious that the losses are greater when the motor is single-phasing.

20-37



In open position

$I = 100/120 = 0.833$ A $\quad Z_1 = 120/0.833 = 144\ \Omega$

$R_1 = 144 \times 0.75 = 108\ \Omega \quad X_1 = \sqrt{144^2 - 108^2} = 92.25\ \Omega$

In closed position

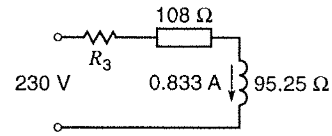
$I = 11.5/120 = 0.09583$ A $\quad Z_2 = 120/0.09583 = 1252\ \Omega$

$0.09583^2 \times R_2 = 3 \quad R_2 = 327\ \Omega$

$X_2 = \sqrt{1252^2 - 327^2} = 1209\ \Omega$

When the holding coil is powered by the 230 V source, a resistor is placed in the circuit so that the current is the same in the open and closed positions. Two resistance values have to be calculated.

In open position

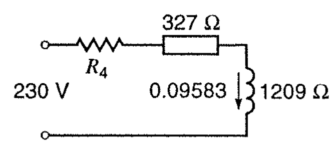


$\left(\frac{230}{0.883}\right)^2 = R_{TD}^2 + 95.25^2 \quad \therefore R_{TD} = 259\ \Omega = R_3 + R_1$

$\therefore R_3 = 259 - 108 = 151\ \Omega$

$P = I^2R_3 = 0.833^2 \times 151 = 105$ W

In closed position



$\left(\frac{230}{0.09583}\right)^2 = R_{TC}^2 + 1209^2 \quad \therefore R_{TC} = 2073\ \Omega$

$R_4 = 2073 - 327 = 1747\ \Omega$

$P = I^2R_4 = 0.09583^2 \times 1747 = 16$ W

CHAPTER 21

21-6 a. $E_d = 0.675\,E = 0.675 \times 2400 = 1620$ V
b. Each diode carries $1/3 \times 600 = 200$ A
c. 600 A

21-7 a. $E_d = 1.35\,E = 1.35 \times 2400 = 3240$ V
b. Each diode carries $1/3 \times 600 = 200$ A

21-8 a. $E_d = 0.9\,E = 0.9 \times 600 = 540$ V $\qquad E_{34} = 540$ V
b. $E_{54} = 540$ V because the inductor IR drop (dc) is negligible.
c. $I = E_{54}/R = 540/30 = 18$ A
d. Each diode carries current half the time
$\therefore I_{avge} = 18/2 = 9$ A
e. $P_{ac} = P_{dc} = 540 \times 18 = 9720$ W

21-9 a. $E_o = E_s f T_a = 3000 \times 50 \times (1/1000) = 150$ V
b. $I_o = E_o/R_o = 150/2 = 75$ A
$P_{load} = E_o I_o = 75 \times 150 = 11\,250$ W
Power drawn from source = 11 250 W
$I_s = P/E_s = 11\,250/3000 = 3.75$ A

21-10 Doubling the on-time doubles the output voltage and, consequently, also the output current. The power output increases to $4 \times 11\,250$ W = 45 kW.

21-11 a. $P = 200\text{ A} \times 0.6\text{ V} \times 6\text{ diodes} = 720\text{ W} = 0.72$ kW
b. $P_o = 3240 \times 600 = 1944$ kW
$\eta = P_o/P_i = 1944/1944.72 = 0.9996$ or 99.96 %

21-12 a. Current actually flows from terminal 4 to terminal 3; $\therefore$ 4 is (+) with respect to 3. E_{43} is (+) and E_{34} is negative.

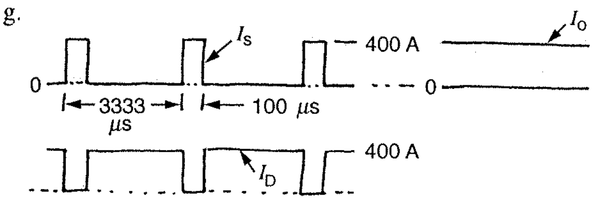
b. 

The current is increasing because the induced voltage tends to produce a current opposite to the 6 A actually flowing in the circuit (see Sec. 2-31).

21-13 a. $E_d = 0.9\,E = 0.9 \times 120 = 108$ V $\quad I_{dc} = 108/3 = 36$ A
b. $P/V = 120\sqrt{2} = 170$ V
c. $W > P/f > (35 \times 108)/60$
$> 64.8\,J$
d. $W = \frac{1}{2}LI^2 \quad \therefore 64.8 = \frac{1}{2}L \times 36^2 \quad L = 0.1\,H$
e. The peak-to-peak ripple is equal to the peak voltage of the source, or 170 V (see Fig. 21-13c)

21-14 a. $E_d = 1.35\,E = 1.35 \times 240 = 324$ V
b. $P = E_d I_d = 324 \times 750 = 243$ kW
c. $I_{peak} = 750$ A
d. Each diode conducts for 1/3 cycle $= \left(\frac{1}{3}\right) \times \left(\frac{1}{60}\right)$
$= \frac{1}{180}$ s = 5.55 ms.
e. $I = 0.816\,I_d = 0.816 \times 750 = 612$ A
f. No reactive power is absorbed
g. E_{KA} swings between $E\sqrt{2}$ and $1.225\,E$ (Fig. 21-21)
ripple across inductor = (1.414 – 1.225) 240 = 45.4 V

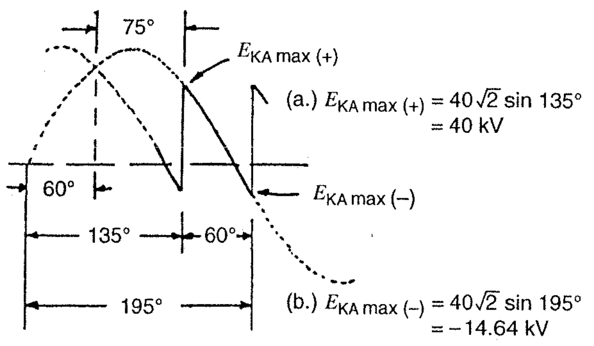
21-15 a. $P = E_o^2/R_o = 60^2/0.15 = 24$ kW
also $I_o = E_o/R_o = 60/0.15 = 400$ A
b. $P_{source} =$ 24 kW = 24 000 W
c. $I_s = 24\,000/E_s = 24\,000/2000 = 12$ A
d. The peak value of I_s is equal to $I_o = 400$ A.
e. $E_o = E_s f T_a \qquad 60 = 2000\,f \times (100 \times 10^{-6})$
$\therefore f = 300$ Hz
f. $R_{apparent} = E_s/I_s = 2000/12 = 167\ \Omega$
g.



21-16 a. zero
b. $E_d = 1.35\,E \cos\alpha$
$60 = 1.35 \times 208 \cos\alpha$
$\therefore \alpha = 77.7°$ (in rectifier mode)
c. $\alpha = (180 - 77.7) = 102.3°$

21-17 a. $E_d = 1.35\,E \cos\alpha = 1.35 \times 40 \times \cos 75 = 14$ kV
b. $P = 14\,000 \times 450 = 6\,300$ kW = 6.3 MW
c. $I = 0.816\,I_d = 0.816 \times 450 = 367$ A
d. $Q = P \tan\alpha = 6.3 \tan 75 = 23.5$ Mvar

21-18 a. Referring to Fig. 21-50, the voltage curves are reproduced as shown below:



c. $E_{peak\text{-}to\text{-}peak} = 14.64 + 40 = 54.64$ kV

21-19 a. $I_{eff} = E_{eff}/R = 600/15 = 40$ A

b. $P = EI = 600 \times 40 = 24$ kW

c. O A

d. 100 %

e. 0 var

21-20 a. $I_H = \sqrt{17.68^2 - 12.34^2} = 12.66$ A. The effective value of a distorted periodic wave is given by:

$$E = \sqrt{E_0^2 + E_1^2 + E_2^2 + E_3^2 + \dots E_n^2}$$

where E = effective value of the given waveform (V)

E_0 = dc component of the given waveform

E_1 = effective value of the fundamental component

$E_2, E_3, \dots, E_n$ = effective value of the harmonics

b. $P = I^2R = 17.68^2 \times 15 = 4.7$ kW

c. distortion power factor = $\dfrac{\text{(rms value of the fundamental) (component of the line current)}}{\text{rms value of the line current}}$

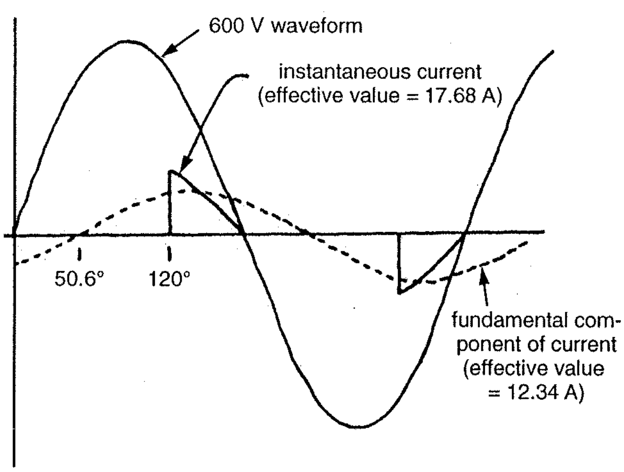
$= \dfrac{12.34}{17.68} = 0.70$ or 70 %

d. $S = 600 \times 17.68 = 10.6$ kVA

e. $\dfrac{P}{S} = \dfrac{4.7}{10.6} = 0.44$ or 44 %

f. $P = EI_F \cos\theta_d$ $\quad 4700 = 600 \times 12.34 \cos\theta_d$

$\therefore \cos\theta_d = 0.635$ or 63.5 % $\quad \theta_d = 50.6°$

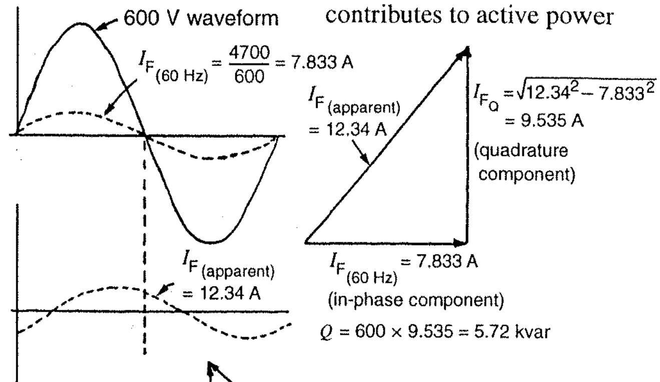


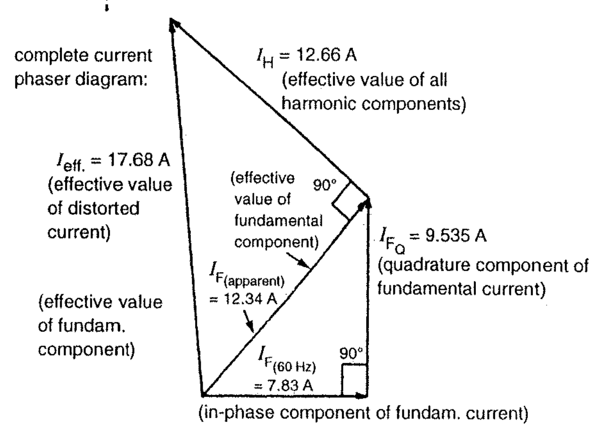
g. $S_{Fund} = 12.34 \times 600 = 7.4$ kVA (at 60 Hz)

$P_{Fund} = 4.7$ kW (60 Hz)

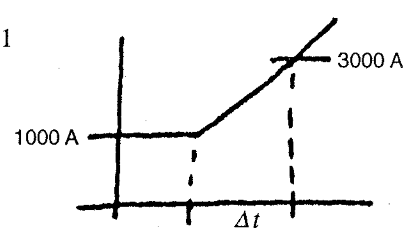
$Q = \sqrt{7.4^2 - 4.7^2} = 5.72$ kvar

explication: only the fundamental (60 Hz) contributes to active power





21-21



$\Delta I = 3000 - 1000 = 2000$ A $\quad \Delta t = 50$ ms

$E = L\Delta I/\Delta t \quad 250 = L \times 2000/0.05 \quad \therefore L = 6.25$ mH

Note that when the short occurs, the dc output voltage appear across the inductor.

21-19 a. $I_{eff} = E_{eff}/R = 600/15 = 40$ A

b. $P = EI = 600 \times 40 = 24$ kW

c. O A

d. 100 %

e. 0 var

21-20 a. $I_H = \sqrt{17.68^2 - 12.34^2} = 12.66$ A. The effective value of a distorted periodic wave is given by:

$$E = \sqrt{E_o^2 + E_1^2 + E_2^2 + E_3^2 + \cdots E_n^2}$$

where E = effective value of the given waveform (V)

E_o = dc component of the given waveform

E_1 = effective value of the fundamental component

$E_2, E_3, \ldots, E_n$ = effective value of the harmonics

b. $P = I^2R = 17.68^2 \times 15 = 4.7$ kW

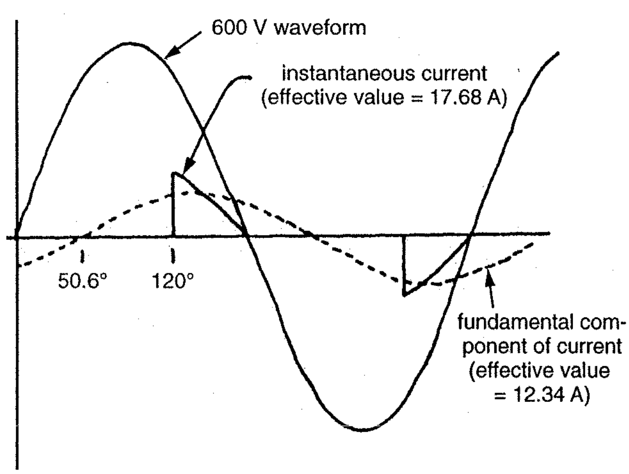
c. $$\text{distortion power factor} = \frac{\text{(rms value of the fundamental) (component of the line current)}}{\text{rms value of the line current}} = \frac{12.34}{17.68} = 0.70 \text{ or } 70\ \%$$

d. $S = 600 \times 17.68 = 10.6$ kVA

e. $\dfrac{P}{S} = \dfrac{4.7}{10.6} = 0.44$ or 44 %

f. $P = EI_F \cos\theta_d \qquad 4700 = 600 \times 12.34 \cos\theta_d$

$\therefore \cos\theta_d = 0.635$ or 63.5 % $\theta_d = 50.6°$

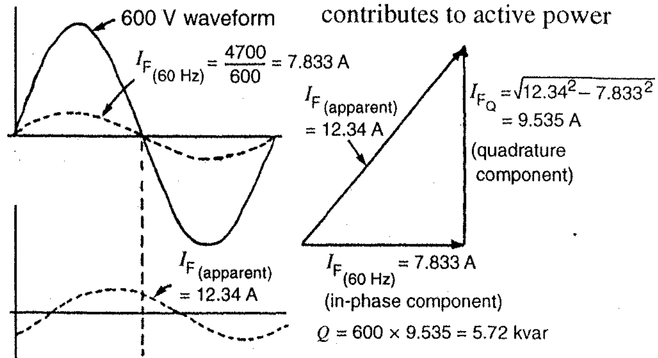


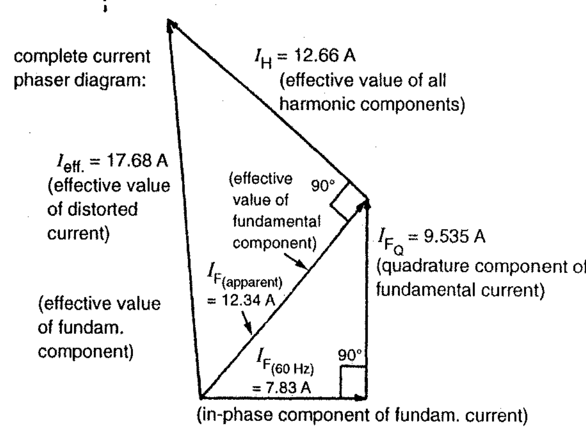
g. $S_{Fund} = 12.34 \times 600 = 7.4$ kVA (at 60 Hz)

$P_{Fund} = 4.7$ kW (60 Hz)

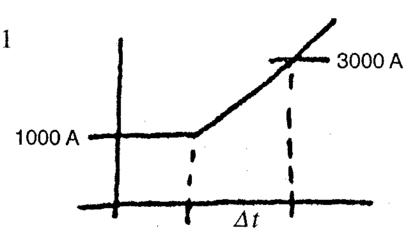
$Q = \sqrt{7.4^2 - 4.7^2} = 5.72$ kvar

explication: only the fundamental (60 Hz) contributes to active power





21-21

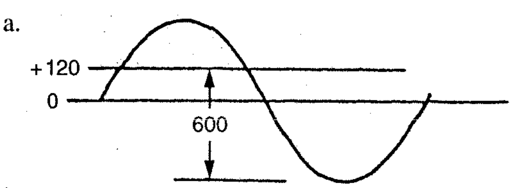


$\Delta I = 3000 - 1000 = 2000$ A $\quad \Delta t = 50$ ms

$E = L\Delta I/\Delta t \qquad 250 = L \times 2000/0.05 \quad \therefore L = 6.25$ mH

Note that when the short occurs, the dc output voltage appear across the inductor.

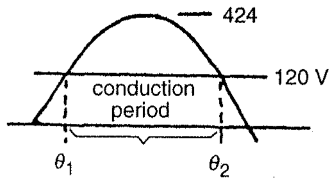
21-22 a.



The peak ac voltage must not exceed $600 - 120 = 480$ V

$E_{eff} = 480/\sqrt{2} = 340$ V

b. RMS means root mean square (sec. 2-10)

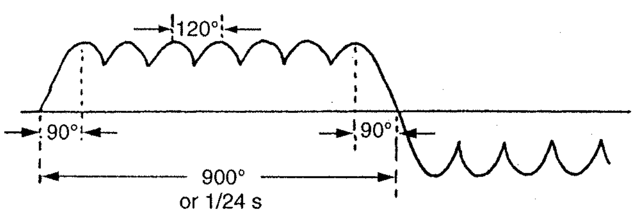


$300\sqrt{2} = 424$ V
θ_1 = arc sin 120/424
= 16.4°
$\theta_2 = 180 - 16.4$
= 163.6

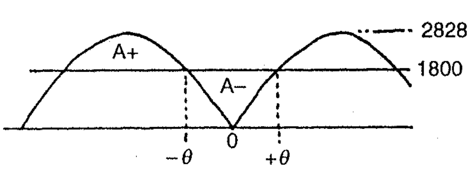
conduction period = (163.6 – 16.4) = 147°

c. $I_{peak} = (424 - 120)/10 = 30.4$ A

21-23 12 Hz has a period of 1/12 s. The interval between g1 and g4 is ∴ 1/24 s on a 60 Hz base this corresponds to $360° \times \frac{(1/24)}{(1/60)} = 900°$. Referring to Fig. 21-35 the rising and falling sides together take up 180° while the peaks are separated by 120°. Hence the number of peaks is: (900 – 180)/120 = 6 + 1 = 7.
The waveshape is given below



21-24 a.



$E_{peak} = 2000\sqrt{2} = 2828$ V $\quad E_{dc} = 0.9\,E = 1800$ V
θ = arc sin 1800/2828 = 39.5°

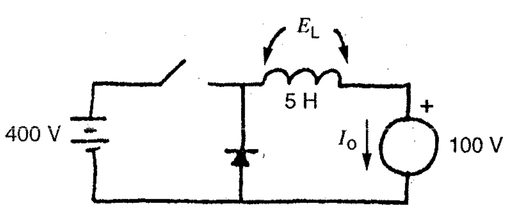
area of $A_{(-)} = \frac{1}{2}(2 \times 39.5 \times 1800) = 71\ 100$ volt degrees

but 1° corresponds to $\left(\frac{1}{60}\right)\left(\frac{1}{360}\right) = 46.3\ \mu$s.

∴ $A_{(-)} = A_{(+)} = 71\ 100 \times 46.3 \times 10^{-6} = 3.29$ V·s

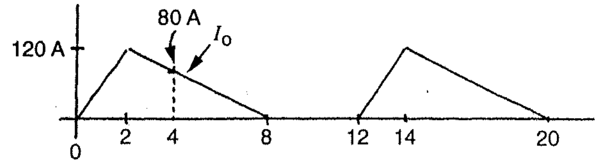
b. $\Delta I = A/L \quad \therefore L = A/\Delta I = 3.29/7 = 0.47$ H

21-25 a.



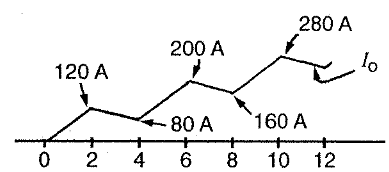
V·s stored in inductor after 2 s is:
$A_+ = (400 - 100)\,2 = 600$ V·s
initial current in inductor = 0

∴ Final current after 2 s = A/L = 600/s = 120 A
when the "switch" opens, E_L = 100 V. The 600 V·s previously accumulated, are discharged in a period T_b = 600/100 = 6 s. The current waveshape of I_o is given below

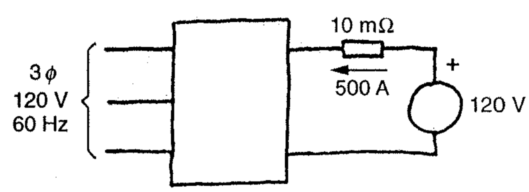


b. average current during 8 s = 120/2 = 60 A
energy per cycle = EIt = 100 × 60 × 8 = 48 kJ
c. P absorbed by the load = 48 kJ/12 s = 4 kW
d. see a.

21-26 a. after 2 s, I_o = 120 A (see Fig. above)
b. after 4 s, I_o = 80 A (see Fig. above)
c. the chopper recloses for another 2 s, and so it gains 120 A. ∴ I_o = 80 + 120 = 200 A
d. After 6 s, the chopper re-opens, and the current drops by 40 A ∴ I_o = 160 A
c. The current builds up gradually, but it is limited ultimately by the resistance of the circuit. The diagram below shows how the current builds up.



21-27 a.



$E_d = 120 - RI = 120 - 0.01 \times 500 = 115$ V
$E_d = 135\,E\cos\alpha$
$115 = 1.35 \times 120 \cos\alpha \quad \therefore \alpha = 44.8°$

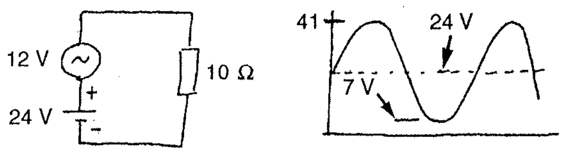
however, this is an inverter and so α = 135.2°

b. P = 115 × 500 = 57.5 kW (neglecting transformer losses [iron and copper])

c. $Q = P\tan\alpha$
= – 57.5 tan 135.2
= 57 kvar

INDUSTRIAL APPLICATION – CHAPTER 21

21-28



(a) E_{ac} peak = $12\sqrt{2} = 17$ V
$E_{max} = 24 + 17 = 41$ V $\quad E_{min} = 24 - 17 = 7$ V

(b) Effective voltage across resistor = $\sqrt{12^2 + 24^2}$
= 26.8 V

(c) $P = E^2/R = 26.8^2/10 = 72$ W

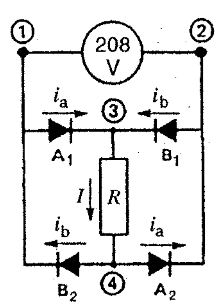
21-29 Let I_F = fundamental component (RMS)
let I_H = RMS value of all the harmonics
let I = effective (RMS) value of the current
we have $I^2 = I_H{}^2 + I_F{}^2$

Total harmonic distortion THD = $\dfrac{I_H}{I_F} = 0.26$

$547^2 = I_F^2 + I_H^2 = I_F^2 + (0.26\,I_F)^2 = 1.0676\,I_F^2$

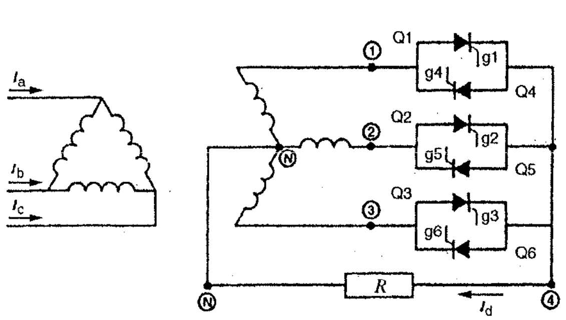
hence $I_F = 547/\sqrt{1.0676} = 529.4$ A
I_F peak = $529.4\sqrt{2} = 748.7$ A
$I_H = 0.26\,I_F = 0.26 \times 529.4 = 137.6$ A

21-30 Before the diode opened, the effective voltage across R was 208 V. Hence $R = E^2/W = 208^2/1400 = 30.9\ \Omega$.



After the diode failure, the current flows in half-wave pulses, and so the power drops to 1/2 × 1400 = 700 W. The effective voltage across the load is now $E = \sqrt{RW} = \sqrt{30.9 \times 700}$ $\quad E = 147.1$ V

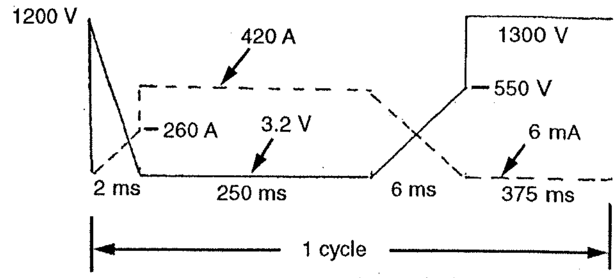
21-31



When Q2 short-circuits it will provide a short circuit path between the transformer terminals for all the other thyristors. As a result, they will all fail soon after Q2 becomes short-circuited.

21-32 To solve this problem we will make the following approximations.

1. During the turn-on period the anode voltage drops linearly from 1200 V to zero.
2. During the turn-off time, the anode voltage increases linearly from zero to 550 V.



21-32 (a) The peak power occurs in the middle of the turn-on period: $P = 600$ V × 130 A = 78 kW

(b) Peak power during the on-state period is:
$P = 3.2$ V × 420 A = 1344 W

(c) It is possible to show that when the voltage and current vary linearly as shown in the 2 ms turn-on period and the 6 ms turn-off period, the average power is equal to 2/3 of the peak power. Hence, during the 2 ms turn-on period, the average power is

$$P_{avge} = \frac{2}{3} \times 78 \text{ kW} = 52 \text{ kW}$$

21-32 (d) The average power during on-state is P_{avge} = 1344 W

(e) Energy dissipated in the GTO during the turn-on = 52 kW × 2 ms = 104 J

(f) Energy in the GTO during the on-state is
1344 × 0.25 s = 336 J

(g) Peak power during turn-off occurs in the middle of the 6 ms period.
P_{peak} = 210 A × 275 V = 57.75 kW
$P_{average}$ = 2/3 × 57.75 = 38.5 kW
Energy during 6 ms period = 38.5 kW × 6 ms = 231 J

(h) Energy during the off-state interval
= 1300 V × 6 mA × 0.375 s = 3 J

Total energy dissipated in one cycle
= 104 + 336 + 231 + 3 = 674 J

Duration of one cycle = (2 + 250 + 6 + 375)
= 633 ms = 0.633 s

Power dissipated = 674 J/0.633 s = 1065 W

(i) Frequency = 1/0.633 = 1.58 Hz

Duty cycle = $\dfrac{T_2}{T} = \dfrac{250}{633} = 0.395$

Note the enormous powers that are dissipated during the turn-on and turn-off periods.

21-33 a) We have $E_L = DE_H$ Eq. 21.21 where D is the duty cycle of switch S1 $\quad 70 = D \times 400$

hence $D = 0.175$ for switch S1

The on-time of S1 $T_a = 0.175 \times 60\ \mu s = 10.5\ \mu s$

The off-time of S1 $T_b = T - T_a = 60 - 10.5 = 49.5\ \mu s$

b) The switching frequency f_c is the reciprocal of $T_a + T_b$.

Hence $f_c = \dfrac{1}{T_a + T_b} = \dfrac{1}{60\ \mu s} = \dfrac{10^6}{60} = 16\ 666$ Hz

$= 16.67$ kHz

21-34 a) DC voltage between A and 2 $= DE_H = 0.35 \times 600$

$= 210$ V

A is (+) with respect to 2 $E_{A2} = +210$ V

b) DC voltage between B and 2 $= (1 - D)\ E_H$

$= (1 - 0.35) \times 600$

$= 390$ V

B is (+) with respect to 2 $E_{B2} = +390$ V

c) From Kirchhoff's voltage law we can write:

$E_{AB} + E_{B2} + E_{2A} = 0$

$\therefore E_{AB} = E_{A2} - E_{B2} = +210 - 390 = -180$ V

hence A is negative with respect to B.

21-35 The duration of one cycle $= \dfrac{1}{25\ 000 \text{ Hz}} = 40 \times 10^{-6}$ s

$= 40\ \mu s$

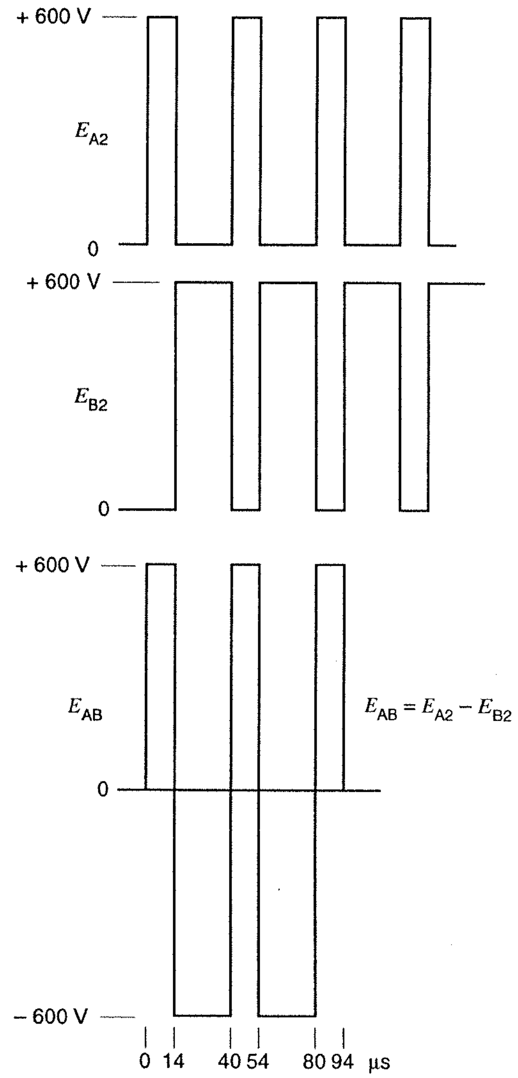
a) Closing time of Q1 = DT $= 0.35 \times 40 = 14\ \mu s$

opening time of Q1 $= (40 - 14) = 26\ \mu s$

b) Closing time of Q3 $= (1 - 0.35) \times 40 = 26\ \mu s$

opening time of Q3 $= (40 - 26) = 14\ \mu s$

c) The waveshapes of E_{A2}, E_{B2} and E_{AB} are shown on the right.



The average value of E_{AB} is calculated as follows:

volt-seconds of positive pulses during one cycle =

$600\text{ V} \times 14\ \mu s = 8900\text{ V}\mu s$

volt-seconds of negative pulses during one cycle =

$-600\text{ V} \times 26\ \mu s = -15\ 600\text{ V}\mu s$

Total volt-seconds during one cycle $= 8400 - 15\ 600$

$= -7200\text{ V}\mu s$

Duration of one cycle $= 40\ \mu s$

Average voltage during one cycle $= \dfrac{-7200\text{ V}\mu s}{40\ \mu s}$

$= -180$ V

21-36 a) $I = \dfrac{360\ 000}{2100\sqrt{3}} = 99$ A

b) Active power $= 360\ 000 \times 0.86 = 309\ 600$ W

current from dc source $= P/E = 309\ 600/4000 = 77.4$ A

c) Line-to-neutral voltage must not exceed $4000\text{ V}/2 = 2000$ V

Effective value of line-to-neutral voltage $= 2000/\sqrt{2} = 1414$ V

Maximum effective line-line voltage $= 1414\sqrt{3} = 2450$ V

CHAPTER 22

22-3 A dc machine is basically an ac machine having a rectifying commutator.

$f = Pn/120$ (Eq. 22-8)
$= 2 \times 5460/120 = 91$ Hz

22-4 a. $E_d = 1.35\,E \cos \alpha = 1.35 \times 480 \cos 15° = 626$ V

b. $P_i = E_d\,I_d = 626 \times 270 = 169$ kW

c. $I_{avge} = 270/3 = 90$ A

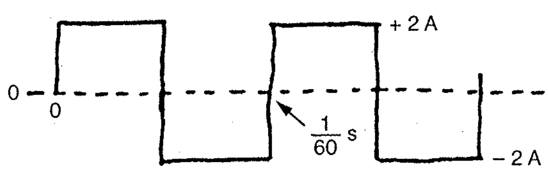
d. $P_o = P_i - I^2R = 169 - \dfrac{270^2 \times 0.07}{1000} = 164$ kW
$= 164 \times 1.34 = 219.76$ hp.
We round this figure off to 220 hp

22-8 a. $E_d = 0.9\,E$ Eq. 21-1
$180 = 0.9\,E$
$\therefore E = 200$ V

b. Ripple (peak-to-peak) $= 200\sqrt{2} = 283$ V

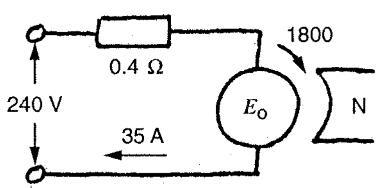
c. No, the current is very smooth owing to the large inductance of the field relative to its resistance. In effect the time constant L/R is much longer than the duration of 1/2 cycle, or 1/120 s.

d.



e. Because the current is rectangular its effective value is equal to its peak value: 2 A.

22-9 a.



for a 3-ph, 6-pulse rectifier we have:

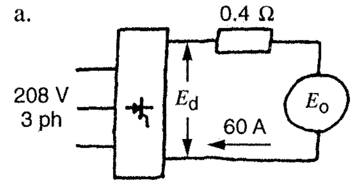
$E_d = 1.35\,E \cos \alpha$
$240 = 1.35 \times 208 \cos \alpha$
$\therefore \alpha = 31.3°$

b. $P = 240 \times 35 = 8.4$ kW
$Q = P \tan \alpha = 8.4 \tan 31.3° = 5.1$ kvar

c. $I = 0.816\,I_d = 0.816 \times 35 = 28.6$ A

d. $E_o = \dfrac{900}{1800}(240 - 35 \times 0.4) = \dfrac{1}{2} \times 226 = 113$ V

22-10 a.



$E_o = 0$
$E_d = 60 \times 0.4 = 24$ V
$E_d = 1.35\,E \cos \alpha$
$24 = 1.35 \times 208 \cos \alpha$
$\therefore \alpha = 85.1°$

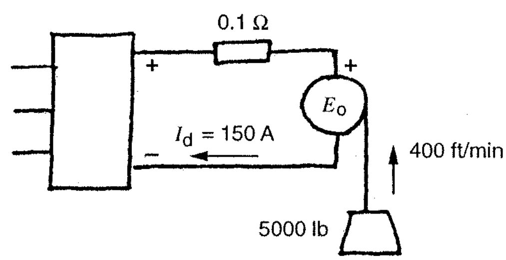
b. $P = 60 \times 24 = 1440$ W
$Q = P \tan \alpha = 1440 \tan 85.1° = 16.8$ kvar
Note that Q is far greater than P and so the power factor of the ac line is very low.

c. The inductor L does not draw any reactive power from the ac line. It is the switching action of the SCRs that produces the demand for reactive power.

22-11 a. The ac ammeter gives the effective value of line current. $I = 0.816\,I_d$ $280 = 0.816\,I_d$ $\therefore I_d = 343$ A

b. $\cos \alpha = 0.83$ $\therefore \alpha = 33.9°$
Because the converter is an inverter $\alpha = 180 - 33.9$
$= 146°$

22-12 a.



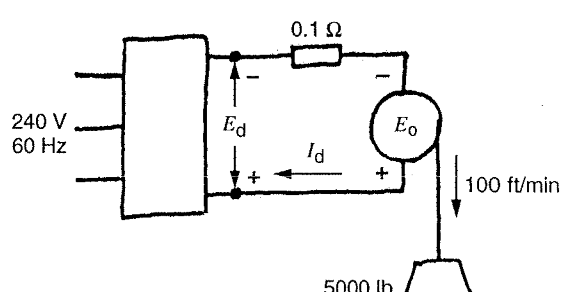
Mechanical power $P_o = Fv$ (see Sec. 3-14)

$F = \dfrac{5000}{2.205}$ kg $\times 9.8 = 22.2$ kW (Eq. 3-1)

$v = 400\ (\div 1.97)\ (\div 100) = 2.03$ m/s
$P_o = 22.2 \times 2.03 = 45$ kW
$P_o = E_o I_d$
$45\,000 = E_o \times 150$ $\therefore E_o = 300$ V

b. $E_d = E_o + I_d R_a = 300 + 150 \times 0.1 = 315$ V

22-13 a.



The torque exerted by the load acts in the same direction and has the same value as when the mass was being raised. The value and direction of the current is the same $I_d = 150$ A

21-13 b. $P_o = Fv = 22.2\ \text{kW} \times (2.03/4) = 11.25\ \text{kW}$

$E_o = P_o/I_d = 11.25 \times 1000/150 = 75\ \text{V}$

The polarity of E_o is reversed because the direction of rotation is reversed.

c. $E_d = E_o - I_dR_a = 75 - 15 = 60$ V polarity as shown above.

d. Active power flows into the ac line

$P_{ac} = E_dI_d = 60 \times 150 = 9\ \text{kW}$

22-14 a. The torque is the same as before, but $E_o = 0$

b. I_d is still 150 A.

c. $E_d = I_dR_a = 15$ V, polarity same as in 22-15a because the motor receives power.

22-15 a. In problem 22-13 $E_d = 60$ V and the converter is an inverter.

$$E_d = 1.35\,E\cos\alpha$$
$$60 = 1.35 \times 240\cos\alpha$$
$$\therefore \alpha = 79.3°$$

actual value = 180 – 79.3 = 100.7°

b. In Problem 22-14 $E_d = 15$ V and the converter is a rectifier

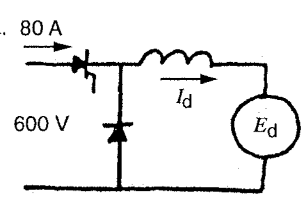
$$E_d = 1.35\,E\cos\alpha$$
$$15 = 1.35 \times 240\cos\alpha$$
$$\therefore \alpha = 87.3°$$

22-16 a. $I_o = 240$ A; $I_s = 8.23$ A (as found in Example 22-5). These are average, or dc values. The dc current in the diode is: $I_D = 240 - 8.23 = 232$ A.

I_D peak $= I_o = 240$ V

b. P1V is 700 V, as can be seen from Fig. 22-18a.

22-17 a.

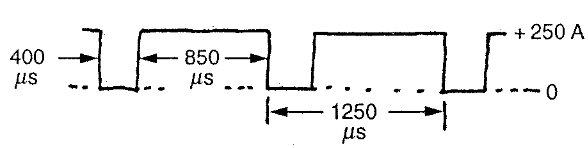


$f = 800$ Hz
$T_a = 400\ \mu s$
$E_d = E_d f T_a$
$= 600 \times 800 \times (400 \times 10^{-6})$
$= 192$ V

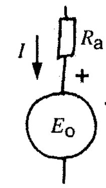
(we neglect the armature *IR* drop)

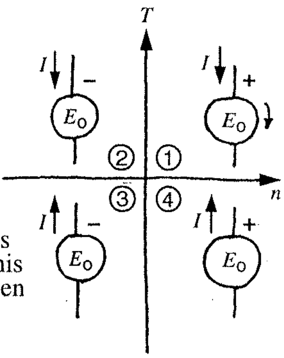
b. $I_d = P/E_d = 600 \times 80/192 = 250$ A

c. $T = 1/f = 1/800 = 1250\ \mu s$



22-18





The above figure represents operation in quadrant 1. This is according to the info given in the problem.

Based upon this we can show the polarity of E_o and the direction of current flow I in the other 3 quadrants (see above).

a. In quadrant 2 converter 1 must be in action because only it can produce the current flow having the direction shown. However, current enters the (–) terminal of E_o, consequently the armature is delivering power to the converter. The latter is ∴ an inverter.

b. converter 2 in action as rectifier

c. converter 2 in action as inverter

d. see diagram on right above

22-19

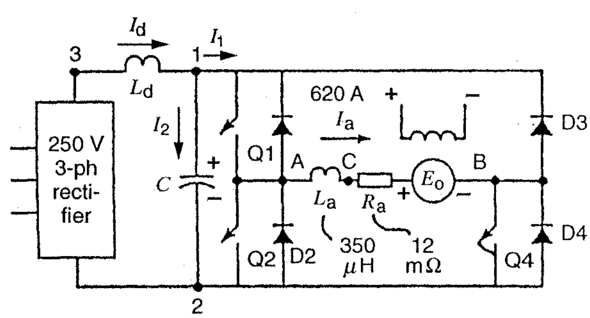


Figure 22-20

(a) In order to show that the converter operates with Q3 open, this GTO has been removed altogether in the figure above. Thus, the converter operates like a buck chopper with Q1, Q2 alone in operation. Q4 is permanently closed.

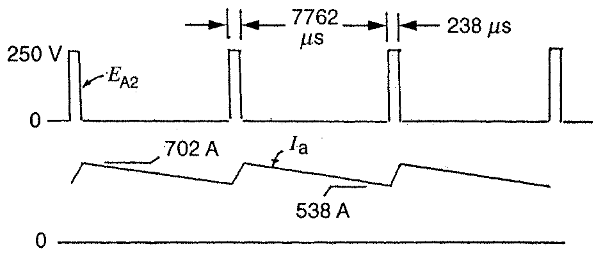
The armature voltage drop = 620 × 0.012 Ω = 7.44 V. The duty cycle to obtain low voltage is given by:

$E_o = DE_s$ i.e. $7.44 = D \times 250$ ∴ $D = 0.02976$

(b) The duration of one switching cycle =

$\frac{1}{f} = \frac{1}{125}$ s = 0.008 s = 8000 μs. Hence Q1 is closed for 0.02976 × 8000 = 238 μs and open for (8000 – 238) = 7762 μs, and this switching sequence repeats continuously.

22-19 cont'd



The voltage across the armature inductance when Q1 is on is (250 – 7.44) = 242.56 V. The volt-seconds accumulatd by the inductance during this "on" time is $A_{(+)} = 242.56 \times 238 \times 10^{-6}$ = 0,05773 V·s. The increase in current during this interval is

$$\Delta I = \frac{A_{(+)}}{L} = \frac{0.05773}{350 \times 10^{-6}} = 164 \text{ A}$$

The average voltage across the inductance when Q1 is open is 7.44 V. The decrease in volt-seconds across the inductance is $7.44 \times 7762 \times 10^{-6} = 0.05775$ V·s. The resulting decrease in current is

$$\Delta I = \frac{A_{(-)}}{L} = \frac{0.05775}{350 \times 10^{-6}} = 164 \text{ A}$$

The peak-to-peak ripple is 164 A, and the armature current fluctuates between $\left(620 + \frac{164}{2}\right) = 702$ A and $\left(620 - \frac{164}{2}\right) = 538$ A, as shown above. Note that although Q2 switches on and off, it never carries any current. It could be permanently open during this starting mode of the motor. DIODES D3 and D4 do not carry any current, but the presence of D2 is essential. However, there is no need to remove any diodes.

c. Suppose the same duty cycle is used despite the 2 V drop in the GTOs and the diodes when they conduct. Thus, when Q1 and Q4 are conducting, the voltage across the armature inductance is

$$(250 - 2 - 2 - 7.44) = 238.56 \text{ V}$$

The current increases by an amount

$$\Delta I = \frac{A_{(+)}}{L} = \frac{238.56 \times 238 \times 10^{-6}}{350 \times 10^{-6}} = 162 \text{ A}$$

However, when Q1 is open and Q4 and D2 are conducting, the average voltage across R_a is still 620 A × 0.012 = 7.44 V. The net voltage across L_a is therefore (7.44 – 2 – 2) = 3.44 V during 7762 µs. The decrease in current is

$$\Delta I = \frac{A_{(-)}}{L} = \frac{3.44 \times 7762 \times 10^{-6}}{350 \times 10^{-6}} = 76 \text{ A}$$

The increase in current of 162 A when Q1 is on and the decrease of 76 A when Q1 is off is not a steady-state condition. Thus, the average armature current of 620 A will increase progressively until the increase ΔI is equal to the decrease ΔI. Suppose the final average current is I. We can then write (at steady-state):

$$\frac{(250 - 2 - 2 - 0.012\, I)\, 238 \times 10^{-6}}{350 \times 10^{-6}} = \frac{(0.012\, I + 4)\, 7762 \times 10^{-6}}{350 \times 10^{-6}}$$

hence $(246 - 0.012\, I) = (0.012\, I + 4)\, 32.6$

which yields $I = 287$ A.

In order to keep $I_a = 620$ A, the dyty cycle D must be increased. To determine its value, we equate the increase in current to the decrease. Suppose the "on" time of Q1 is T microseconds. The off time is then $(8000 - T)$ microseconds. In the steady-state condition we have:

$$\frac{(250 - 4 - 744)\, T}{350 \times 10^{-6}} = \frac{(7.44 + 4)\,(8000 - T)}{350 \times 10^{-6}}$$

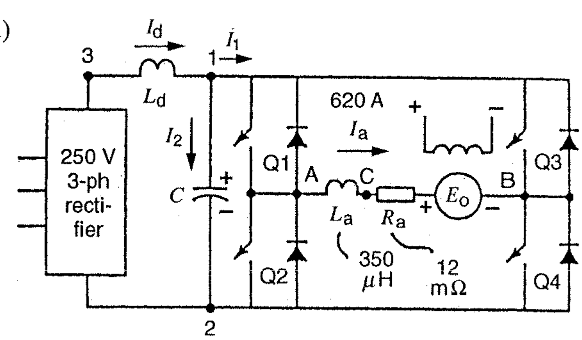
$$238.56\, T = 11.44\, (8000 - T)$$

which yelds $T = \frac{11.44 \times 8000}{250} = 366$ µs

The duty cycle is therefore $D = 366/8000 = 0.04576$.

The pk-pk ripple $= \frac{366\,(250 - 4 - 7.44)}{350} = 249$ A

(d)



If the converter is operated in the 4-quadrant mode, all the GTOs are in operation. We find the duty cycle is given by

$$E_{LL} = E_H\,(2D - 1) \qquad [21.24]$$

Thus, neglecting the voltage drops in the GTOs and diodes, we have 7.44 = 250 (2 D – 1), and so D = 0.51488. As a result, Q1 and Q4 are on for 0.51488 × 8000 = 4119 μs and off for 3881 μs. If we assume the average armature current is 620 A, the volt-seconds across the armature inductance during the "on" time = $4119 \times (250 - 7.44) \times 10^{-6}$ = 0.9991V·s. The resulting increase in current is

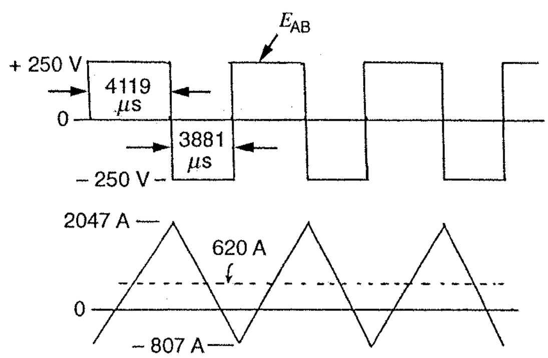
$$\Delta I = \frac{0.9991}{350 \times 10^{-6}} = 2854 \text{ A}$$

Next, when Q3 and Q4 are conducting, the voltage across the inductance is (250 + 7.44) = 257.44 V during 3881 μs. As a result, the decrease in current is $\frac{257.44 \times 3881 \times 10^{-6}}{350 \times 10^{-6}} = 2854$ A.

The peak-to-peak ripple is 2854 A, which means that the armature current fluctuates between

$\left(620 + \frac{2854}{2}\right) = 2047$ A and $\left(620 - \frac{2854}{2}\right) = -807$ A.

The fluctuations are shown below.



The current ripple is much larger, and serious vibrations at 2 × 125 Hz = 250 Hz would be produced. Furthermore, the high current peaks would produce overheating and commutation problems.

22-20 a. $E = Blv = 0.5 \times (0.05 \times 2 \times 200) \times (\pi \times 0.1 \times 840/60)$ = 44 V

b. 44 V

c. $f = pn/120 = 2 \times 840/120 = 14$ Hz

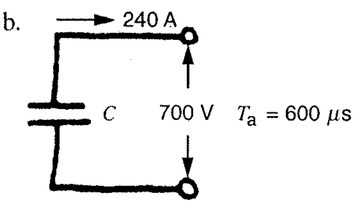
d. 14 Hz

e. $P = EI = 44 \times 5 = 220$ W

f. $T = \frac{9.55\,P}{n} = \frac{9.55 \times 220}{840} = 2.5$ N·m

22-21 a. The sharp current pulses cannot be furnished by the line and consequently, when the chopper "closes", the current in the diode is not immediately cut off.

b.



$$i = C\frac{\Delta E}{\Delta t}$$

$$240 = C \times \frac{50}{600 \times 10^{-6}}$$

$\therefore C = 2880\,\mu$F

22-22 a. At standstill, $E_0 = 0$ V

$E_d = RI = 0.4 \times 60 = 24$ V

b. $E_d = 1.35\,E\,(1 - \cos\,(120 - \alpha))$

$24 = 1.35 \times 240\,(1 - \cos\,(120 - \alpha))$

$24 = 324 - 324 \cos\,(120 - \alpha)$

$\cos\,(120 - \alpha) = 0.926$

$\alpha = 97.8°$

c. $P = E_d I_d = 24 \times 60 = 1440$ W

$\phi_d = 30 + \alpha/2$

$= 30 + (97.8/2)$

$= 78.9°$

$Q = P \tan \phi_d$

$= 1440 \tan 78.9$

$= 7340$ var

INDUSTRIAL APPLICATION – CHAPTER 22

22-23

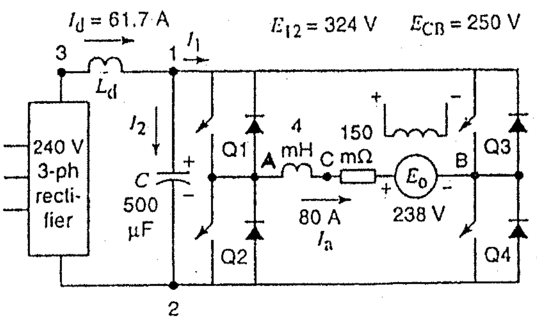


Figure 22.21a

The 4 mH inductance opposes the decrease in the 80 A current, and so C is (+) with respect to A. This is in accordance with Lenz's law.

23-24 The increase in current = 6000 × 0.003 = 18 A

the current after the 3 ms = 80 + 18 = 98 A

voltage between terminals A and C $= L\dfrac{\Delta I}{\Delta t}$

$= 0.004 \times \dfrac{18\text{ A}}{0.003\text{ s}}$

$= 24\text{ V}$

22-25 The current flowing into the capacitor = 153 – 140 = 13 A. The capacitor is charging up, because I_2 flows into the (+) terminals.

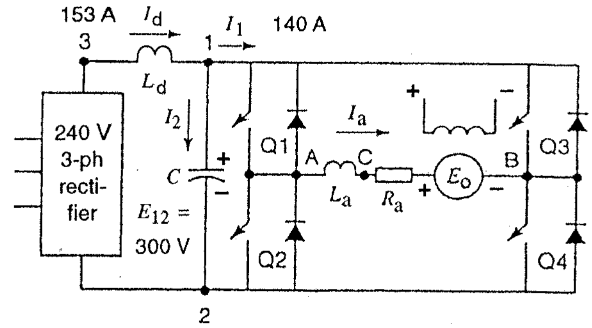


Figure 22.20

$$I_2 = C\frac{\Delta E}{\Delta t} \quad \therefore \frac{\Delta E}{\Delta t} = \frac{I_2}{C} = \frac{13}{7000 \times 10^{-6}} = 1857\text{ V/s}$$

22-26 $I_a = +5$ A which means the current is flowing in the direction of the arrow, i.e. from A to C in the inductance L_a. Using KVL, we can write $E_{AB} - E_o - I_a R_a + E_{CA} = 0$
$\therefore 60 - 65 - 5 \times 1.2 + E_{CA} = 0$

$E_{CA} = +11$ V which means that C is (+) with respect to A. Consequently I_a is decreasing.

$$E_{CA} = L_a\frac{\Delta I_a}{\Delta t} \quad \therefore \frac{\Delta I_a}{\Delta t} = \frac{E_{CA}}{L_a} = \frac{11}{20 \times 10^{-3}} \quad \frac{\Delta I_a}{\Delta t} = 550\text{ A/s}$$

CHAPTER 23

23-3 A 16 pole 60 Hz motor has a synchronous speed of:

$n_s = 120\ f/p = 120 \times 60/16 = 450$ r/min.

To run at 225 r/min, the voltage and frequency must be reduced in the ratio 225/450 = 1/2

$E = 460/2 = 230$ V $\qquad f = 60/2 = 30$ Hz

23-4 a. $n_s = \dfrac{120\,f}{p} = \dfrac{120 \times 60}{4} = 1800$ r/min

from Fig. 23-19:

$n_{FL} = 0.9\ n_s = 0.9 \times 1800 = 1620$ r/min

b. $P_m = 2$ hp $\div$ 1.34 = 1.49 kW

$$T_m = \frac{9.55\ P_m}{n} = \frac{9.55 \times 1490}{1620} = 8.78 \text{ N·m}$$

23-5 The top output frequency is about 50 % of the input frequency = 50 % × 60 = 30 Hz.

$n = 120\ f/p = 120 \times 30/6 = 600$ r/min

23-7 The induction motor cannot produce the reactive power needed by the inverter.

23-8 No, there is no difference at all. This plainly shows that a cycloconverter is essentially a dual converter that can function as a rectifier or inverter for any voltage polarity and any current flow.

23-9 The sheapest solution is probably the cycloconverter, because it is inherently a low-frequency source.

23-10 a. At no-load, $n \approx n_s \approx 160$ r/min

$$f = \frac{pn}{120} = \frac{6 \times 160}{120} = 8 \text{ Hz}$$

b. 42 V

23-11 a. $\cos \alpha = 0.8 \qquad \alpha = 36.9° \qquad I$ lags E by 36.9°

rectifier for: 180 – 36.9 = 143.1° (see Fig. 23-3)

$$t = \frac{143.1}{360} \times \frac{1}{8} = 50 \text{ ms}$$

b. inverter is for 36.9°

$$t = \frac{36.9}{360} \times \frac{1}{8} = 50 \text{ ms}$$

23-12 a. $T_{FL} = 8$ N·m

$n_{FL} = 0.9 \times 1200 = 1080$ r/min

$$T_{FL} = \frac{9.55\ P_{FL}}{n_{FL}} \Rightarrow 8 = \frac{9.55\ P_{FL}}{1080}$$

$\therefore P_{FL} = 904.7 \times 1.34/1000 =$ 1ùù2 hp

b. $T_2 = 175\ \% \times \left(\dfrac{120}{240}\right)^2 = 43.75\ \%$ of T_1

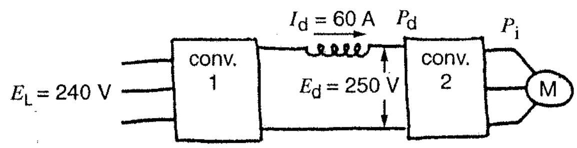
$= 0.4375 \times 8 = 3.5$ N·m

[calculating T_2 is more precise than a reading from curve (2)]

$n_2 = 60\ \%$ of $n_s = 0.6 \times 1200 = 720$ r/min

$$P = \frac{T \times n}{9.55} = \frac{3.5 \times 720}{9.55} = 263.9 \times \frac{1.34}{1000} = 0.35 \text{ hp}$$

23-13 a.



$P_d = P_i = 250 \times 60 = 15$ kW

$P_m = 15 \times 0.82 = 12.3 \times 1.34 = 16.5$ hp

b. $E_d = 1.35\ E \cos \alpha$

$250 = 1.35 \times 240 \times \cos \alpha \quad \therefore \alpha = 39.5°$

c. displacement angle $\phi_D = \alpha$

$Q = P \tan \alpha$ (eq. 21-14)

$= 15 \tan 39.5°$

$= 12.4$ kvar

23-15 a. $I_d = 422$ A current in each diode = 422/3 = 140.7 A

b. $I_{peak} = 422$ A

c. PIV = $\sqrt{2}\ E = \sqrt{2} \times 400 = 566$ V

d. $f = \dfrac{np}{120} = \dfrac{700 \times 8}{120} = 46.7$ Hz

23-17 a. The rated output power = 0.25 hp = 186.6 W.

The rated (100 %) torque is:

$T = 9.55\ p/n = 9.55 \times 186.6/1620 = 1.1$ N·m

$s = (1800 - 1620)/1800 = 0.1$

$P_m = (1 - s)P_r \quad \therefore 186.6 = (1 - 0.1)P_r$

$\therefore P_r = 207.3$ W $\quad P_{jr} = 207.3 - 186.6 = 20.7$ W

b. When the voltage drops to half its rated value, the torque is 43.74 % of the rated torque (see solution of Problem 23-12). Hence $T = 0.4375 \times 1.1 = 0.48$ N·m. The corresponding speed = 60% × 1800 = 1080 r/min.

$P_m = nT/9.55 = 1080 \times 0.48/9.55 = 54.4$ W

$s = (1800 - 1080)/1800 = 0.4$

$P_m = (1 - s)P_r$

$54.4 = (1 - 0.4)P_r$

$\therefore P_r = 90.7$ W

$P_{jr} = P_r - P_m$

$= 90.7 - 54.4$

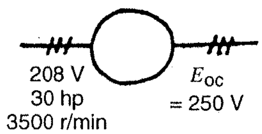
$= 36.3$ W

c. The rotor is much hotter at the reduced voltage (b). Compare 36.3 W against 20.7 W.

23-18 810 r/min is 810/1800 = 0.45 or 45 % of n_s at this speed, the torque exerted by the fan is 25 % of rated torque (see Fig. 23-19). The motor must therefore develop a torque of 0.25 × 1.1 = 0.275 N·m. When full voltage is applied, the motor torque at 45 % speed is about 140 % of rated torque (see Fig. 23-12).
The motor torque is: 1.4 × 1.1 = 1.54 N·m.

The voltage must be reduced to $460 \times \sqrt{\frac{0.275}{1.54}} = 194$ V.

23-19 a.

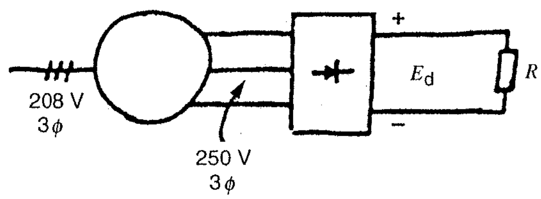


The synchronous speed is obviously 3600 r/min

b. $T_m = 9.55\, P_r/n_s$ Eq. 13-9

$40 = 9.55\, P_r/3600$ $\therefore P_r = I^2R = 15$ kW

c.



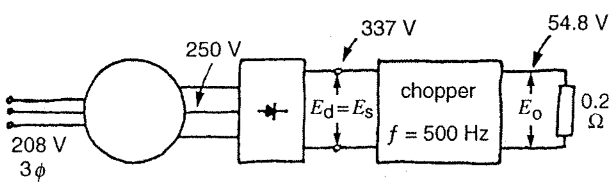
The rotor line voltage is about the same as on open-circuit, ie 250 V

$\therefore E_d = 1.35\, E = 1.35 \times 250$ V = 337 V

d. Neglecting the effect of the rotor winding resistance, we have 15 kW dissipated in the external rheostat:

$E^2/R = W$ $\frac{337^2}{R} = 15\,000$ $\therefore R = 7.6\ \Omega$

23-20



$E_o = E_s f T_a$ (Eq. 21-14) 54.8 V = 337 × 500 T_a
also $E_o^2/0.2 = 15\,000$ $T_a = 335$ μs
$\therefore E_o = 54.8$ V

23-21 a. n_s at 60 Hz = 1200 r/min. The slip speed to develop full torque = 1200 − 1100 = 100 r/min. The slip speed is again 100 r/min when the motor develops full torque at 200 r/min.

$\therefore n_s = 200 + 100 = 300$ r/min

$f = (300/1200) \times 60 = 15$ Hz;

$E_{a4} = (300/1200) \times 460 = 115$ V

b. I_a peak = $60\sqrt{2}$ = 85 A. Each thyristor, at one point in time, carries a current of 85 A.

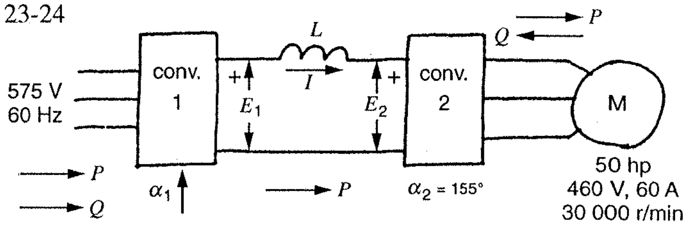
23-22 The motor current flows in rectangular pulses of 120° duration. The peak current must be equal to I, the dc link current. We have $I^2 \times 120 = I_a^2 \times 180 = 26^2 \times 180$

$\therefore I = 26\sqrt{180/120} = 31.8$ A

23-23 The slip at full torque is 1800 − 1750 = 50 r/min n_s for 400 r/min = 400 + 50 = 450 r/min

$f = \left(\frac{450}{1800}\right) \times 60 = 15$ Hz; $E = \frac{450}{1800} \times 200 = 50$ V

23-24



a. $f = pn/120 = 2 \times 30\,000/120 = 500$ Hz

b. $E_d = 1.35\, E \cos \alpha$
$= 1.35 \times 460 \times \cos 155$
$= -563$ V
(The negative sign indicates inverter action)

c. $E_d = 1.35\, E \cos \alpha$
$563 = 1.35 \times 575 \cos \alpha_1$
$\alpha_1 = 43.5°$

d. The dc power must equal the active ac power
$\therefore 563\, I = 41\,500$
$I = 73.7$ A

e. frequency = 6 × 60 = 360 Hz

f. frequency in E_2 = 6 × 500 = 3000 Hz

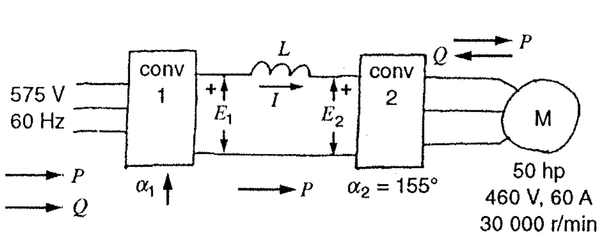
g. $\cos \alpha_1 = \cos 43.5° = 0.725$
$\therefore$ Power factor on 60 Hz line = 72.5 %

h. Effective value of $I_s = 0.816\, I_d$
$= 0.816 \times 73.7 = 60$ A

i. see figure above for power flow. Both converters absorb reactive power from their respective ac lines. The is never any reactive power in the dc link.

INDUSTRIAL APPLICATION – CHAPTER 23

23-24



(a) $f = pn/120 = 2 \times 30\,000/120 = 500$ Hz

(b) $E_d = 1.35\, E \cos \alpha$
$= 1.35 \times 460 \times \cos 155$
$= -563$ V
(The negative sign indicates inverter action)

(c) $E_d = 1.35\, E \cos \alpha$
$563 = 1.35 \times 575 \cos \alpha_1$
$\alpha_1 = 43.5°$

(d) The dc power must equal the active ac power
$\therefore\ 563\, I = 41\,500 \quad I = 73.7$ A

(e) frequency $= 6 \times 60 = 360$ Hz

(f) frequency in $E_2 = 6 \times 500 = 3000$ Hz

(g) $\cos \alpha_1 = \cos 43.5° = 0.725$
$\therefore$ Power factor on 60 Hz line = 72.5 %

(h) Effective value of $I_s = 0.816\, I_d$
$= 0.816 \times 73.7 = 60$ A

(i) see figure above for power flow. Both converters absorb reactive power from their respective ac lines. There is never any reactive power in the dc link.

23-25 Rated torque $T = 9.55\, p/n$ (3.5)
$= 9.55 \times (5 \times 746)/1760$
$= 20.2$ N·m

The starting torque is equal to 2 pu when rated voltage is applied.

Thus, the starting torque $= 2 \times 20.2 = 40.4$ N·m

(a) The torque varies as the square of the applied voltage.The kick-start torque is therefore
$T = (0.8)^2 \times 40.4 = 25.8$ N·m
The initial torque $= (0.4)^2 \times 40.4 = 6.4$ N·m

(b) Due to the thyristor voltage drop, the power loss = 3.5 watts/ampere × 6.2 A = 21.7 W.

23-26 (a) Net tangential force per pole = (9.6 + 14.4 + 9.6 – 4.8) = 28.8 N

(b) The currents in the bars are proportional to the respective bar voltages. The current in bar 4 is 240 A, and the flux density = 0.8 T.

Hence the tangential force on bar 4 is
$F = BLI = 0.8 \times 0.1 \times 240 = 19.2$ N.
Similarly, the force on bars 3 and 5 is
$F = 0.693 \times 0.1 \times 208 = 14.4$ N.
The force on bars 2 and 6 is
$F = BLI = 0.4 \times 0.1 \times 120 = 4.8$ N.
The total force per pole $= 19.2 + 2\,(14.4 + 4.8)$
$= 57.6$ N.

23-27 (a) Synchronous speed $= 120\, f/p = 120 \times 60/8$
$= 900$ r/min.
Also $f_2 = sf$ (13.3)
$40 = s \times 60$ and so slip $s = 0.666$
The slip speed $= 0.666 \times 900 = 600$ r/min
Rotor speed $= 900 - 600 = 300$ r/min

(b) The net tangential force per pole = 28.8 N (see solution to Problem 23-26). The torque is

$$T = 28.8 \times \frac{140}{2}\ \text{mm} \times \frac{1}{1000} \times 8\ \text{poles} = 16.1\ \text{N·m}$$

23-28 Figure 23-44a shows a total torque for the 3 phases of 6.5 N.m. The torque increases as the square of the voltage. Thus, to obtain 10.1 N·m the voltage must be raised to $26.5 \times \sqrt{\dfrac{10.1}{6.5}} = 33.0$ V (line-to-neutral). The line voltage must therefore be $33.0\sqrt{3} = 57.2$ V.

23-29 (a) $P_o = 14$ MW $\quad P_i = \dfrac{14}{0.973} = 14.388$ MW
dc field losses = 84 kW = 0.084 MW.
Active power to stator $= 14.388 - 0.084$
$= 14.30$ MW
Because power factor = 1, $S = 14.30$ MVA

$$\text{stator current} = \frac{14.30 \times 10^6}{1000\sqrt{3}} = 8258\ \text{A}$$

(b) The motor has two windings, therefore current in each 3-phase winding = 4129 A.

(c) The legend states that one cycloconverter is used for each winding, and 36 thyristors are used. The thyristors are arranged similar to the connections shown in Fig. 23-10. At one moment or another, each thyristor will be carrying the full peak current in one phase. This peak is $4129\sqrt{2} = 5839$ A.

23-30 (a) The speed ranges from 50 r/min to 140 r/min. The motor have 14 poles. The frequency ranges from

$$f = \frac{p\,n_s}{120} = \frac{14 \times 50}{120} = 5.83 \text{ Hz to } \frac{14 \times 140}{120} = 16.33 \text{ Hz.}$$

(b) $S = 10\ 260$ kVA,
$P = S \times \cos\theta = 10\ 260 \times 0.75 = 7695\ k$

$$Q = \sqrt{10\ 260^2 - 7695^2} = 6786 \text{ kvar}$$

23-30 (c) The reason is that cycloconverters draw a lot of reactive power even when they drive a unity power factor load.

(d) Rated service speed = 19.5 knots. It is known that 1 knot = 1.15 mi/h. Time to cover 500 miles = 500/(19.5 × 1.15) = 22.3 h.

23-31

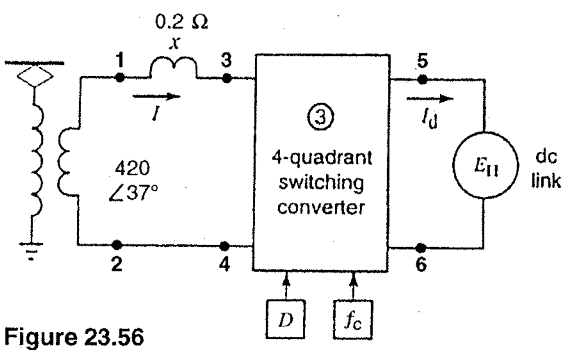


Figure 23.56

(a) Using the circuit solving methodology described in Section 2.35, we write the following KVL:

$E_{21} + j\,x\,I + E_{34} = 0$

$$\begin{aligned} \therefore E_{34} &= E_{12} - jIx = 420\ \angle 37° - j\,(330\ \angle 42°)\ 0.2 \\ &= 420\ (\cos 37 + j \sin 37) - 66.0\,j \\ &\quad (\cos 42 + j \sin 42) \\ &= 335.4 + 252.8\,j - 49\,j + 44.2 \\ &= 379.6 + 203.8\,j = 430.8\ \angle 28.2° \end{aligned}$$

(b) To determine P and Q at the input to the converter, we use the method explained in Section 7.18. The conjugate of I is $I^* = 330\ \angle -42°$. We have $S = E_{34}\,I^*$

$$\begin{aligned} S &= (430.8\ \angle 28.2)\ (330\ \angle -42°) = 142\ 164\ \angle -13.8° \\ &= 142.1\ \angle -13.8 \text{ kVA} = 138 - 33.9\,j \end{aligned}$$

Since $P = +\ 138$ kW the converter absorbs active power

Since $Q = -\ 33.9$ kvar the converter delivers reactive power to the reactor and transformer. The reactor absorbs

$$\frac{330^2 \times 0.2}{1000} = 21.78 \text{ kvar}$$

and the remaining (33.9 – 21.78) = 12.1 kvar is delivered to the transformer.

23-32

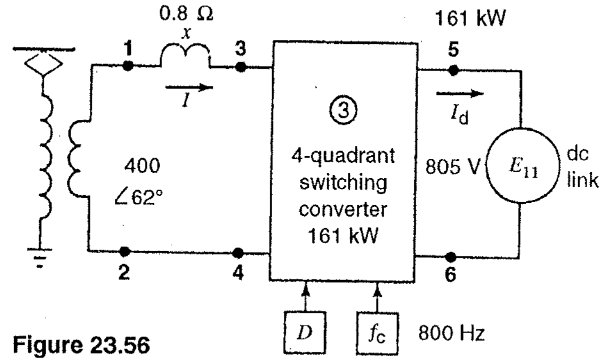


Figure 23.56

(a) $I_d = 161\ 000/805\ \text{V} = 200$ A

(b) Because I is in phase with E_{12} and because losses are neglected, it follows that $I = 161\ 000/400$ V $= 402.5\ \text{A}\ \angle 62°$

(c) $$\begin{aligned} E_{34} &= E_{12} - jIx \\ &= 400\ \angle 62° - j\ (402.5\ \angle 62°) \times 0.8 \\ &= 400\ \angle 62° - 322\,j\ \angle 62° = 513.5\ \angle 23.2° \end{aligned}$$

(d) Peak value of $E_{CD} = 513.5\sqrt{2} = 726.2$ V

$$\text{Amplitude modulation ratio} = \frac{726.2}{805} = 0.902$$

23-33 The 60 Hz ac voltage varies periodically from $+\ 430\sqrt{2}$ to $-\ 430\sqrt{2}$ volts, i.e. between + 608 V and – 608 V. We want to determine D when the voltage is momentarily + 500 V and – 30 V. Using Eq. 21.24 we have

$E_{LL} = E_H\ (2\,D - 1)$

$$500 = 680\ (2\,D - 1) \rightarrow \therefore D = \left(\frac{500}{680} + 1\right)\frac{1}{2} = 0.868$$

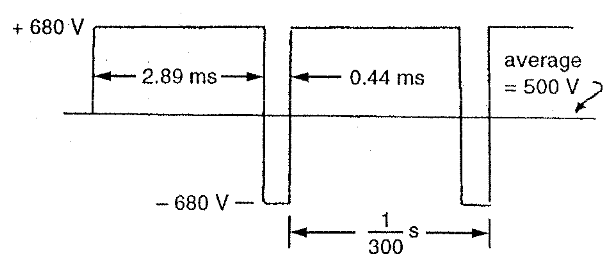
when $E_{LL} = -\ 30$ V

$$-\ 30 = 680\ (2\,D - 1) \rightarrow \therefore D = \left(\frac{-\ 30}{680} + 1\right)\frac{1}{2} = 0.478$$

The pulse shape at 500 V gives an "on" time of

$$0.868 \times \frac{1}{30}\text{ s} = 2.89 \text{ ms}$$

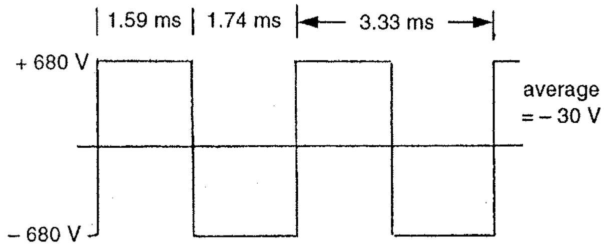
and an "off" time of $\left(\frac{1000}{300} - 2.89\right) = 0.44$ ms. See below



when $D = 0.478$, the "on" time $= 0.478 \times \dfrac{1000}{300}$
$= 1.59$ ms

The "off" time = $\left(\frac{1000}{300} - 1.59\right) = 1.74$ ms.

The pulse shape is shown below



23-34

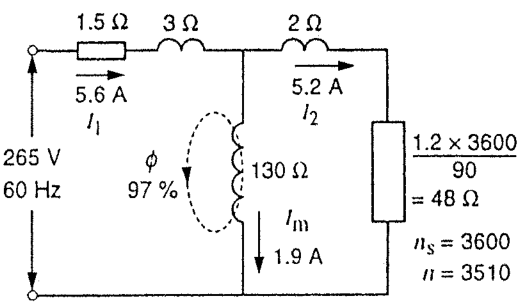
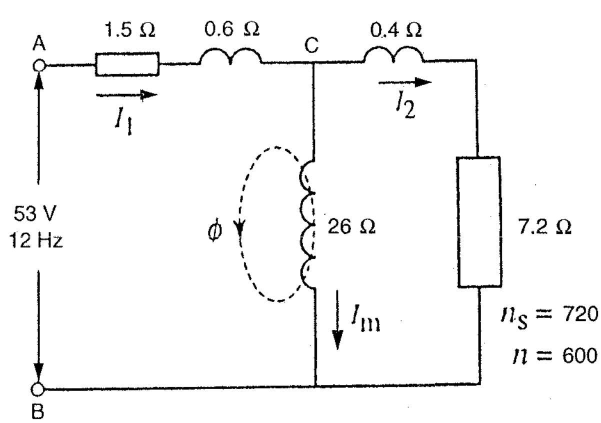


Figure 23.42a

In Fig. 23.42a we are only interested in the resistance and reactance components of the circuit. The voltages and currents shown therein do not come into play. At a frequency of 12 Hz, the reactances are reduced by a factor 60 Hz/12 Hz = 5. The synchronous speed is 3600 ÷ 5 = 720 r/min and the slip speed = (720 – 600) = 120 r/min. The (a) power resistance is = $\frac{1.2\, n_s}{S} = \frac{1.2 \times 720}{120} = 7.2\ \Omega$.

The line-to-neutral voltage = $92/\sqrt{3}$ = 53 V

The resulting equivalent circuit is shown below.



(b) To calculate the stator current I_1, we find the impedance Z_{AB} between terminals A, B.

$$Z_{AB} = 1.5 + 0.6j + \frac{26j\,(7.2 + 0.4j)}{7.2 + 26.4j}$$
$$= 8 + 2.76j = 8.46\ \angle 19°$$

$$I_1 = \frac{E_{AB}}{Z_{AB}} = \frac{53\ \angle 0°}{8.46\ \angle 19°} = 6.26\ \angle{-19°}$$

(c) We will use the power triangle method to calculate I_m

Active power supplied to motor = 53 × 6.26 cos 19
= 314 W

Reactive power to motor = 53 × 6.26 sin 19°
= 108 var

Active power consumed in stator = $6.26^2 \times 1.5$
= 58.8 W

Reactive power absorbed in stator = $6.26^2 \times 0.6$
= 23.5 var

Active power at input to CB = 314 – 58.8 = 255 W

Reactive power at input to CB = 108 – 23.5
= 84.5 var

Apparent power at input to CB = $\sqrt{255^2 + 84.5^2}$
= 269 VA

Voltage between terminals CB = $\frac{269}{|I_1|} = \frac{269}{6.26}$
= 43 V

I_m = 43/26 = 1.65 A

(d) Z of torque-producing branch = $\sqrt{7.2^2 + 0.4^2} = 7.21\ \Omega$

$$I_2 = \frac{E_{CB}}{7.21} = \frac{43}{7.21} = 5.95\ \text{A}$$

(e) $P_r = 5.95^2 \times 7.2 = 255$ W (one phase)

$$\text{Torque} = \frac{9.55\, P_r}{n_s} = \frac{9.55 \times 255}{720} \times 3$$
= 10.1 N·m (3 phases)

23-35

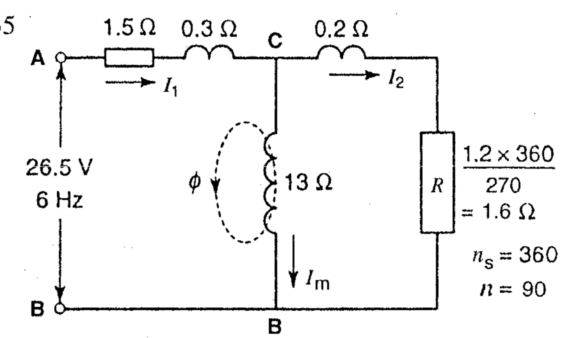


Figure 23.44a

The impedance between terminals A and B is

$$Z_{AB} = 1.5 + j\,0.3 + \frac{(1.6 + j\,0.2)\,j\,13}{1.6 + j\,13.2}$$

After some vector algebra we find $Z_{AB} = 3.15 \angle{+}\,12.7°$

Hence $I_1 = \dfrac{26.5 \angle 0°}{3.15 \angle{+}\,12.7} = 8.53 \angle{-}\,12.7°$

Here are the complete calculations using an alternative power triangle methodology. Suppose $I_2 = 10$ A.

Active power in $R = 10^2 \times 1.6 = 160$ W

Reactive power in 0.2 Ω = $10^2 \times 0.2 = 20$ var

Apparent power to the right of CB = $\sqrt{160^2 + 20^2} = 161$ V

$$E_{CB} = \frac{161}{I_2} = \frac{161}{10} = 16.1 \text{ V}$$

Hence $I_m = \dfrac{16.1}{13\,\Omega} = 1.24$ A

Q in 13 Ω = $1.24^2 \times 13 = 20$ var

Reactive power at input to CB = 20 + 20 = 40 var

Active power at input to CB = 160 W

S at input to CB = $\sqrt{160^2 + 40^2} = 164.9$ VA

I_1 at input to CB = $\dfrac{164.9}{E_{CB}} = \dfrac{164.9}{16.1} = 10.2$ A

Reactive power in 0.3 Ω = $10.2^2 \times 0.3 = 31.2$ var

Active power in 1.5 Ω = $10.2^2 \times 1.5 = 156$ W

Total P at input to AB = 156 + 160 = 316 W

Total Q at input to AB = 31.2 + 40 = 71.2 var

Total S at input to AB = $\sqrt{316^2 + 71.2^2} = 323.9$ VA

$$E_{AB} = \frac{323.9}{I_1} = \frac{323.9}{10.2} = 31.76 \text{ V}$$

HOWEVER, the actual value of E_{AB} = 26.5 V consequently all the previously assumed values of I_1, I_2 I_m must be multiplied by 26.5/31.76 = 0.8334.

The actual value of $I_1 = 10.2 \times 0.8334 = 8.51$ A

actual value of $I_2 = 10 \times 0.8334 = 8.34$ A

actual value of $I_m = 1.24 \times 0.8334 = 1.03$ A

$P_r = 8.34^2 \times 1.6 \times 3$ phases = 333.9 W

$$\text{Torque} = \frac{9.55\,P_r}{n_s} = \frac{9.55 \times 333.9}{360} = 8.86 \text{ N·m}$$

Note that the values calculated differ slightly from the answers listed in the book. The reason is that a different methodology was used and the rounding of numbers explains the minuscule difference.

Many instructors prefer the vector algebra solution instead of the above "power triangle" methodology. The following uses this more traditional approach. From KVL we can write:

$$E_{BA} + I_1\,(1.5 + j\,0.3) + E_{CB} = 0$$

$$\begin{aligned} E_{CB} &= E_{AB} - I_1\,(1.5 + j\,0.3) \\ &= 26.5 \angle 0° - (8.53 \angle{-}\,12.7)(1.53 \angle 11.3) \\ &= 26.5 - 13.05 \angle{-}\,1.4° \\ &= 26.5 - 13.05 + j\,0.3188 \\ &= 13.45 \angle 1.36° \end{aligned}$$

To calculate I_m we write the KVL equation

$$E_{CB} = I_m\,(13\,j) = 0$$

$$I_m = \frac{E_{CB}}{13\,j} = \frac{13.45 \angle 1.36°}{13 \angle 90} = 1.03 \angle{-}\,88.6°$$

To calculate I_2 we write the KVL equation

$$E_{CB} - I_2\,(1.6 + j\,0.2) = 0$$

$$I_2 = \frac{E_{CB}}{1.6 + j\,0.2} = \frac{13.45 \angle 1.36°}{1.612 \angle 7.12°} = 8.35 \angle{-}\,5.76°$$

A solution by computer would be executed much more quickly.

CHAPTER 24

24-7 $P = 9.8\,q.h = 9.8 \times 5000 \times 24 = 1\,176\,000\text{ kW} = 1176\text{ MW}$

24-11 a. $1300\text{ km}^3 = 1300\,(\text{km})^3 = 1300\,(1000\text{ m})^3$

$= 1.3 \times 10^{12}\text{m}^3$

$t = 365 \times 24 \times 3600 = 31.536 \times 10^6\text{ s}$

$$\therefore q = \frac{1.3 \times 10^{12}}{31.536 \times 10^6} = 41\,223\text{ m}^3/\text{s} = 41.2 \times 10^3\text{ m}^3/\text{s}$$

b. $P = 9.8\,qh = 9.8 \times 41\,223 \times 100 = 40.4 \times 10^6\text{ kW}$

$= 40\,400\text{ MW}$

c. $1300\text{ km}^3 = 1300\,(\div 1.609)^3\text{ mi}^3 = 312\text{ mi}^3$

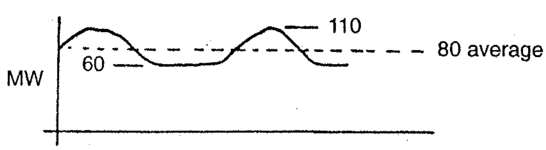
24-12 Energy in 20 kt $= 20 \times 1.167 \times 10^6 \times 3.6 \times 10^6\text{ J}$

$= 8.4 \times 10^{13}\text{ J}$

$P = 1500 \times 10^6\text{ W}$

$$\therefore t = \frac{\text{Energy}}{\text{Poweer}} = \frac{8.4 \times 10^{13}}{1500 \times 10^6} = 56\,000\text{ s} = 15.6\text{ h}$$

24-13



a. base power = 60 MW peak powr = 50 MW

b. base power = 80 MW peak power = 30 MW

24-14 a. $P = S\cos\theta = 6000 \times 0.9 = 5400\text{ MW}$

b. $Q = \sqrt{S^2 - P^2} = \sqrt{6000^2 - 5400^2} = 2615\text{ Mvar}$

c. $\text{water power} = \dfrac{5400}{0.92 \times 0.98} = 5989\text{ MW}$

$p = 9.8\,qh$

$$5989 \times 1000 = 9.8\,q \times \left(\frac{280}{3.28}\right) \qquad \therefore q = 7159\text{ m}^3/\text{s}$$

24-14 $7159\text{ m}^3/\text{s} = 7159 \times 1.308\text{ yd}^3/\text{s} = 9364\text{ yd}^3/\text{s}$

24-16 referring to the modelin Fig. 24-24,

a. 720 MW is 60 times larger. All quantities are multiplied by 60. Thus 60 kg/s of coal is consumed:

$$60\,\frac{\text{kg}}{\text{s}} = \frac{60\,(\div 907)}{(\div 3600 \div 24)}\,\frac{t}{d} = 5715\text{ tons per day}$$

b. According to the model the air intake is 10 times the coal intake ∴ 57 150 tons per day. The material intake is 57 150 + 5715 = 62 865 tons per day. Of this intake, at least 57 150 tons per day must go up the stack

c. Cooling water needed = 60 × 360 = 21 600 kg/s because 1 m^3 weighs 1000 kg, this amounts to 21.6 m^3/s.

24-17 About 2 % of the cooling water needs are drawn from the stream (see Sec. 24-15). This amounts to

$$2\,\% \times 21.6 = 0.43\text{ m}^3/\text{s}.$$

This water evaporates to the atmosphere and cannot be recovered.

24-18 a. $\text{Energy} = 372.5 \times 10^3 \times \dfrac{19}{12} \times 365 \times 24 \times 3600$

$= 1.86 \times 10^{13}\text{ J}$

$= 1.86 \times 10^{13}\,(\div 1000)\,(\div 1.055)$

$= 1.76 \times 10^{10}\text{ Btu}$

b. $E = mc^2$

$1.86 \times 10^{13} = m\,(3 \times 10^2)^2$

$\therefore m = 2.07 \times 10^{-4}\text{ kg} = 0.207\text{ g}$

24-19 a. A base load of 6 GW running all year long represents 58 % of the annual energy. The annual energy is therefore:

$$W = \frac{6 \times 10^9 \times 365 \times 24}{0.58} \Big/ 10^{12} = 90.6\text{ T W·h}$$

b. $\text{The peak load} = \dfrac{90.6 \times 10^{12}}{365 \times 24 \times 10^9} = 10.34\text{ GW}$

(compare this with the actual peak of 15 GW as given in Fig. 24-3).

24-20 We can solve this problem by considering the amount of heat transferred in 1 s. Thus, D_2O through the 12 heat exchangers in 1 s = 7.7 t = 7700 kg.

$Q = mc\Delta t$ Eq. 3-17

$= 7700 \times 4560 \times (294 - 249) = 1580\text{ MJ}$

The heat transferred in 1 s is 1580 MJ

∴ the thermal power transmitted is

$$P_{th} = 1580\text{ MJ/s} = 1580\text{ MW}$$

INDUSTRIAL APPLICATION – CHAPTER 24

24-21 The frequency at 10:09 = 59.97 Hz
The frequency at 10:16.5 = 60.0 Hz

(a) Average frequency during the 7.5 minute period
= (60 + 59.97)/2 = 59.985 Hz

(b) Cycles during the 7.5 minute period
= 7.5 × 60 × 59.985 = 26 993

(c) Number of cycles if the frequency had been 60 Hz:
= 7.5 × 60 × 60 = 27 000

(d) Number of cycles lost during the 7.5 minute intervals = 27 000 – 26 993 = 7 cycles

This introduces an error of 7 × 1/60 = 0.116 or about 116 milliseconds, as far as clock time is concerned.

24-22 The speed of an inducion motor is proportional to the frequency. The ratio of the powers at 60 Hz and 59.97 Hz is

$$\frac{P_{60}}{P_{59.97}} = \left(\frac{n_1}{n_2}\right)^3 = \left(\frac{60}{59.97}\right)^3 = 1.0015$$

Thus $P_{59.97} = \frac{10\ 000\ \text{hp}}{1.0015} = 9\ 985$ hp

The power dropped by 15 hp.

24-23 $P = 9.8\ qh$ (24.1)

$q = 270$ ft³/min $= 270 \div 27 \div 1.308$ m³/min
$= 7.645$ m³/min $= 0.1274$ m³/s

$h = 55$ ft $= 55 \div 3.28 = 16.7$ m.

$P = 9.8 \times 0.1274 \times 16.7 = 20.8$ kW

$80\ \% \times 20.8 = 16.6\ \text{kW} = \frac{16.6 \times 1000}{746} = 22$ hp

Hence a 20 hp motor operating as an asynchronous generator would be satisfactory. However, the turbine speed is determined by hydraulic considerations and a gear box or pulleys may be needed to couple the motor to the turbine.

24-24 35 mi/h = 35 ÷ 2.237 m/s = 15.65 m/s
(2.237 taken from conversion charts)

$P_a = 0.6\ v^3 = 0.6 \times 15.65^3 = 2300$ W/m²

Power that can be extracted = 24% × 2300
= 552 W/m²

24-25 Wind speed = 45 km/h = 45 × 27.8 ÷ 100 m/s
= 12.51 m/s

$P_a = 0.6\ v^3 = 0.6 \times 12.51^3 = 1175$ W/m²

Available power = 1175 × 25% = 293.6 W/m²

Area swept by propeller blades

$$A = \pi r^2 = \pi \times \left(\frac{1.5}{2}\right)^2 = 1.77\ \text{m}^2$$

Power of turbine = 1.77 × 293.6 = 520 W

24-26 a. From Eq. 3.5 $P = \frac{nT}{9.55}$

$$3 \times 10^6 = \frac{16.1 \times T}{9.55}$$

$$T = 1.779 \times 10^6\ \text{N·m} = 1780\ \text{kN·m}$$

b. $3\ \text{MW} = 3 \times 10^6\ \text{W} = \frac{3 \times 10^6}{746} = 4021$ hp

24-27 a. Apparent power $S = P$/power factor
= 750 W/0.86 = 872 kVA

b. $I = S/E\sqrt{3} = 872\ 000/690\sqrt{3} = 730$ A

c. Reactive power absorbed by generator

$$Q = \sqrt{S^2 - P^2} = \sqrt{872^2 - 750^2} = 445\ \text{kvar}$$

The capacitors must furnish this reactive power, to reach unity power facror.

24-28 a. Net power to grid
420 × 98.8% × 94.6% × 98.6% = 387 kW

b. Overall efficiency $= \frac{387}{420} = 0.921 = 92.1\%$

24-29 Synchronous speed $n = \frac{120\ f}{P} = \frac{120 \times 57.6}{4} = 1728$ r/min

Speed of rotation of blades = 1728 ÷ 45 = 38.4 r/min

24-30 Height of tower = 75 m = 75 × 3.28 ft = 246 ft
Number of storeys = 246 ÷ 10 = 24.6

24-31 Generator speed of rotation = 22.75 × 80 = 1820 r/min
Frequency of power grid = 60 Hz

Synchronous speed $n = \frac{120\ f}{P} = \frac{120 \times 60}{4} = 1800$ r/min

The generator operates with 4 poles because the power exceeds 200 kW.

Slip speed = 1820 – 1800 = 20 r/min

Slip = 20/1800 = 0.0111

Approximate power from rotor to stator $P_r = 672$ kW

Power delivered to rotor $= sP_r = 0.0111 \times 672 = 7.46$ kW or about 7.5 kW

24-32 28 mi/h = 28 ÷ 2.237 m/s = 12.5 m/s
From Fig. 24.41 we obtain power = 2500 kW = 2.5 MW

24-33 a. Length of blades = 44 m
Circumference described by tips = $2\pi r = 2\pi \times 44$
= 275.5 m
Speed of tips = 276.5 × 19.1 = 5280 m/min
= 5280 ÷ 60 m/s = 88 m/s
88 m/s = 88 × 3.6 = 317 km/h
b. Tip speed/wind speed = 88/17.5 = 5.0

24-34 Combined power = 11 turbines × 750 kW = 8250 kW
Households that can be furnished = 8250 ÷ 5 = 1650

24-35 Total theoretical energy = 40 MW × 24 h × 365 days
= 350 400 MWh

$$\text{Ratio} = \frac{89\,000}{350\,400} = 0.254 = 25.4\%$$

24-36 Area swept out by turbine blades
$A = \pi r^2 = \pi \times 44^2 = 6082 \text{ m}^2$
Total power in wind per square metre
$P_a = 0.6\, v^3 = 0.6 = 0.6 \times 12.5^3 = 1172 \text{ W/m}^2$
Total power $P = P_a A = 1172 \times 6082$
$= 7.13 \times 10^6 \text{ W} = 7.13 \text{ MW}$
Power developed by turbine at 12.5 m/s = 2.5 MW

$$\text{Ratio} = \frac{2.5 \text{ MW}}{7.13 \text{ MW}} = 0.35 = 35\%$$

24-37 a) Synchronous speed is the speed of the flux created by the stator.

$$n = \frac{120\,f}{P} = \frac{120 \times 50}{4} = 1500 \text{ r/min}$$

b) Speed of rotor = speed of blades × gearbox ratio
= 20 × 90 = 1800 r/min
c) Slip speed = 1800 – 1500 = 300 r/min
d) Slip = 300 r/min/1500 r/min = 0.2
e) Mechanical power input to rotor = 3 MW
Electrical power output of stator + rotor = 3 MW
Power from rotor to stator = P_r
Power from rotor to converter (5) = sP_r
Consequently, $P_r + sP_r = 3$ MW
But $s = 0.2$ and so

$$P_r + 0.2\,P_r = 3 \text{ MW}$$
$$1.2\,P_r = 3 \text{ MW}$$
$$P_r = 2.5 \text{ MW}$$

f) Power of rotor converter (5)

$$sP_r = 0.2 \times 2.5 = 0.5 \text{ MW}$$

g) Power carried by each converter = 0.5 MW
h) $\text{Ratio} = \dfrac{0.5 \text{ MW}}{3 \text{ MW}} = 0.1666 = 16.7\%$
i) The frequency in the rotor is

$$f_2 = sf = 0.2 \times 50 = 10 \text{ Hz.}$$

That is the frequency imposed by converter (5).

CHAPTER 25

25-4 a. No, the voltages are about the same.

b. Yes there is a phase angle difference between the respective line-to-neutral voltages at the opposite ends of the line.

25-7 745 mi = 745 × 1.609 × 1000 m = 1.2×10^6 m

No. of towers = $\dfrac{1.2 \times 10^6}{480}$ = 2500 (approx.)

25-9 According to Table 25-D, I = 750 A.

The resistivity of copper is lower and so it can carry more current for the same heating effect and consequent temperature rise.

25-10 a. $P = EI\sqrt{3} = 735\,000 \times 2000\sqrt{3} \times (2 \text{ lines}) = 5092$ MW

b. current per sub-conductor = 2000/4 = 500 A

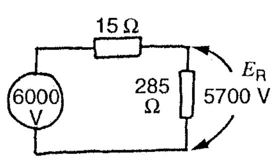
length of each sub-conductor = 350 × 1.609 = 563 km

resistance per sub-conductor = 0.045 × 563 = 25.3 Ω

total I^2R loss for the 24 sub-cond = $500^2 \times 25.3 \times 24$ = 151.8 MW

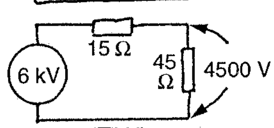
c. percent loss = (151.8/5092) × 100 = 2.98 ≈ 3 %

25-11 a.



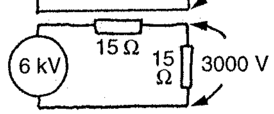
$E_R = \left(\dfrac{6000}{285 + 15}\right) \times 285$ = 5700 V

$P = E_R^2/R = 5700^2/285$ = 114 kW

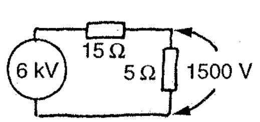


E_R = (6000/60) × 45 = 4500 V

$P = 450^2/45$ = 450 kW



$P = 3000^2/15$ = 600 kW



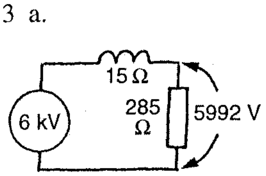
E_R = (6000/20) × 5 = 1500 V

$P = 1500^2/5$ = 450 kW

b. See graph below in solution 25-13.

25-12 Because the circuit elements are all resistive, E_R is always in phase with E_s.

25-13 a.

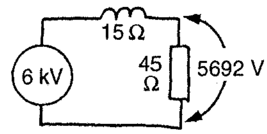


Z of circuit = $\sqrt{15^2 + 285^2}$ = 285.39 Ω

I = (6000/285.39) = 21.02 A

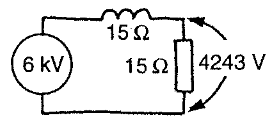
E_R = 21.02 × 285 = 5992 V

$P = E_R^2/R_{load} = \dfrac{5992^2}{285}$ = 126 kW



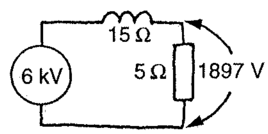
$E_R = \dfrac{6000}{\sqrt{15^2 + 45^2}} \times 45 = 5692$ V

$P = 5692^2/45$ = 720 kW



$E_R = \dfrac{6000}{\sqrt{15^2 + 15^2}} \times 15 = 4243$ V

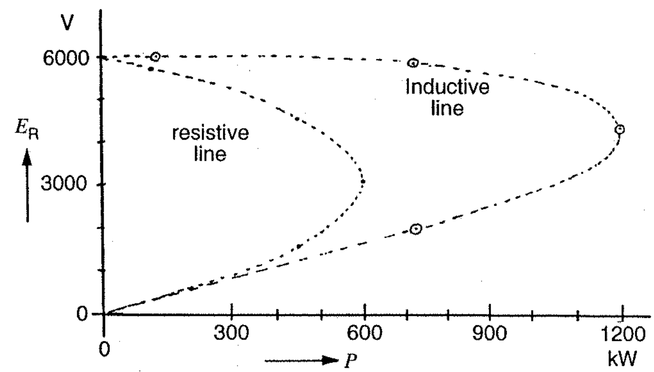
$P = 4243^2/15$ = 1200 kW



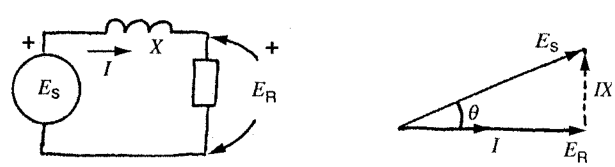
$E_R = \dfrac{6000}{\sqrt{15^2 + 5^2}} \times 5 = 1897$ V

$P = 1897^2/5$ = 720 kW

b. Graph of E_R vs P: see below.



25-14



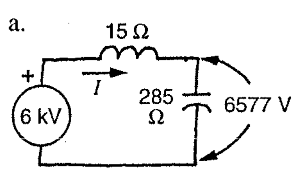
According to the phasor diagram E_R lags behind E_s.

We have I = 5692/45 = 126.5 A

length of phasor IX = 126.5 × 15 = 1897 V

∴ θ = arc tan 1897/5692 = 18.4°

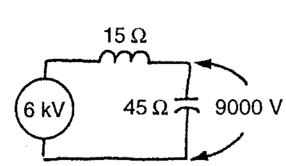
25-15 a.



Z = 285 – 15 = 260 Ω

I = 6000/120 – 23.08 A

E_R = 23.08 × 285 = 6577 V

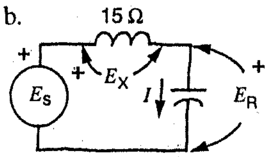


Z = 45 – 15 = 30 Ω

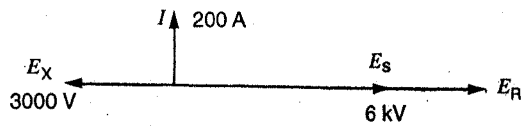
I = 6000/30 – 200 A

E_R = 200 × 45 = 9000 V

b.

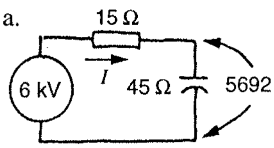


I = 200 A leading E_R by 90°
E_X = 200 × 15 = 3000 V leading I by 90°



E_R is in phase with E_S.

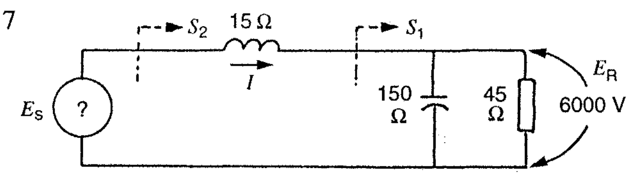
25-16 a.



$Z = \sqrt{15^2 + 45^2} = 47.43\ \Omega$
$I = 6000/47.43 = 126.5$ A
$E_R = 126.5 \times 45 = 5692$ V

b. No, a capacitor only raises the voltage for inductive lines, or lines that have some inductance in addition to their resisance.

25-17



a. $Q_c = 6000^2/150 = -240$ kvar (the minus sign only indicates that the power is capacitive).

b. Power to load = $6000^2/45$ = 800 kW = P

$S_1 = \sqrt{P^2 + Q_c^2} = \sqrt{800^2 + 240^2} = 835{,}2$ kVA

$I = S_1/E_R = 835\ 200/6000 = 139.2$ A.

c. $Q_L = I^2 X_{Line} = 139.2^2 \times 15 = +290.65$ kvar

d. reactive power at inupt line is

$Q_s = Q_L + Q_c = 290.65 - 240 = +50.65$ kvar

because Q_s is positive the line absorbs reactive power from the source.

e. active power input to line = 800 kW

$\therefore\ S_2 = \sqrt{P^2 + Q_s^2} = \sqrt{800^2 + 50.65^2} = 801.6$ kVA

f. $E_s = S_2/I = 801\ 600/139.2 = 5759$ V

g. If E_s = 6 kV, the value of E_R increases in proportion:

$$E_R = \frac{6000}{5759} \times 6000 = 6251\ \text{V}$$

Note that the capacitor raises the termnal voltage considerably. In effect, without the capacitor the voltage was found to be 5692 V (see Problem 25-13).

The power is $P = 6251^2/45 = 868$ kW

25-18 We can use standard circuit techniques to calculate the phase angle, but we shall use another approach that is sometimes useful.

The power factor at the load terminals is:

$\cos\theta_1 = P/S_1 = 800/835.2 = 0.958 \quad \therefore\ \theta_1 = 16.7°$

The current I leads E_R by 16.7° because of the capacitor.

The power factor at the source is

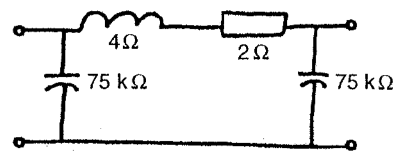
$\cos\theta_2 = P/S_2 = 800/801.6 = 0.998 \quad \therefore\ \theta_2 = 3.6°$

We found that Q_s was positive, indicating that I lags behind E_s (by 3.6°) We conclude that E_R lags behind E_s by an angle $\theta = 3.6 + 16.7 = 20.3°$

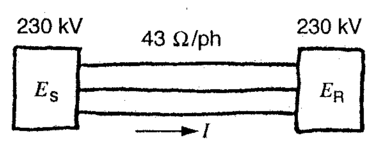
25-19 There are 8 sections:

$R = 8 \times 0.25 = 2\ \Omega \quad X_L = 8 \times 0.5 = 4\ \Omega$

The capacitances are effectively in parallel and so the resul-ting capacitance is $X_c = 300/8 = 37.5$ kΩ. However, it is distributed at each end ∴ the circuit is therefore as follows:

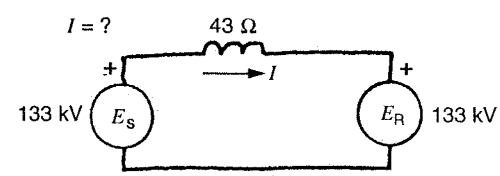


25-21 a.



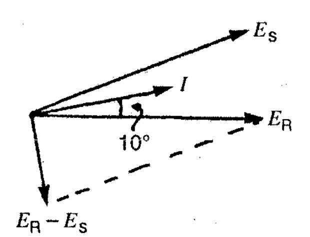
$$P = \frac{E^2}{X}\sin\delta = \frac{230^2}{43}\sin 20° = 421\ \text{MW}$$

b.



The phase angle between E_s and E_R = 20° also we write the circuit equation:

$-E_s + j\,43\,I + E_R = 0 \quad \therefore\ I = j\,(E_R - E_s)/43$



Letting $E_R = 133\ \angle 0$ kV we have $E_s = 133\ \angle{+20}$ kV

$E_R - E_s = 46.2\ \angle{-80°}$ kV $\therefore\ I = \dfrac{46\ 200}{43} = \angle{+10°}$
$= 1074\ \angle{+10°}$ A

25-21 c. Reactive power absorbed by the line:

$Q = 3\, I^2 X_L = 3 \times 1074^2 \times 43 = 148.8$ Mvar

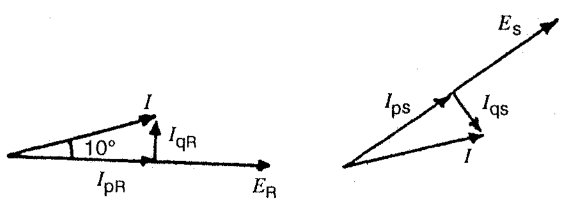
d. The phase angle between E_s and I and E_R and I is 10°; the power factor at the sender and receiver is therefore the same $\cos\theta = \cos 10 = 0.9848$.

The apparent power for both is

$S = P/\cos\theta = 421/0.9848 = 427.5$ MVA

$Q_s = Q_R = \sqrt{427.5^2 - 421^2} = 74.3$ Mvar

Both the sender and receiver deliver reactive power to the line. In other words, they are both reactive sources. This can be seen by observing the component of I that is in quadrature with E_R. It leads E_R but according to Sec 7-6 and noting the polarities, it is evident that E_R supplies reactive power. As regards E_s, the current lags by 10°. The quadrature current with respect to E_s lags behind E_s, making E_s a source of reactive power.



I_{qR} leads E_R $\quad$ I_{qs} lags E_s

I_{pR} in phase with E_R

ALTERNATIVE SOLUTION

We can calculate the value of P and Q at both ends of the transmission line using phasor algebra entirely. Thus, we have: $I = 1074\ \angle{+10}$

Power delivered by E_s is:

$S_s = E_s I^* = 133\ \angle{+20} \times 1074\ \angle{-10°}$

[I^* = conjugate I]

$= 142.8\ \angle{+10} = 142.8 \cos 10 + 142.8\, j \sin 10$

$= 140.6 + j\,24.8$ (per phase [MW])

$= 421.8 + j\,74.4$ [MW] total

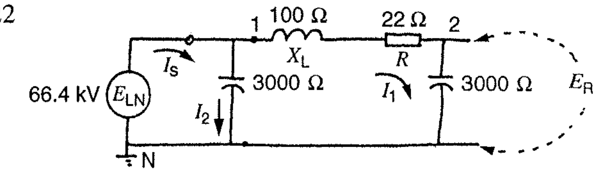
Thus E_s supplies 421.8 MW of active power and 74.4 Mvar of reactive power. As regards E_R, the power is:

$S_R = E_R I^* = 133\ \angle 0 \times 1074\ \angle{-10} = 142.8\ \angle{-10}$

which, by inspection gives S_R $140.6 - j\,24.8$ per phase

It follows from the assigned polarities and current direction, that E_R receives 421.8 MW and delivers 74.4 Mvar.

25-22



$E_{LN} = 115/\sqrt{3} = 66.4$ kV $\quad R = 0.11 \times 200 = 22\ \Omega$

$X_L = 0.5 \times 200 = 100\ \Omega \quad X_c = 300\,000/200 = 1500\ \Omega$

$\therefore 2\, X_c = 3000\ \Omega$

a. The equivalent circuit of one phase is given above

b. $Z_{1N} = \sqrt{22^2 + (3000 - 100)^2} = 2900\ \Omega$ $\quad$ Eq. 2-14

$I_1 = 66\,400/2900 = 22.9$ A

$E_{2N} = E_R = 22.9 \times 3000 = 68\,700$ V $= 68.7$ kV

$\therefore E_{Line} = \underline{119\text{ kV}}$

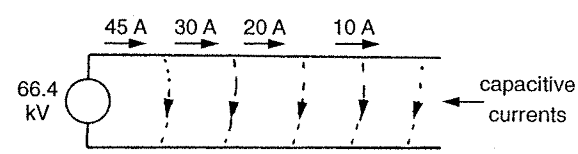
c. $I_s = I_1 + I_2$ (phasor sum). However, current I_1 lags almost exactly 90° behind E_{LN} and so we can add I_1 and I_2 arithmetically.

$I_2 = 66\,400/3000 = 22.1$ A

$\therefore I_s = 22.1 + 22.9 = \underline{45\text{ A}}$

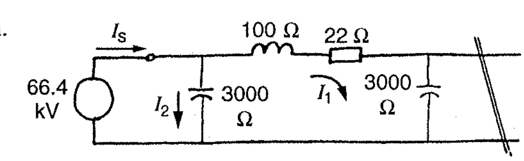
d. $Q = E_s I_s \times 3 = 66.4 \times 10^3 \times 45 \times 3 = 9$ Mvar

e. The I^2R loss is $3\, I_1^2 R = 3 \times 22.9^2 \times 22 = \underline{34.6\text{ kW}}$



Note that in the actual transmission line the current decreases progressively from 45 A to zero as it is shunted by the invisible line capacitance. The I^2R loss per unit length increases progressively as we approach the source. However, the total distributed I^2R loss is very close to the value calculated in (e) above.

25-23 a.



$I_1 = 66\,400/\sqrt{100^2 + 22^2} = 648.5$ A

b. This current is less than the ampacity of the conductors (750 A, Table 25D).

CHAPTER 26

26-3 $P = I^2R \quad \therefore 200 = 10\,000^2R \quad R = 2 \times 10^{-6} = 2\ \mu\Omega$

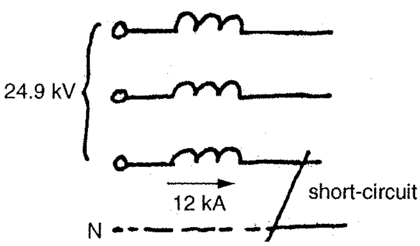
26-6 $E = IR = 50\,000 \times 0.35 = 17\,500$ V

26-8 a. $E_{peak} = 34.5\sqrt{2} = 48.8$ kV
b. According to the graph, $I = 0$

26-9 a. $I_{(peak)} = 12\,000$ A
b. $P_{(peak)} = 12\,000 \times 80\,000 = 960$ MW
c. Energy $= 960 \times 10^6 \times 5 \times 10^{-6} = 4800$ J

26-11 Switches 5 and 7 must be open.

26-12



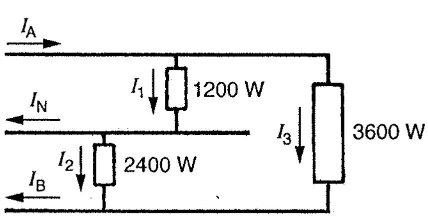
If a short circuit occurs near the substation, the line-to-neutral voltage appears across the reactor

$$\therefore X_L \text{ must} = \frac{24\,900}{\sqrt{3} \times 12\,000} = 1.2\ \Omega$$

$$L = X_L/2\pi f = 1.2/2\pi \times 60 = 3.18 \text{ mH}$$

Note that if a phase-to-phase short occurs the voltage across two reactors in series is 24.9 kV. The short-circuit current is then. $I_{sc} = 24.9/2 \times 1.2 = 10.4$ kA which is within the OCB rating.

26-13 We have: $I_A = I_1 + I_3 \qquad I_B = I_2 + I_3$



$$I_1 = \frac{1200}{120} = 10 \text{ A} \quad I_2 = \frac{2400}{120} = 20 \text{ A} \quad I_3 = \frac{3600}{240} = 15 \text{ A}$$

a. $I_A = I_1 + I_3 = 25$ A $\qquad I_B = 35$ A

b. $I_{neutral} = I_N = I_1 - I_2 = -10$ A or simply 10 A.

The negative value has no significance here because we are dealing with effective ac currents.

c. Total power supplied by the MV line = 1200 + 2400 + 3600 = 7200 W. $\therefore$ line current $= \dfrac{7200}{14\,400} = 0.5$ A

26-14 The MV lines must supply the same apparent power as that absorbed by the LV line. Thus,

$$I = S/E\sqrt{3} = \frac{420\,000}{24\,900\sqrt{3}} = 9.74 \text{ A.}$$

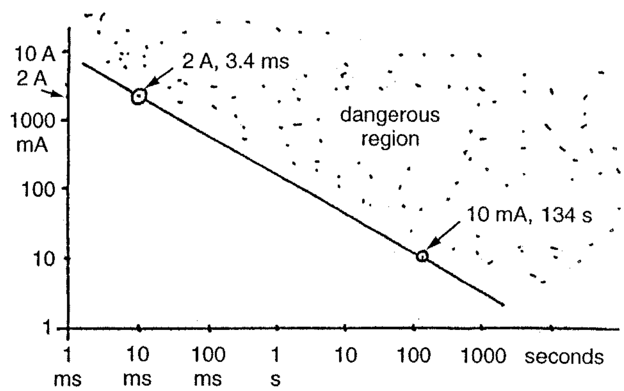
26-15 $I = \dfrac{116}{\sqrt{t}} \quad \therefore \quad t = \left(\dfrac{116}{I}\right)^2$

for $I = 10$ mA $\quad t = \left(\dfrac{116}{10}\right)^2 = 134$ s

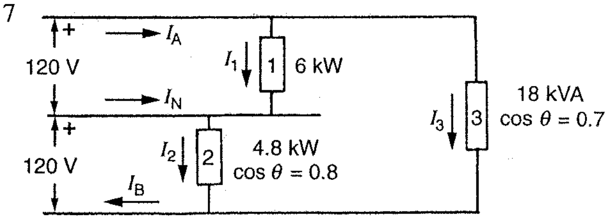
for $I = 2$ A $\quad t = \left(\dfrac{116}{2000}\right)^2 = 3.4$ ms

owing to the wide range covered both in current and time, we use a logarithmic scale over. The I vs t curve is then a line.

a. 300 mA for 10 ms is not dangerous
b. 30 mA for 2 min (120 s) is hazardous



26-17



Load analysis: Load 1: $P_1 = 6$ kW, $Q_1 = 0$

Load 2: $P_2 = 4.8$ kW; $S_2 = \dfrac{4.8}{0.8} = 6$ kVA; $Q_2 = 3.6$ kvar

Load 3: $S_3 = 18$ kVA; $P_3 = 18 \times 0.7 = 12.6$ kW;

$$Q_3 = \sqrt{18^2 - 12.6^2} = 12.85 \text{ kvar}$$

$$I_1 = \frac{S_1}{120} = \frac{6000}{120} = 50 \text{ A } \angle 0°$$

$$I_2 = \frac{S_2}{120} = \frac{6000}{120} = 50 \text{ A } \angle -36.87°$$

$$I_3 = \frac{S_3}{240} = \frac{18\,000}{240} = 75 \text{ A } \angle -45.57°$$

26-17 a. We can solve for I_A and I_B either by drawing the phasors to scale and adding them according to the equations: $I_A = I_1 + I_3$; $I_B = I_2 + I_3$ and $I_N = I_2 - I_1$ or we can solve them mathematically, as follows:

$$I_A = I_1 + I_3 = 50 \angle 0 + 75 \angle{-45.57}$$
$$= 50 + 75\,(\cos(-45.75) + j\sin(-45.57))$$
$$= 50 + 52.5 - j\,53.6 = 102.5 - j\,53.6$$
$$= 115.6 \angle{-27.6°}\ \text{A}$$

$$I_B = I_2 + I_3 = 50 \angle{-36.87} + 75 \angle{-45.57°}$$
$$= 50\,(0.8 - j\,0.6) + 52.5 - j\,53.6$$
$$= 40 - j\,30 = + 52.5 - j\,53.6$$
$$= 92.5 - j\,83.6 = 124.7 \angle{-42.1°}\ \text{A}$$

$$I_N = I_2 - I_1 = (40 - j\,30) - 50 = -10 - j\,30$$
$$= 31.6 \angle{-108.4}\ \text{A}$$

Note that I_N is not zero, even if $I_1 = I_2 = 50$ RMS. The reason is that I_1 and I_2 are not in phase.

b. $P_1 + P_2 + P_3 = 23.4$ kW = active power in MV line

$Q_1 + Q_2 + Q_3 = (3.6 + 12.85) = 16.45$ kvar in MV line

$\therefore\ S_{tot} = \sqrt{16.45^2 + 23.4^2} = 28.6$ kVA

$\therefore\ I_{Line} = 28\,600/14\,400 = 2$ A

c. $\cos\theta = P/S = 23.4/28.6 = 0.818 = 81.8$ % lagging

26-18 For M1: $S_1 = 50$ kVA; $P_1 = 50 \times 0.5 = 25$ kW

$Q_1 = \sqrt{50^2 - 25^2} = 43.3$ kvar

For M2: $S_2 = 160$ kVA; $P_2 = 160 \times 0.8 = 128$ kW

$Q_2 = \sqrt{160^2 - 128^2} = 96$ kvar

The 3 single-phase loads consume $3 \times 30 = 90$ kW $= P_3$

Total $P = P_1 + P_2 + P_3 = 25 + 128 + 90 = 243$ kW

Total $Q = Q_1 + Q_2 = 43.3 + 96 = 139.3$ kvar

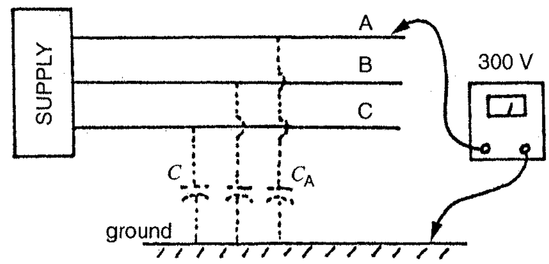
Total $S = \sqrt{243^2 + 139.3^2} = 280$ kVA

a. I per line = current in each winding $= \dfrac{280\,000}{208\,\sqrt{3}} = 777$ A

b. $I = 777 \times \dfrac{208}{2400} = 67.3$ A

$\cos\theta = P/S = 243/280 = 86.8$ %

26-19



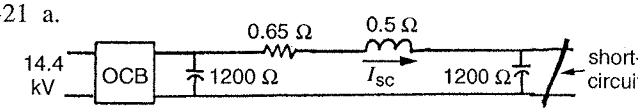
The distributed capacitance of the transmission line makes an invisible capacitve connection between the three lines and ground. The voltage across each "capacitor" is $600/\sqrt{3} = 346$ V.

When a voltmeter is connected between say, phase A and ground, it is in parallel with C_A. The voltmeter leads phase A slightly, and so the voltage it reads will be less than 346 V. The problem states 300 V, which is reasonable.

26-20 The folowing steps are followed:

1. Trip the 25 kA MV circuit breaker (No 14) on the secondary side. This removes the load from the transformer, but the primary windings are still excited.
2. Open the MV disconnect to positively isolate the secondary side of the transformer from any line voltage.
3. Open the motorized disconnect (No 8) on the HV side. It is able to interrupt the exciting current.
4. Close grounding switch 11 ensuring that the HV terminals are definitaly at ground potential.

26-21 a.



Line $R = 0.13 \times 5 = 0.65$ Ω

Line $X_L = 0.1 \times 5 = 0.5$ Ω

Line $X_C = 3000/5 = 600$ Ω $\therefore$ 1200 Ω at each end

$E_{LN} = 24.9/\sqrt{3} = 14.4$ kV

b. $Z = \sqrt{0.65^2 + 0.5^2} = 0.82$ Ω

$I_{sc} = 14\,400/0.82 = 17.5$ kA

Note that the capacitance has no appreciable effect on the calculation of the short-circuit current.

c. Yes, a line reactor is needed even for a short-circuit occurring at the very end of the line.

CHAPTER 27

27-2

minimum charge:	5.00
first 100 kW·h @ 5 ¢	5.00
next 200 kW·h @ 3 ¢	6.00
remainder (920 – 300) = 620 @ 2 ¢	12.40
Total	$ 28.40

27-5

$ 3 × 150 kW	$ 450
(100 h × 150 kW) = 15 000 kW·h @ 4 ¢ =	$ 600
remaining kW·h = (36 000 – 15 000) = 21 000	
21 000 kW·h @ 2 ¢/kW·h =	$ 420
Total	$ 1470

27-6 a. The capacitors would not have changed the maximum demand, because they do not affect the real power drawn by the factory.

b. The billing demand would drop.

27-7 At 7:30, first pointer is at 2 MW, second at 3 MW (no change from readings at 7:00). Average power between 7:30 and 7:45 is (7 × 5 + 2 × 5 + 4 ×5)/15 = 4.33 MW. At 7:45 both pointers are at 4.33 MW. Average power between 7:45 and 8:00 is obviously 4 MW. At 8:00, the first pointer has dropped to 4 MW, but the second is at 4.33 MW.

(Compare this with 4.17 MW registered by the 30-min demand meter. A shorter demand interval always results in a higher demand, unless the pointer is absolutely constant).

27-8 a. $(300\,000/2 \times 10^6) \times 26\,500 = 3975$ GW·h

b. $\frac{40}{1000} \times 3975 \times 10^6 = 159$ million dollars

27-9 a. $P = 75$ kW

$S = P/\cos\theta = 75/0.72 = 104$ kVA

$Q = \sqrt{104^2 - 75^2} = 72$ kvar

b. Q_{Line} after capacitor is installed = 52 kvar

$S = \sqrt{75^2 + 52^2} = 91$ kVA $\quad P = 75$ kW

c. The line current is proportional to S decrease in $S = (104 - 91) = 13$ kVA

Percent decrease = (13/104) × 100 = 12.5 %.

27-10 a. $P = 160$ kW $S = 160/0.55 = 291$ kVA

$Q = \sqrt{291^2 - 160^2} = 243$ kvar.

The plant absorbs 243 kvar, and so we must install 243 kvar to bring the power factor to unity.

b. The S drawn from the line $= \frac{160}{0.9} = 178$ kVA

Q drawn from line $= \sqrt{178^2 - 160^2} = 78$ kvar

Q absorbed by the plant = 243 kvar

Q to be supplied by capacitors: 243 – 78 = 165 kvar

decrease in installed capacity = 243 – 165 = 78 kvar

percent decrease = (78/243) × 100 = 32 %

(The cost is directly proportional to the kvars).

27-11 a. $\frac{4000}{1.34} \times \frac{1}{.96} = 3109$ kW drawn from the line

cost/hour = 3109 × (15/1000) = $ 46.64 per hour

b. If efficiency is 97 %, cost/h $= \frac{96}{97} \times 46.64 = \$\ 46.16$, a saving of 48¢/h.

Annual saving = 0.48 × 24 × 365 = $ 4205

27-12 a. ($ 5 + 20 × 0.05)/20 = 0.3 = 30 ¢/kW·h

b. The minimum possible rate is 2 ¢/kW·h

∴ cost = 2 ¢ × 1.2 kW × 1 h = 2.4 ¢

27-13 115 000 Btu is equivalent to

115 000 (× 1.055) (÷ 1000) (÷ 3.6) = 33.7 kW·h

We can only use 35 % of the available heat energy = 0.35 × 33.7 = 11.8 kW·h

cost per gallon = 32/42 = $ 0.7619 = 76.2 ¢

∴ cost per kilowatthour $= \frac{76.2}{11.8} = 6.45$ ¢

27-15 10 r/min: the capacitor absorbs no active power.

27-16 10 turns = 10 × 3 = 30 W·h in one minute

= 30 × 60 = 1800 W·h in 1 hour = 1800 W.

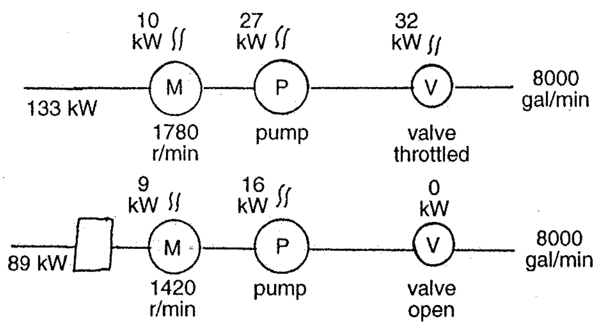
27-17 a. For a given speed, if the flux decreases by 0.5 %, the induced voltage drops by 0.5 %, and the induced current also falls by 0.5 %. Because the braking torque depends upon the product $\phi \times I$, the new torque is 0.995 × 0.995 = 0.99 at its original value. However, the motor torque is therefore 1 % less than it was originally. In other words, the disc turns at the same speed, for a load that is now only 99 % of what it was originally. In other words, a 0.5 % reduction in the flux, makes the meter read 1 % higher.

b. No change.

27-18 Maximum error $= 800 \times \frac{0.7}{100} = \pm\ 5.6$ kW·h

INDUSTRIAL APPLICATION – CHAPTER 27

27-19 To evaluate the savings, we will only compare the inverter drive with the throttled condition.



(a) Throttled conditions:

Energy consumed in 17 h = 17 × 133 = 2261 kW·h

Inverter operation:

Energy consumed in 17 h = 17 × 89 = 1513 kW·h

Energy saved per day = (2261 – 1513) = 748 kW·h

(b) Savings per day = 748 × 0.06 = $ 44.88

Savings per year = 365 × 44.88 = $ 16 380

It is clear that the installation of an inverter drive is feasible.

The purpose of Table 27 D is to show in more detail the kind of losses that are involved. Note in particular the big losses in the valve when it is throttled.

It is also interesting to observe that the motor losses and the pump losses are also reduced by using the lower speed provided by the inverter.

CHAPTER 28

28-5 Based on the model of Fig. 28-4, we have:

a. $E_{AC} = 90 \times \frac{50\,000}{100\,000} \approx 45$ kV

b. $I = 820 \times \frac{600}{1000} \approx 492$ A

28-6 a. Power of pole 1 = 150 kV × 600 A = 90 MW

Power of pole 2 = 150 × 400 = 60 MW

Total power = 90 + 60 = 150 MW

b. Ground current - 600 – 400 = 200 A

28-7 a. E_{d1} = 102 kV; E_{d2} – 96 kV

Line drop = (102 – 96) = 6 kV

I_d = 6000/10 Ω = 600 A

P to network 2 = $E_{d2} \times I_d$ = 96 000 × 600 = 57.6 MW

28-10 a. I = 1200/3 = 400 A

b. PIV is equal to the peak lne voltage. For an output of 50 kW (dc), the line voltage is about 45 kV (see Problem 28-5). ∴ PIV = $45\sqrt{2} \approx 64$ kV.

It is easy to understand that the PIV is equal to $E_{Line} \times \sqrt{2}$, by referring to Fig. 28-2. Suppose Q3 is conducting while Q1 and Q5 are not then both Q1 and Q5 must have a reverse voltage, otherwise they would immediately start conducting. With Q3 shorted (conducting), the voltage across Q1 is E_{12}, and the voltage across Q5 is E_{23}. The maximum value of E_{12} or E_{23} is obviously $E\sqrt{2}$ and this is the maximum possible value of the PIV. A similar reasoning applies to all the other valves.

28-11 Power per pole = 1440/2 = 720 MW

$I = 720 \times 10^6/400\,000$ = 1800 A.

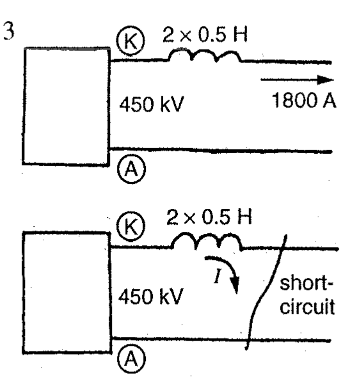
Based on the model of Fig. 28-4, the reactive power

$= \frac{70 \text{ Mvar}}{100 \text{ MW}} \times 1440 \text{ MW} = 1000$ Mvar

28-12 Ground current = 1700 – 1400 = 300 A

$P = 300^2 \times 0.5 = 45$ kW

28-13

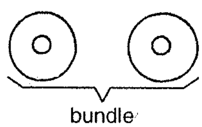


initial conditions

dc voltage drop across the inductors is zero (except for the IR drop) under steady-state conditions.

When the short occurs, the full converter voltage is applied across the two inductors in series (L = 1 H). We have the volt-seconds accumulated after 5 ms = 0.005 × 450 000 = 2250. According to Eq. 2-28, $I = A/L$ = 2250 v·s/1 H = 2250 A. The current has therefore increased by 2250 A and so its value at the end of 5 ms = 2250 × 1800 = 4050 A.

28-14 a.



cross section of 1 strand:

$A_s = \pi d^2/4 = \pi \times 0.16^2/4$

$= 0.0201$ in^2

Total cross section = 0,0201 × 72 × 2 = 2.9 in^2

$A = 1{,}87 \times 10^{-3}$ m^2

For aluminium:

b. $p_{20} = p_0(1 + \alpha_0 t) = 26\,(1 + 0.00439 \times 20) = 28.28$ nΩ·m

550 mi = 550 × 1.609 × 1000 = 884 950 m

$$R = p\frac{l}{A} = 28.28 \times 10^{-9} \times \frac{884\ 950}{1.87 \times 10^{-3}} = 13.38\ \Omega$$

c. $P = I^2R = 1800^2 \times 13.38 = 43.4$ MW

d. IR drop = 13.38 × 1800 = 24 kV

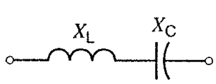
E_{d2} = 450 – 24 = 426 kV

e. P_o = 426 kV × 1.8 kA = 766.8 MW (per pole)

P_i = 450 kV × 1.8 kA = 810 MW

$\therefore\ \eta = P_o/P_i = (766.8/810) \times 100 = 94.7\ \%$

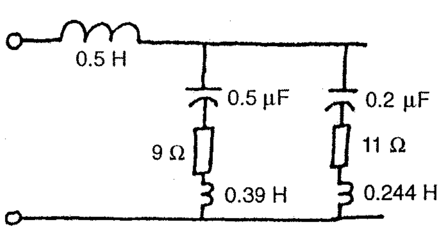
28-15 a.



At resonance $X_L = X_C$

$$\therefore\ 2\,\pi f L = \frac{1}{2\,\pi f C}$$

$$\text{or } f = \frac{1}{2\,\pi\sqrt{LC}}$$



For the 9 Ω filter:

$$f = \frac{1}{2\,\pi\sqrt{0.39 \times 0.5 \times 10^{-6}}} = 360\ \text{Hz}$$

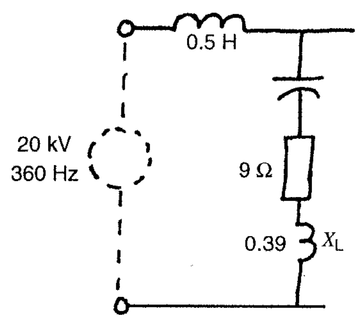
For the 11 Ω filter:

$$f = \frac{1}{2\,\pi\sqrt{0.244 \times 0.2 \times 10^{-6}}} = 720\ \text{Hz}$$

b. Because X_L and X_C cancel, the impedance of the respective filters is 9 Ω and 11 Ω (resistive)

c. The full dc line voltage 150 kV appears across the capacitors. They must therefore be made up of several units in series.

28-16 a. The 10 kV, 360 Hz voltage appears at the output of the converter. Neglecting the presence at the filter tuned to 720 Hz, the circuit is composed of the 0.5 H inductor in series with the 360 Hz filter.



L_{TOTAL} = 0.5 + 0.39 = 0.89 H

$X_L = 2\,\pi \times 360 \times 0.89 = 2013\ \Omega$

$X_C = 1/2\,\pi \times 360 \times 0.5 \times 10^{-6} = 884\ \Omega$

$Z = \sqrt{9^2 + (2013 - 884)^2} = 1129\ \Omega$ (Eq. 2-14)

I_{360} = 20 000/1129 = 17.7 A

b. $E_{360} = IX = 17.7 \times (2\,\pi \times 360 \times 0.5) = 20$ kV

c. $E_{360} = 17.7 \times 9 = 159$ V (across R) = voltage at the input to the second line reactor.

CHAPTER 29

29-2 The losse in the GTO become excessively high at frequencies above 2 kHz.

29-3 23^{rd} hamonics frequency = 23 × 60 = 1380 Hz.

29-4 Each thyristor carries either the positive or negative peak current; it is $684\sqrt{2} = 967$ A.

29-5 A stiff feeder is one that has a low impedance relative to its current-carrying capacity. As a result, the voltage drop from no-load to full-load is low. For example, if a 2000 A feeder operates at a voltage of 69 kV and the voltage drops to 67 kV when it delivers its rated current, it would be considered to be a stiff feeder. Another way of describing a stiff feeder is by the short-circuit current it can deliver relative to its rated current. For example, if a 2000 A feeder can deliver a short-circuit current of 100 000 A (50 times the rated current) it would be in the "stiff feeder" class.

29-6 There is two answers to this problem. If the converter opperates in the rectangular wave mode, the rms line-to-line voltage is given by Equation (23.1) $E_{line} = 0.78\ E_d$ and so we get $E_{line} = 0.78 \times 2400 = 1872\ V \approx 1870\ V$. On the other hand, if the converter operates in PWM mode, with an amplitude ratio $m = 1$, the output voltage is given by Equation 21.36

$$E_{rms} = 0.612\ E_H = 0.612 \times 2400 = 1469\ V \approx 1470\ V$$

29-7 The current can be interrupted in one half cycle or less. The longest interruption time is therefore:

$$0.5 \times \frac{1}{60}\ s = 8.3\ ms.$$

29-10 Effective current = $\sqrt{870^2 + 124^2} = 879$ A. See Eq. 21.10, Section 21.14.

29-11 The maximum possible pead current is obtained when the fundamental and harmonic peaks coincide. The peak current is then $(870\sqrt{2} + 124\sqrt{2}) = 1406$ A.

29-12 $x_a = 2\pi fL \Rightarrow 1.71 = 2\pi \times 60 \times L \quad \therefore L = 4.5\ mH$

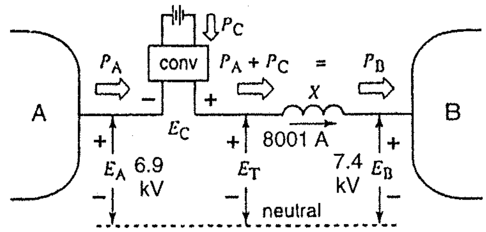
$$x_C \times \frac{1}{2\pi fC} \Rightarrow 12 = \frac{1}{2\pi \times 60 \times C} \quad \therefore C = 221\ \mu F$$

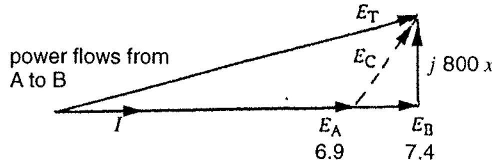
29-13 According to Fig.. 29-6, the peak line voltage is

$$1.1\ E_H = 1.1 \times 3400 = 3740$$

The peak line-to-neutral voltage = $3740/\sqrt{3} = 2159$ V of the sinusoidal component of the rectangular wave.

29-14





The power transfer is maximum when the 800 A current is in phase with E_A and E_B. The KVL equations are

$$-E_T + j\,800\,x + E_B = 0 \quad (1)$$

and

$$-E_A - E_C + E_T = 0 \quad (2)$$

(1) indicates the magnitude and phase of E_T because $E_T = E_B + j\,800\,x$

(2) indicates that $E_C = E_T - E_A$ which is the same as stating that $E_A + E_C = E_T$.

The maximum value of E_C is 1.5 kV. Therefore the maximum possible value of 800 x is given by

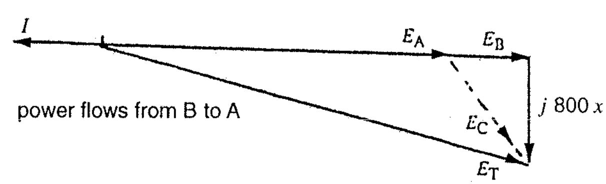
$$800\,x = \sqrt{1.5^2 - (7.4 - 6.9)^2} = 1.41\ kV = 1410\ V.$$

Thus, to obtain the maximum active power transfer, the reactance of the line must be no greater than

$$x = 1410/800 = 1.76\ \Omega.$$

Note that in the mode shown above the converter supplies 800 × (7400 – 6900) = 400 kW and source A provides 6900 × 800 = 5520 kW. Region B receives a total of 7400 × 800 = 5920 kW. The converter also supplies the reactive power $Q = 800^2\,x = 640\,x$ kvar that is absorbed by the line reactance.

It is understood that all powers are per phsse. It is also possible to force power to flow from B to A. To do so, the direction of I must be reversed, becoming 180° out of phase with E_A and E_B, as shown below.



Equation (1) and (2) still apply, which yields the phasor diagram shown. Note that the power reversal is achieved by changing the phase angle of E_C with respect to E_A (and E_B). Under these conditions, region B supplies a maximum of 5920 kW and region A receives a maximum of 5520 kW. Converter absorbs the difference of 400 kW while at the same time it delivers 640 x kvar to the transmission line.

29-16 Active power delivered = 20 MW. Neglecting losses, this power is supplied by the 150 kV line. The apparent power is 20 MW/0.96 = 20.83 MVA. From $S = EI\sqrt{3}$ we obtain $20.83 \times 10^6 = 150\,000\, I\sqrt{3}$ and so $I = 80.2$ A.

29-17 Let the discharge current be I amperes and the discharge time be T hours. The energy delivered by the battery is therefore

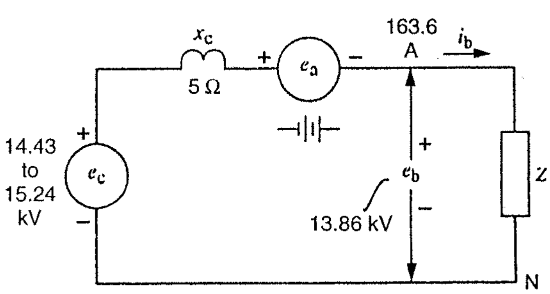
Energy = $240 \times I \times T \times 3600$

wattseconds = $864 \times 10^3\, I\, T$ joules

but energy stand = 40 MJ = 40×10^6 J. Equating the two values, we find $864 \times 10^3\, I\, T = 40 \times 10^6$ hence $I\,T = 46.3$ ampere hours.

29-18 The question is: for how long can the battery supply 6700 kW, knowing that the stored energy is 40 MJ. We have $6700\,000 \times t = 40 \times 10^6$ $\therefore$ $t = 6$ seconds. This is a very short period, but it can still be quite adequate, bearing in mind that voltage sags and interruptions usually last for only a few hundred milliseconds.

29-19



(a)

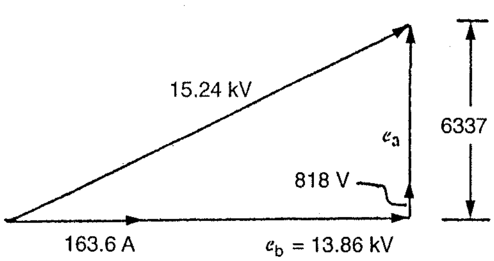
Figure 29-31

e_c = line-to-neutral voltage = $25/\sqrt{3}$ = 14.43 kV to $26.4/\sqrt{3}$ = 15.24 kV.

e_b = line-to-neutral voltage = $24/\sqrt{3}$ = 13.86 kV

$$i_b = \text{line current} = \frac{6.8 \times 10^6}{24\,000\,\sqrt{3}} = 163.6 \text{ A}$$

i_b is in phase with e_b because the power factor is 1.



(a) Because the compensator must not consume or receive any long-term active power, it follows that e_a must be at right angles to i_b. The voltage drop across the 5 Ω line reactance is equal to 163.6 × 5 = 818 V, also at right angles to phasor i_b. e_a is therefore in phase with 818 V. The largest voltage that the compensator must develop is when e_c = 15.24 kV. The phasor diagram is shown onthe left. It is seen that $13.86^2 + (e_a + 0.818)^2 = 15.24^2$.

Consequently, e_a = 5.57 kV.

(b) The rated power = $e_a\, i_b \times 3$ phases
= 5.57 × 163.6 × 3 = 2.7 MVA

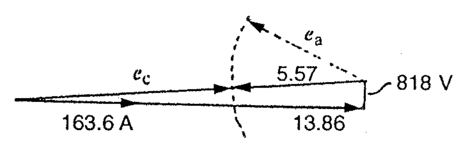
(c) There are two possible answers to this question.

(i) If the compensator cannot absorb or deliver any active power (kilowatts), the minimum e_c voltage is 24 kV, line-to-line. In effect, the compensator generates 818 V which is 180° out of phase with the 818 V drop across the 5 Ω line reactance. Under this condition

$$e_c = \sqrt{13.86^2 + 0.818^2} = 13.88 \text{ kV}$$

$$\text{Line-line} = 13.88\sqrt{3} = 24 \text{ kV}$$

(ii) On the other hand, if the compensator is equipped with a battery, it can deliver both active and reactive power to the system. Having established that the compensator can generate 5.57 kV the minimum line-to-neutral voltage e_a is given by the phasor diagram below. The value of e_c is:

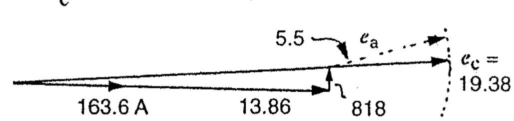


$$e_c = \sqrt{13.86^2 + 0.818^2} - 5.57 = 8.31 \text{ kV}.$$

The corresponding line voltage is:

$8.38\sqrt{3} = 14.4$ kV.

(d) Again, two answers are possible. If the compensator has no energy storage system, the maximum swell is 26.4 kV, as given in the specification. But if there is energy storage, the maximum line-to-neutral voltage for e_c is:



$$e_c = \sqrt{13.86^2 + 0.818^2} + 5.57 = 19.45 \text{ kV}$$

The corresponding line-to-line voltage for e_c is:

$19.45\sqrt{3} = 33.7$ kV.

CHAPTER 30

30-1 a. $I = \sqrt{30^2 + 20^2} = \underline{36.0\text{ A}}$

b. fundamental $f = \underline{60\text{ Hz}}$

c. harmonic $f = 5 \times 60\text{ Hz} = \underline{300\text{ Hz}}$

30-2 $E_H = \sqrt{E^2 + E_F^2} = \sqrt{485^2 - 480^2} = \underline{62.2\text{ V}}$

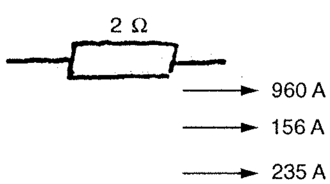
30-3 $\text{TDH} = \frac{E_H}{E_F} = \frac{62.2\text{ V}}{481\text{ V}} = 0.129 = \underline{12.9\ \%}$

30-4 a. $I = \sqrt{I_F^2 + I_5^2 + I_7^2} = \sqrt{960^2 + 156^2 + 235^2} = \underline{1000\text{ A}}$

b. $I_H = \sqrt{I_5^2 + I_7^2} = \sqrt{156^2 + 235^2} = 282\text{ A}$

$\text{TDH} = \frac{282}{960} = 0.294 = \underline{29.4\ \%}$

30-5



a. $P_F = I_F^2 R = 960^2 \times 2\ \Omega = 1843\text{ kW}$

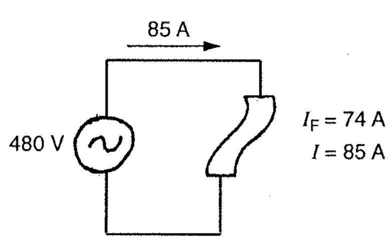
$P_5 = I_5^2 R = 156^2 \times 2\ \Omega = 48.7\text{ kW}$

$P_7 = I_7^2 R = 235^2 \times 2\ \Omega = 110\text{ kW}$

TOTAL = 2002 kW

Note that $P_{TOTAL} = I^2 \times 2\ \Omega = 1000^2 \times 2 = 2000\text{ kW}$
The difference between 2000 kW and 2002 kW is due to rounding.

30-6

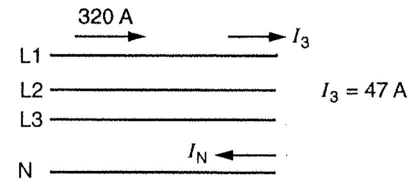


a. Displacement power factor = cos 32° = 0.848 = $\underline{84.8\ \%}$

b. $P = E I_F \cos\theta = 480 \times 74 \times 0.848 = 30\,123\text{ W} = 30.1\text{ kW}$

c. $\text{Total power factor} = \frac{P}{\text{VA}} = \frac{30.1 \times 1000}{480 \times 85} = 0.738 = \underline{73.8\ \%}$

30-7



$I_N = 3 \times 47 = \underline{141\text{ A}}$

30-8 a. $E = 4300\text{ V}$ THD = 26 % = 0.26

$E = \sqrt{E_H^2 + E_F^2}$ (1) $\text{THD} = \frac{E_H}{E_F} = 0.26$ (2)

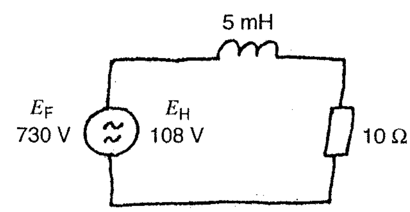
$E^2 = E_H^2 + E_F^2 = (0.26\,E_F)^2 + E_F^2 = 1.0676\,E_F^2$

$4300^2 = 1.0676\,E_F^2$

$E_F = \sqrt{4300^2/1.0676} = \underline{4163\text{ V}}$

b. $E_H = 0.26\,E_F = 0.26 \times 4163 = \underline{1082\text{ V}}$

30-9



a. $X_F = 2\pi f L = 2\pi \times 60 \times 5 \times 10^{-3} = 1.885\ \Omega$

$Z_F = \sqrt{10^2 + 1.885^2} = 10.18\ \Omega$

$I_F = \frac{730\text{ V}}{10.18\ \Omega} = \underline{71.7\text{ A}}$

b. $X_5 = 5 \times 1.885\ \Omega = 9.425\ \Omega$

$Z_5 = \sqrt{10^2 + 9.425^2} = 13.74\ \Omega$

$I_5 = \frac{108\text{ V}}{13.74\ \Omega} = \underline{7.86\text{ A}}$

c. $I = \sqrt{I_F^2 + I_H^2} = \sqrt{71.7^2 + 7.86^2} = \underline{72.1\text{ A}}$

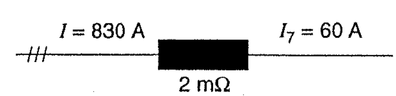
d. $E_R = IR = 72.1 \times 10 = 721\text{ V}$

e. $E_{L(F)} = I_F X_F = 71.7 \times 1.885 = 135.1\text{ V}$

$E_{L(5)} = I_5 X_5 = 7.86 \times 9.425 = 74.1\text{ V}$

$E_L = \sqrt{E_{L(F)}^2 + E_{L(5)}^2} = \sqrt{135.1^2 + 74.1^2} = \underline{154.1\text{ V}}$

30-10



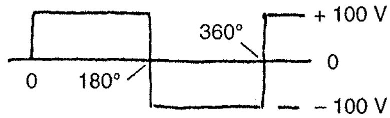
Loss in each line due to 7th H:

$P = I_7^2 R = 60^2 \times 2 \times 10^{-3} = 7.2\text{ W}$

Loss in 3 cables = $3 \times 7.2\text{ W} = \underline{21.6\text{ W}}$

The losses will decrease by 21.6 W when the 3rd H is eliminated.

30-11



H = 1 D = 30°

number of readings for 1 cycle = 12

angle q	amplitude A	A sin Hq	A cos Hq
0	0	0.00	0.00
30	100	50.00	86.60
60	100	86.60	50.00
90	100	100.00	0.00
120	100	86.60	-50.00
150	100	50.00	-86.60
180	0	0.00	0.00
210	-100	50.00	86.60
240	-100	86.60	50.00
270	-100	100.00	0.00
300	-100	86.60	-50.00
330	-100	50.00	-86.60
360	0	0.00	0.00
	SUM	746.41	0.00
		S1	S2
$X = \frac{746.4 \times 30°}{180°} = 124.4$ V			
$Y = 0$			
Peak value in Table 2 A = 127.3			
% error = $\frac{127.3 - 124.4}{127.3} \times 100 = 2.3$ %			

E_F peak = 124.4 V

30-12

		Problem 30-12	
angle q	amplitude A	A sin Hq	A cos Hq
0	0	0.00	0.00
30	33.33	16.67	28.86
60	66.66	57.73	33.33
90	100	100.00	0.00
120	66.66	57.73	-33.33
150	33.33	16.67	-28.86
180	0	0.00	0.00
210	-33.33	16.67	28.86
240	-66.66	57.73	33.33
270	– 100	100.00	0.00
300	– 66.66	57.73	-33.33
330	– 33.33	16.67	-28.86
360	0	0.00	0.00
	SUM	497.58	0.00
		S1	S2
$X = \frac{S_1D}{180} = \frac{497.58 \times 30°}{180°} = 82.9$			
Effective value = $\frac{82.9}{\sqrt{2}} = 58.6$ V			
(EXACT VALUE = 57.3 V)			

30-13 In this problem, we have to calculate the 5^{th} H, so we select the intervals correspondingly. The minimum number of readings = 10 H = 10 × 5 = 50. Using 60 gives an interval $D = 6°$. We draw up a table similar to that in Problem 30-12, but with 60 intervals of 60°.

a. The peak value of the fundamental = 95.4 A

b. Peak value of 3^{rd} H ≈ 0

c. Peak value of 5^{th} H = 18.7 A
(exact value = 19.1 A)

30-14 Use same procedure as in Problem 30-13.
Fundamental peak = 110.2 A 3^{rd} H = 0 5^{th} H = 21.6 A

30-15 a. Effective value of current in Fig. 30-40

$$I_{eff} = \sqrt{\frac{50^2 \times 60° + 100^2 \times 60° + 50^2 \times 60°}{180°}} = 70.7 \text{ A}$$

b. Effective value of fundamental = $\frac{95.41}{\sqrt{2}}$ = 67.5 A

c. Effective $I_H = \sqrt{70.7^2 - 67.46^2}$ = 21.1 A

d. TDH = $\frac{21.1}{67.46}$ = 0.314 = 31.4 %

30-16 a. $X_s = \frac{E_s^2}{S_{sc}} = \frac{24\,000^2}{60 \times 10^6} = 9.6\ \Omega$

b. Short-circuit current

$$I_{sc} = \frac{E}{\sqrt{3}} \times \frac{1}{X_s} = \frac{24\,000}{\sqrt{3} \times 9.6} = 1443 \text{ A}$$

30-17 a. Using same method as in Section 30.18 and using intervals of 6°, we find $I_F = 121\ \text{A}/\sqrt{2}$ = 85.6 A.

b. The 5^{th} H is eliminated $I_5 = 0$
The 3^{rd} H has a peak value of 24.7 A.

30-18 a. Referring to Eq. 2.2, we write for the fundamental
$E = 850 \sin 18\,000\,t = E_m \sin (360\,ft + 0)$
Thus $18\,000\,t = 360\,ft$

and so $f = \frac{18\,000}{360}$ = 50 Hz

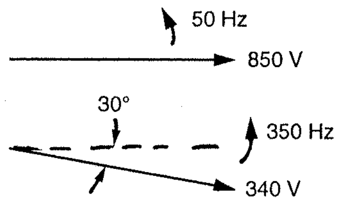
The harmonic freq. = $\frac{126\,000}{360}$ = 350 Hz

b. $E_F = \frac{850}{\sqrt{2}}$ = 161 V, $E_H = \frac{340}{\sqrt{2}}$ = 240 V

c. $E = \sqrt{601^2 + 240^2}$ = 647 V

d. $E_{inst} = 850 \sin 18\,000 \times 0.001$
$= + 340 \sin \left(\frac{126\,000}{1000} + 30°\right)$
$= 850 \sin 18° + 340 \sin (156°)$
$= 262.7 + 338 =$ 601 V

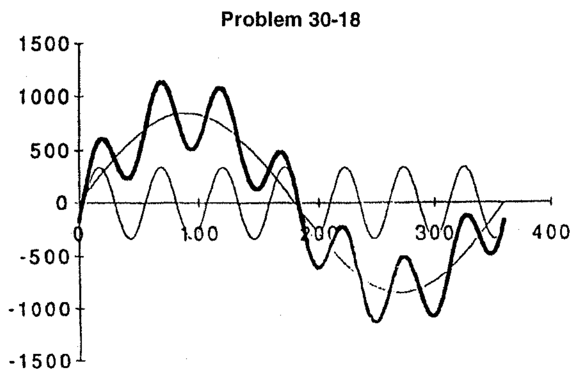
30-18 e.



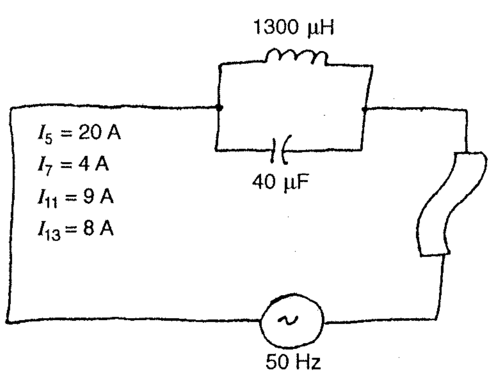
Let us set 18 000 $t = \theta$, then 126 000 $t = 7\ \theta$, and so we can write:

$$E = 850 \sin \theta + 340 \sin (7\ \theta - 30°)$$

The resulting waveshape is shown below.



30-19 a.



H	X_L	X_C	Z
5th	2.04	15.9	2.34
7th	2.86	11.4	3.82
11th	4.49	7.2	11.9
13th	5.30	6.1	40.4

$$Z = \frac{X_C X_L}{X_C - X_L}$$

at $5 \times 50 = 250$ Hz

$X_L = 2\ \pi \times 250 \times 1.3 \times 10^{-3} = 2.04\ \Omega$

$$X_C = \frac{10^6}{2\ \pi \times 250 \times 40} = 15.9\ \Omega$$

$E_5 = 20 \times 2.34 = \underline{46.8\text{ V}}$

$E_7 = 4 \times 3.82 = \underline{15.3\text{ V}}$

$E_{11} = 9 \times 11.9\ \Omega = \underline{107\text{ V}}$

$E_{13} = 8 \times 40.4 = \underline{323\text{ V}}$

b. $E = \sqrt{40.8^2 + 15.3^2 + 107^2 + 323^2} = \underline{344\text{ V}}$

c. Current in the capacitor

$$I_5 = \frac{E_5}{X_C} = \frac{46.8}{15.9} = 2.94\text{ A}$$

$$I_7 = \frac{15.3}{11.4} = 1.34\text{ A}$$

$$I_{11} = \frac{107}{7.2} = 14.9\text{ A}$$

$$I_{13} = \frac{323}{6.1} = 53.0\text{ A}$$

$$I = \sqrt{2.94^2 + 1.34^2 + 14.9^2 + 53.0^2} = 55.1\text{ A}$$

30-20 Using the procedure of section 30.18 we find the following:

Fundamental peak = $\underline{83.5\text{ A}}$

Phase angle = $\underline{-32.4°}$

(Exact values are 84 A, – 32.5°)

30-21 Using the procedure of section 30.18, we find:

a. E_F peak = 50.0 V, $\alpha = \underline{0°}$

effective = $50/\sqrt{2} = \underline{35.36\text{ V}}$

b. dc component = $\underline{31.8\text{ V}}$

c. effective voltage $= \dfrac{E_m}{\sqrt{2}} \times \dfrac{1}{\sqrt{2}} = \dfrac{E_m}{2} = \underline{50\text{ V}}$

d. The evffective voltage is composed of:

(i) dc component 31.8 V

(ii) fundamental component of 35.36 V

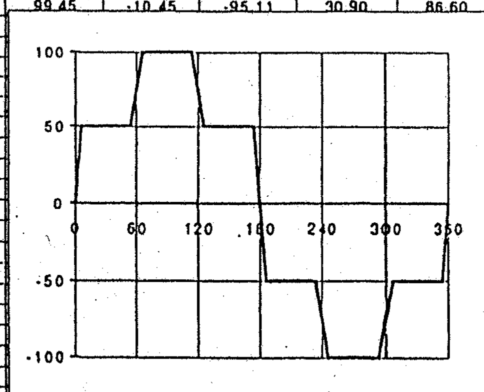
(iii) the harmonics E_H.

Thus: $E^2 = E_d^2 + E_F^2 + E_H^2$

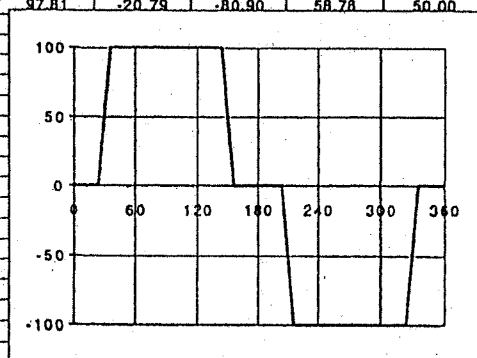
$$50^2 = 31.8^2 + 35.36^2 + E_H^2$$

and so $E_H^2 = 238.4$; $E_H = \underline{15.4}$

PROBLEM 30-13							
			SEE FIG. 30-40				
angle		H = 1	H =1	H = 3	H =3	H = 5	H = 5
degrés	valeur						
q	A	A sin Hq	A cos Hq	A sin Hq	A cos Hq	A sin Hq	A cos Hq
0	0	0.00	0.00	0.00	0.00	0.00	0.00
6	50	5.23	49.73	15.45	47.55	25.00	43.30
12	50	10.40	48.91	29.39	40.45	43.30	25.00
18	50	15.45	47.55	40.45	29.39	50.00	0.00
24	50	20.34	45.68	47.55	15.45	43.30	-25.00
30	50	25.00	43.30	50.00	0.00	25.00	-43.30
36	60	29.39	40.45	47.55	-15.45	0.00	-50.00
42	50	33.46	37.16	40.45	-29.39	-25.00	-43.30
48	50	37.16	33.46	29.39	-40.45	-43.30	-25.00
54	50	40.45	29.39	15.45	-47.55	-50.00	0.00
60	75	64.95	37.50	0.00	-75.00	-64.95	37.50
66	100	91.35	40.67	-30.90	-95.11	-50.00	86.60
72	100	95.11	30.90	-58.78	-80.90	0.00	100.00
78	100	97.81	20.79	-80.90	-58.78	50.00	86.60
84	100	99.45	10.45	-95.11	-30.90	86.60	50.00
90	100	100.00	0.00	-100.00	0.00	100.00	0.00
96	100	99.45	-10.45	-95.11	30.90	86.60	-50.00
102	100						-86.60
108	100						-100.00
114	100						-86.60
120	75						-37.50
126	50						0.00
132	50						25.00
138	50						43.30
144	50						50.00
150	50						43.30
156	50						25.00
162	50						0.00
168	50						-25.00
174	50						-43.30
180	0						0.00
186	-50						43.30
192	-50						25.00
198	-50						0.00
204	-50						-25.00
210	-50						-43.30
216	-50	29.39	40.45	47.55	-15.45	0.00	-50.00
222	-50	33.46	37.16	40.45	-29.39	-25.00	-43.30
228	-50	37.16	33.46	29.39	-40.45	-43.30	-25.00
234	-50	40.45	29.39	15.45	-47.55	-50.00	0.00
240	-75	64.95	37.50	0.00	-75.00	-64.95	37.50
246	-100	91.35	40.67	-30.90	-95.11	-50.00	86.60
252	-100	95.11	30.90	-58.78	-80.90	0.00	100.00
258	-100	97.81	20.79	-80.90	-58.78	50.00	86.60
264	-100	99.45	10.45	-95.11	-30.90	86.60	50.00
270	-100	100.00	0.00	-100.00	0.00	100.00	0.00
276	-100	99.45	-10.45	-95.11	30.90	86.60	-50.00
282	-100	97.81	-20.79	-80.90	58.78	50.00	-86.60
288	-100	95.11	-30.90	-58.78	80.90	0.00	-100.00
294	-100	91.35	-40.67	-30.90	95.11	-50.00	-86.60
300	-75	64.95	-37.50	0.00	75.00	-64.95	-37.50
306	-50	40.45	-29.39	15.45	47.55	-50.00	0.00
312	-50	37.16	-33.46	29.39	40.45	-43.30	25.00
318	-50	33.46	-37.16	40.45	29.39	-25.00	43.30
324	-50	29.39	-40.45	47.55	15.45	0.00	50.00
330	-50	25.00	-43.30	50.00	0.00	25.00	43.30
336	-50	20.34	-45.68	47.55	-15.45	43.30	25.00
342	-50	15.45	-47.55	40.45	-29.39	50.00	0.00
348	-50	10.40	-48.91	29.39	-40.45	43.30	-25.00
354	-50	5.23	-49.73	15.45	-47.55	25.00	-43.30
360	0	0.00	0.00	0.00	0.00	0.00	0.00
		S1=	S2=	S1=	S2=	S1=	S2=
		2862.17	0.00	0.00	0.00	559.81	0.00
		X	Y	X3	Y3	X5	Y5
		95.41	0.00	0.00	0.00	18.66	0.00
		A	atan Y/x	A3	atan Y3/X3	A5	atan Y5/X5
		95.41	0.00	0.00	59	18.66	0
exact values		95.49	0	0	-	19.1	0



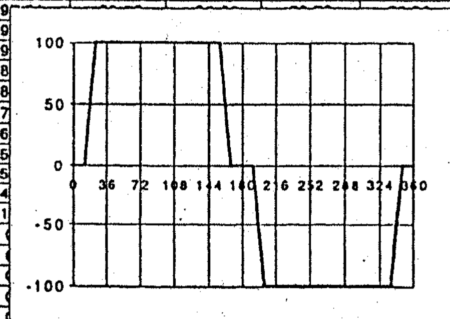
PROBLEM 30-14							
			SEE FIG. 30-41				
angle		H = 1	H =1	H = 3	H =3	H = 5	H = 5
degrés	valeur						
q	A	A sin Hq	A cos Hq	A sin Hq	A cos Hq	A sin Hq	A cos Hq
0	0	0.00	0.00	0.00	0.00	0.00	0.00
6	0	0.00	0.00	0.00	0.00	0.00	0.00
12	0	0.00	0.00	0.00	0.00	0.00	0.00
18	0	0.00	0.00	0.00	0.00	0.00	0.00
24	0	0.00	0.00	0.00	0.00	0.00	0.00
30	50	25.00	43.30	50.00	0.00	25.00	-43.30
36	100	58.78	80.90	95.11	-30.90	0.00	-100.00
42	100	66.91	74.31	80.90	-58.78	-50.00	-86.60
48	100	74.31	66.91	58.78	-80.90	-86.60	-50.00
54	100	80.90	58.78	30.90	-95.11	-100.00	0.00
60	100	86.60	50.00	0.00	-100.00	-86.60	50.00
66	100	91.35	40.67	-30.90	-95.11	-50.00	86.60
72	100	95.11	30.90	-58.78	-80.90	0.00	100.00
78	100	97.81	20.79	-80.90	-58.78	50.00	86.60
84	100	99.45	10.45	-95.11	-30.90	86.60	50.00
90	100	100.00	0.00	-100.00	0.00	100.00	0.00
96	100	99.45	-10.45	-95.11	30.90	86.60	-50.00
102	100	97.81	-20.79	-80.90	58.78	50.00	-86.60
108	100						-100.00
114	100						-86.60
120	100						-50.00
126	100						0.00
132	100						50.00
138	100						86.60
144	100						100.00
150	50						43.30
156	0						0.00
162	0						0.00
168	0						0.00
174	0						0.00
180	0						0.00
186	0						0.00
192	0						0.00
198	0						0.00
204	0						0.00
210	-50	25.00	43.30	50.00	0.00	25.00	-43.30
216	-100	58.78	80.90	95.11	-30.90	0.00	-100.00
222	-100	66.91	74.31	80.90	-58.78	-50.00	-86.60
228	-100	74.31	66.91	58.78	-80.90	-86.60	-50.00
234	-100	80.90	58.78	30.90	-95.11	-100.00	0.00
240	-100	86.60	50.00	0.00	-100.00	-86.60	50.00
246	-100	91.35	40.67	-30.90	-95.11	-50.00	86.60
252	-100	95.11	30.90	-58.78	-80.90	0.00	100.00
258	-100	97.81	20.79	-80.90	-58.78	50.00	86.60
264	-100	99.45	10.45	-95.11	-30.90	86.60	50.00
270	-100	100.00	0.00	-100.00	0.00	100.00	0.00
276	-100	99.45	-10.45	-95.11	30.90	86.60	-50.00
282	-100	97.81	-20.79	-80.90	58.78	50.00	-86.60
288	-100	95.11	-30.90	-58.78	80.90	0.00	-100.00
294	-100	91.35	-40.67	-30.90	95.11	-50.00	-86.60
300	-100	86.60	-50.00	0.00	100.00	-86.60	-50.00
306	-100	80.90	-58.78	30.90	95.11	-100.00	0.00
312	-100	74.31	-66.91	58.78	80.90	-86.60	50.00
318	-100	66.91	-74.31	80.90	58.78	-50.00	86.60
324	-100	58.78	-80.90	95.11	30.90	0.00	100.00
330	-50	25.00	-43.30	50.00	0.00	25.00	43.30
336	0	0.00	0.00	0.00	0.00	0.00	0.00
342	0	0.00	0.00	0.00	0.00	0.00	0.00
348	0	0.00	0.00	0.00	0.00	0.00	0.00
354	0	0.00	0.00	0.00	0.00	0.00	0.00
360	0	0.00	0.00	0.00	0.00	0.00	0.00
		S1=	S2=	S1=	S2=	S1=	S2=
		3304.95	0.00	0.00	0.00	-646.41	0.00
		X	Y	X3	Y3	X5	Y5
		110.16	0.00	0.00	0.00	-21.55	0.00
		A	atan Y/x	A3	atan Y3/X3	A5	atan Y5/X5
		110.16	0.00	0.00	67	21.55	0
exact value		110,27	0	0	-	22,0	0



PROBLEM 30-17

SEE FIG. 30-42

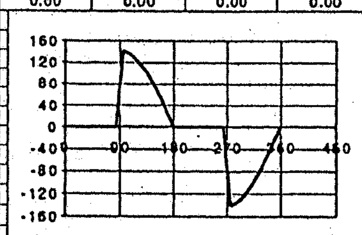
angle degrés q	valeur A	H = 1 A sin Hq	H =1 A cos Hq	H = 3 A sin Hq	H =3 A cos Hq	H = 5 A sin Hq	H = 5 A cos Hq
0	0	0.00	0.00	0.00	0.00	0.00	0.00
6	0	0.00	0.00	0.00	0.00	0.00	0.00
12	0	0.00	0.00	0.00	0.00	0.00	0.00
18	50	15.45	47.55	40.45	29.39	50.00	0.00
24	100	40.67	91.35	95.11	30.90	86.60	-50.00
30	100	50.00	86.60	100.00	0.00	50.00	-86.60
36	100	58.78	80.90	95.11	-30.90	0.00	-100.00
42	100	66.91	74.31	80.90	-58.78	-50.00	-86.60
48	100	74.31	66.91	58.78	-80.90	-86.60	-50.00
54	100	80.90	58.78	30.90	-95.11	-100.00	0.00
60	100	86.60	50.00	0.00	-100.00	-86.60	50.00
66	100	91.35	40.67	-30.90	-95.11	-50.00	86.60
72	100	95.11	30.90	-58.78	-80.90	0.00	100.00
78	100	97.81	20.79	-80.90	-58.78	50.00	86.60
84	100	99.45	10.45	-95.11	-30.90	86.60	50.00
90	100	100.00	0.00	-100.00	0.00	100.00	0.00
96	100	99.45	-10.45	-95.11	30.90	86.60	-50.00
102	100						-86.60
108	100						-100.00
114	100						-86.60
120	100						-50.00
126	100						0.00
132	100						50.00
138	100						86.60
144	100						100.00
150	100						86.60
156	100						50.00
162	50						0.00
168	0						0.00
174	0						0.00
180	0						0.00
186	0						0.00
192	0						0.00
198	-50	15.45	47.55	40.45	29.39	50.00	0.00
204	-100	40.67	91.35	95.11	30.90	86.60	-50.00
210	-100	50.00	86.60	100.00	0.00	50.00	-86.60
216	-100	58.78	80.90	95.11	-30.90	0.00	-100.00
222	-100	66.91	74.31	80.90	-58.78	-50.00	-86.60
228	-100	74.31	66.91	58.78	-80.90	-86.60	-50.00
234	-100	80.90	58.78	30.90	-95.11	-100.00	0.00
240	-100	86.60	50.00	0.00	-100.00	-86.60	50.00
246	-100	91.35	40.67	-30.90	-95.11	-50.00	86.60
252	-100	95.11	30.90	-58.78	-80.90	0.00	100.00
258	-100	97.81	20.79	-80.90	-58.78	50.00	86.60
264	-100	99.45	10.45	-95.11	-30.90	86.60	50.00
270	-100	100.00	0.00	-100.00	0.00	100.00	0.00
276	-100	99.45	-10.45	-95.11	30.90	86.60	-50.00
282	-100	97.81	-20.79	-80.90	58.78	50.00	-86.60
288	-100	95.11	-30.90	-58.78	80.90	0.00	-100.00
294	-100	91.35	-40.67	-30.90	95.11	-50.00	-86.60
300	-100	86.60	-50.00	0.00	100.00	-86.60	-50.00
306	-100	80.90	-58.78	30.90	95.11	-100.00	0.00
312	-100	74.31	-66.91	58.78	80.90	-86.60	50.00
318	-100	66.91	-74.31	80.90	58.78	-50.00	86.60
324	-100	58.78	-80.90	95.11	30.90	0.00	100.00
330	-100	50.00	-86.60	100.00	0.00	50.00	86.60
336	-100	40.67	-91.35	95.11	-30.90	86.60	50.00
342	-50	15.45	-47.55	40.45	-29.39	50.00	0.00
348	0	0.00	0.00	0.00	0.00	0.00	0.00
354	0	0.00	0.00	0.00	0.00	0.00	0.00
360	0	0.00	0.00	0.00	0.00	0.00	0.00
		S1=	S2=	S1=	S2=	S1=	S2=
		3629.45	0.00	742.23	0.00	0.00	0.00
		X	Y	X3	Y3	X5	Y5
		120.98	0.00	24.74	0.00	0.00	0.00
		A	atan Y/x	A3	atan Y3/X3	A5	atan Y5/X5
		120.98	0.00	24.74	0	0.00	67



PROBLEM 30-20

SEE FIG. 30-11

angle degrés q	valeur A	H = 1 A sin Hq	H =1 A cos Hq	H = 3 A sin Hq	H =3 A cos Hq	H = 5 A sin Hq	H = 5 A cos Hq	angle radians
0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0	0.00	0.00	0.00	0.00	0.00	0.00	0.10
12	0	0.00	0.00	0.00	0.00	0.00	0.00	0.21
18	0	0.00	0.00	0.00	0.00	0.00	0.00	0.31
24	0	0.00	0.00	0.00	0.00	0.00	0.00	0.42
30	0	0.00	0.00	0.00	0.00	0.00	0.00	0.52
36	0	0.00	0.00	0.00	0.00	0.00	0.00	0.63
42	0	0.00	0.00	0.00	0.00	0.00	0.00	0.73
48	0	0.00	0.00	0.00	0.00	0.00	0.00	0.84
54	0	0.00	0.00	0.00	0.00	0.00	0.00	0.94
60	0	0.00	0.00	0.00	0.00	0.00	0.00	1.05
66	0	0.00	0.00	0.00	0.00	0.00	0.00	1.15
72	0	0.00	0.00	0.00	0.00	0.00	0.00	1.26
78	0	0.00	0.00	0.00	0.00	0.00	0.00	1.36
84	0	0.00	0.00	0.00	0.00	0.00	0.00	1.47
90	71	71.00	0.00	-71.00	0.00	71.00	0.00	1.57
96	140	139.46	-14.66	-133.36	43.33	121.44	-70.11	1.68
102	138	134.90	-28.67	-111.58	81.07	68.96	-119.44	1.78
108	134	127.54	-41.44	-78.82	108.49	0.00	-134.10	1.88
114	129	117.67	-52.39	-39.80	122.51	-64.40	-111.55	1.99
120	122	105.75	-61.05	0.00	122.11	-105.75	-61.05	2.09
126	114	92.29	-67.05	35.25	108.49	-114.07	0.00	2.20
132	105	77.87	-70.11	61.59	84.77	-90.75	52.39	2.30
138	94	63.13	-70.11	76.33	55.46	-47.17	81.71	2.41
144	83	48.71	-67.05	78.82	25.61	0.00	82.88	2.51
150	71	35.25	-61.05	70.50	0.00	35.25	61.05	2.62
156	57	23.33	-52.39	54.54	-17.72	49.67	28.67	2.72
162	44	13.46	-41.44	35.25	-25.61	43.57	0.00	2.83
168	29	6.10	-28.67	17.23	-23.72	25.39	-14.66	2.93
174	15	1.54	-14.66	4.55	-14.02	7.37	-12.76	3.04
180	0	0.00	0.00	0.00	0.00	0.00	0.00	3.14
186	0	0.00	0.00	0.00	0.00	0.00	0.00	3.25
192	0	0.00					0.00	3.35
198	0	0.00					0.00	3.46
204	0	0.00					0.00	3.56
210	0	0.00					0.00	3.67
216	0	0.00					0.00	3.77
222	0	0.00					0.00	3.87
228	0	0.00					0.00	3.98
234	0	0.00					0.00	4.08
240	0	0.00					0.00	4.19
246	0	0.00					0.00	4.29
252	0	0.00					0.00	4.40
258	0	0.00					0.00	4.50
264	0	0.00	0.00	0.00	0.00	0.00	0.00	4.61
270	-71	71.00	0.00	-71.00	0.00	71.00	0.00	4.71
276	-140	139.46	-14.66	-133.36	43.33	121.44	-70.11	4.82
282	-138	134.90	-28.67	-111.58	81.07	68.96	-119.44	4.92
288	-134	127.54	-41.44	-78.82	108.49	0.00	-134.10	5.03
294	-129	117.67	-52.39	-39.80	122.51	-64.40	-111.55	5.13
300	-122	105.75	-61.05	0.00	122.11	-105.75	-61.05	5.24
306	-114	92.29	-67.05	35.25	108.49	-114.07	0.00	5.34
312	-105	77.87	-70.11	61.59	84.77	-90.75	52.39	5.45
318	-94	63.13	-70.11	76.33	55.46	-47.17	81.71	5.55
324	-83	48.71	-67.05	78.82	25.61	0.00	82.88	5.65
330	-71	35.25	-61.05	70.50	0.00	35.25	61.05	5.76
336	-57	23.33	-52.39	54.54	-17.72	49.67	28.67	5.86
342	-44	13.46	-41.44	35.25	-25.61	43.57	0.00	5.97
348	-29	6.10	-28.67	17.23	-23.72	25.39	-14.66	6.07
354	-15	1.54	-14.66	4.55	-14.02	7.37	-12.76	6.18
360	0	0.00	0.00	0.00	0.00	0.00	0.00	6.28
	SO =	S1=	S2=	S1=	S2=	S1=	S2=	
	0.00	2116.00	-1341.53	-1.00	1341.53	1.00	-433.95	
		X	Y	X3	Y3	X5	Y5	
		70.53	-44.72	-0.03	44.72	0.03	-14.47	
		A	atan Y/x	A3	atan Y3/X3	A5	atan Y5/X5	
		83.51	-32.37	44.72	-90	14.47	-90	
exact value		84	−32,5					

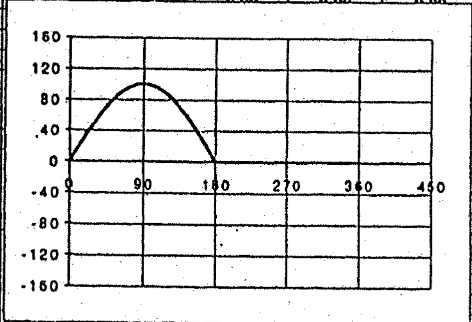


Page 1

PROBLEM 30-21

SEE FIG. 30-43

angle degrés q	valeur A	H = 1 A sin Hq	H =1 A cos Hq	H = 3 A sin Hq	H =3 A cos Hq	H = 5 A sin Hq	H = 5 A cos Hq	angle radians
0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	10	1.09	10.40	·3.23	9.94	5.23	9.05	0.10
12	21	4.32	20.34	12.22	16.82	18.01	10.40	0.21
18	31	9.55	29.39	25.00	18.16	30.90	0.00	0.31
24	41	16.54	37.16	38.68	12.57	35.22	-20.34	0.42
30	50	25.00	43.30	50.00	0.00	25.00	-43.30	0.52
36	59	34.55	47.55	55.90	-18.16	0.00	-58.78	0.63
42	67	44.77	49.73	54.13	-39.33	-33.46	-57.95	0.73
48	74	55.23	49.73	43.68	-60.12	-64.36	-37.16	0.84
54	81	65.45	47.55	25.00	-76.94	-80.90	0.00	0.94
60	87	75.00	43.30	0.00	-86.60	-75.00	43.30	1.05
66	91	83.46	37.16	-28.23	-86.88	-45.68	79.12	1.15
72	95	90.45	29.39	-55.90	-76.94	0.00	95.11	1.26
78	98	95.68	20.34	-79.13	-57.49	48.91	84.71	1.36
84	99	98.91	10.40	-94.58	-30.73	86.13	49.73	1.47
90	100	100.00	0.00	-100.00	0.00	100.00	0.00	1.57
96	99	98.91	-10.40	-94.58	30.73	86.13	-49.73	1.68
102	98	95.68	-20.34	-79.13	57.49	48.91	-84.71	1.78
108	95	90.45	-29.39	-55.90	76.94	0.00	-95.11	1.88
114	91	83.46	-37.16	-28.23	86.88	-45.68	-79.12	1.99
120	87	75.00	-43.30	0.00	86.60	-75.00	-43.30	2.09
126	81	65.45	-47.55	25.00	76.94	-80.90	0.00	2.20
132	74	55.23	-49.73	43.68	60.12	-64.36	37.16	2.30
138	67	44.77	-49.73	54.13	39.33	-33.46	57.95	2.41
144	59	34.55	-47.55	55.90	18.16	0.00	58.78	2.51
150	50	25.00	-43.30	50.00	0.00	25.00	43.30	2.62
156	41	16.54	-37.16	38.68	-12.57	35.22	20.34	2.72
162	31	9.55	-29.39	25.00	-18.16	30.90	0.00	2.83
168	21	4.32	-20.34	12.22	-16.82	18.01	-10.40	2.93
174	10	1.09	-10.40	3.23	-9.94	5.23	-9.05	3.04
180	0	0.00	0.00	0.00	0.00	0.00	0.00	3.14
186	0	-0.00	0.00	0.00	0.00	0.00	0.00	3.25
192	0						0.00	3.35
198	0						0.00	3.46
204	0						0.00	3.56
210	0						0.00	3.67
216	0						0.00	3.77
222	0						0.00	3.87
228	0						0.00	3.98
234	0						0.00	4.08
240	0						0.00	4.19
246	0						0.00	4.29
252	0						0.00	4.40
258	0						0.00	4.50
264	0						0.00	4.61
270	0						0.00	4.71
276	0						0.00	4.82
282	0						0.00	4.92
288	0						0.00	5.03
294	0	0.00	0.00	0.00	0.00	0.00	0.00	5.13
300	0	0.00	0.00	0.00	0.00	0.00	0.00	5.24
306	0	0.00	0.00	0.00	0.00	0.00	0.00	5.34
312	0	0.00	0.00	0.00	0.00	0.00	0.00	5.45
318	0	0.00	0.00	0.00	0.00	0.00	0.00	5.55
324	0	0.00	0.00	0.00	0.00	0.00	0.00	5.65
330	0	0.00	0.00	0.00	0.00	0.00	0.00	5.76
336	0	0.00	0.00	0.00	0.00	0.00	0.00	5.86
342	0	0.00	0.00	0.00	0.00	0.00	0.00	5.97
348	0	0.00	0.00	0.00	0.00	0.00	0.00	6.07
354	0	0.00	0.00	0.00	0.00	0.00	0.00	6.18
360	0	0.00	0.00	0.00	0.00	0.00	0.00	6.28
	SO =	S1=	S2=	S1=	S2=	S1=	S2=	
	1908.11	1500.00	0.00	0.00	0.00	0.00	0.00	
		X	Y	X3	Y3	X5	Y5	
		50.00	0.00	0.00	0.00	0.00	0.00	
	A0	A	atan Y/x	A3	atan Y3/X3	A5	atan Y5/X5	
	31.80	50.00	0.00	0.00	-	0.00	-	
exact value	31,83	50	0	0	-	0	-	



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FIGURES FOR OVERHEAD PROJECTION

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