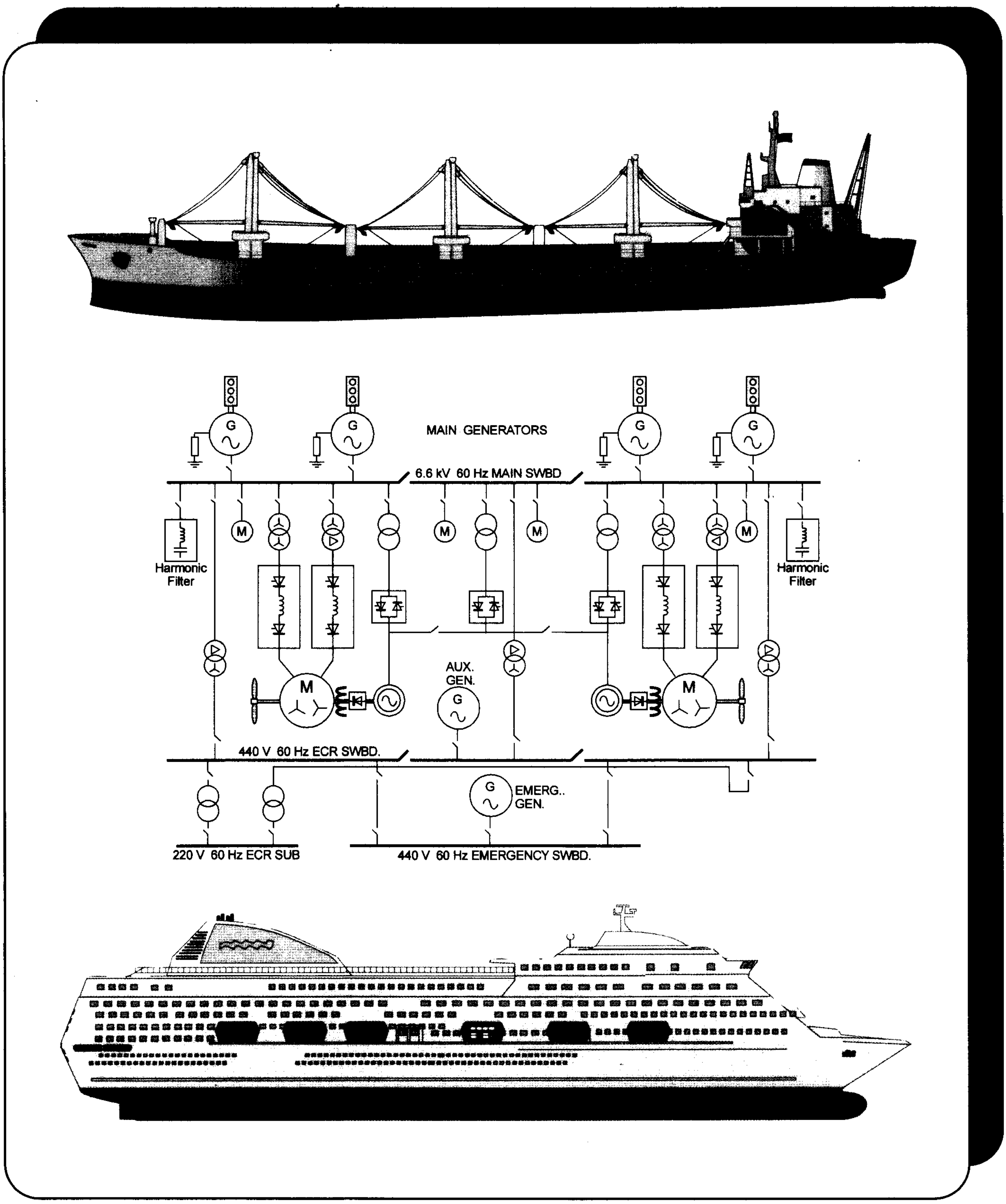
PRACTICAL MARINE ELECTRICAL KNOWLEDGE

Second Edition

Dennis T. Hall B.A. (Hons), C. Eng., M.I.E.E., M.I.Mar.E



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Dennis T. Hall

BA (Hons), CEng MIEE, MIMarE

Rcvd p. Rotterdam
24/11/2004

First Published 1984
Second Edition 1999
ISBN 1 85609 182 1

Witherby & Co Ltd
32-36 Aylesbury Street
London ECIR 0ET
Tel No: 0207 251 5341
Fax No: 0207 251 1296
International Tel No: +44 207 251 5341
International Fax No: +44 207 251 1296
Email: books@witherbys.co.uk
www.witherbys.com

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PUBLISHERS

British Library Cataloguing in Publication Data
Hall, Dennis T.
Practical Marine Electrical Knowledge
– Second Edition
1. Title

ISBN 1 85609 182 1

This book is designed to assist sea-going personnel in their understanding of the safe operation, testing and maintenance of ships electrical equipment and services.
The publication also supports a series of eight film/video cassettes (with the same chapter titles) which examine practical electrical maintenance and fault-finding procedures on board various ship types.

Further details of the film/video cassettes can be obtained from the producers:

Videotel Productions,
84 Newman Street,
London W1P 3LD,
U.K.

Telephone: +44 207 299 1800
Fax: +44 207 299 1818
E-mail: mail@videotelmail.com
Website: http://www.videotel.co.uk

Videotel Productions and Witherby Publishers would like to thank the following organisations for their contribution and assistance in the production of Practical Marine Electrical Knowledge:

South Tyneside College
P & O Cruises (UK) Ltd.
Atlantic Power
PGS Offshore Technology
BP Shipping Ltd.
Shell Tankers (UK) Ltd.
Mobil Shipping Co. Ltd.
Lothian Shipping
R & B Switchgear Services Ltd.
The Institute of Marine Engineers
International Maritime Organisation (IMO)

We wish to thank the following authors and publishers for permission to use some of the illustrations in this book:
M.L. Lewis, Electrical Installation Technology 2 (Hutchinson)
M. Neidle, Electrical Installations and Regulations (Macmillan)
M. Neidle, Basic Electrical Installation Principles (Macmillan)

Preface

This book describes up-to-date electrical practice employed in international shipping. The chapters have the same titles as *eight* electrical training videos within a series also entitled Practical Marine Electrical Knowledge. The content of the book has been designed to be complete in itself but is also arranged to give training support to the practical video material. It has been particularly written to assist marine engineer and electrical officer personnel in their understanding of electrical systems, equipment and its maintenance.

A ship's electrical power system is explained in terms of its main and emergency generation plant and the distribution network. Electrical safety and safe working practice is stressed throughout. The types and significance of circuit faults are examined together with the various forms of protection methods and switchgear operation.

An appreciation of generator construction and its control is followed by a guide to its protection and maintenance. Motor and starter construction, operation and protection are explained. A survey of variable speed control methods for motors applicable to ships is also included.

A wide range of ancillary electrical services for ships lighting, catering, refrigeration, air-conditioning, laundry equipment and cathodic protection are described together with battery support, care and maintenance.

The special design and maintenance for electrical equipment used in potentially hazardous areas is reviewed in relation to oil, gas and chemical tankers. Various explosion-protected (Ex) methods are outlined along with electrical testing in hazardous areas.

Specific parts of the electrical network together with its correct operation and safety, including UMS requirements, are examined in relation to the standards to be met for a successful electrical survey by a classification society.

The application and operation of electrical propulsion for ships is explained, together with high voltage practice, safety procedures and testing methods.

About the author:

Dennis Hall has a long experience with the marine industry. His initial training in shipbuilding was followed by practical experience in the merchant navy as an electrical officer. This was followed by design and inspection work for large power industrial electrical systems around the world. Further experience and knowledge was acquired in the Royal Navy where he was introduced to the requirements and effective delivery methods for the training of engineering personnel. At South Tyneside College, as lecturer and manager, his cumulative knowledge has been very usefully applied to the training of merchant navy electrical and engineering candidates from cadet to senior officer level. As Head of Electrical Power Systems at the college, he has examined many ship types and visited many marine colleges in Europe, USA and Japan in his drive to meet the training and education needs of the marine industry.

Contents

Chapter One
Ships' Electrical Systems, Safety and Maintenance

1.0. Introduction

An overview of a ship's electrical system is presented and describes various types of circuit diagrams used in electrical work. Electrical calculations, safety precautions, circuit diagrams and testing methods are outlined together with a description of general electrical maintenance and fault finding techniques.

1.1. Ships' Electrical System

Auxiliary services on board ship range from engine room pumps, compressors and fans, deck winches and windlasses, to general lighting, catering and air conditioning. Electrical power is used to drive the majority of these auxiliary services. The electrical power system on board ship is designed to provide a secure supply to all loads with adequate built-in protection for the equipment and operating personnel.

The general scheme of a ship's electrical power system is common to nearly all ships.

The *main* a.c. generators (sometimes called alternators) produce the electrical power. It is supplied to the main switchboard and then distributed to the various auxiliary services comprising the electrical load. An *emergency generator* and *emergency switchboard* maintain supplies in the event of a main power failure.

Compare this general layout in Fig. 1.1 with the system on your ship. Note the great similarities and also note the differences – all ships' systems differ in some respect.

The generators may be driven by a diesel engine, by a steam or gas turbine, or by the main propulsion engine as a *shaft* generator. The type of prime mover is determined by the design of the ship and by economic factors.

The combined power rating of the generators is determined by the overall demand of the ship's electrical load.

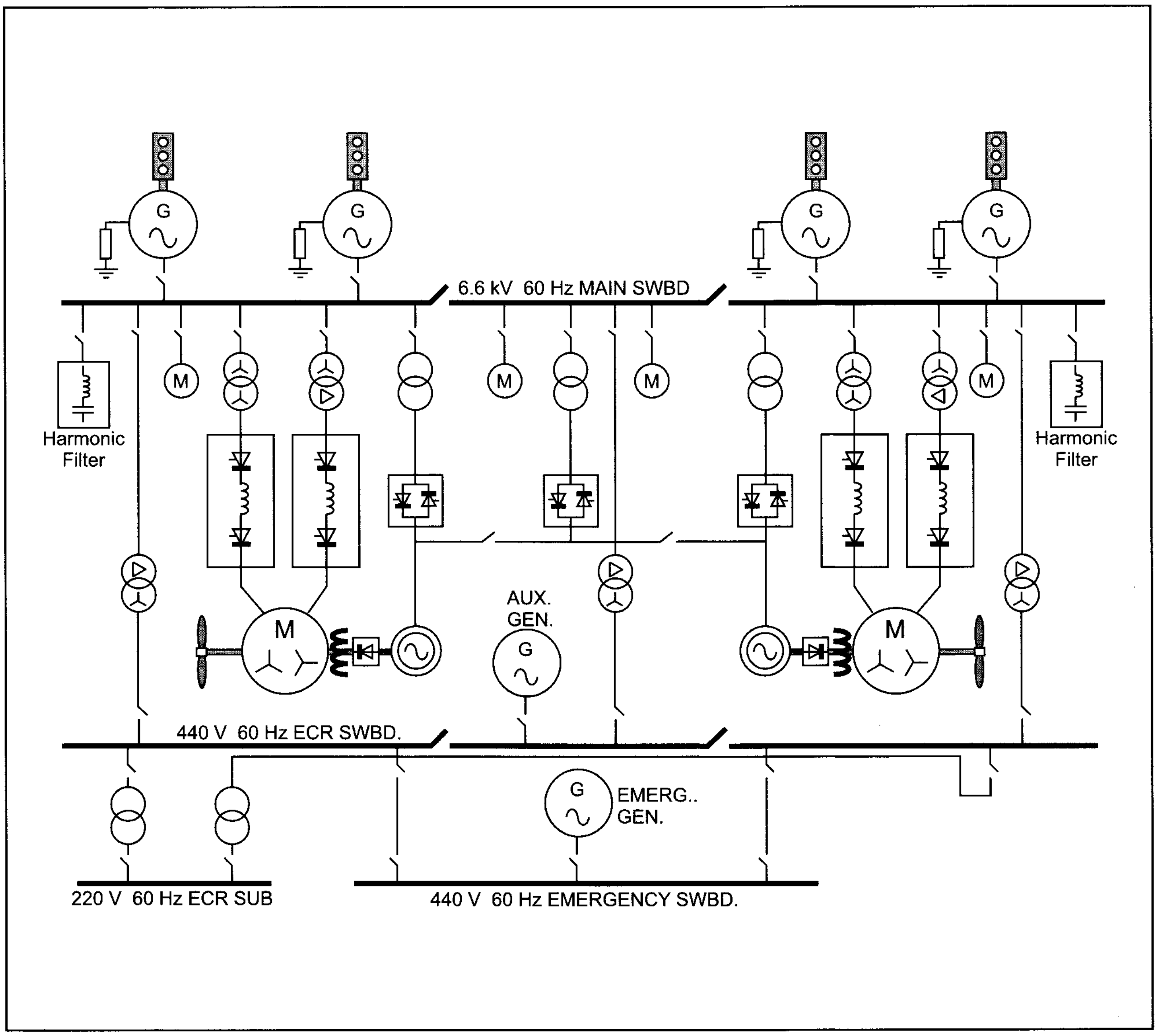


Fig. 1.1 Electric power system.

Large passenger ships usually have four large generators rated at 10 MW or more to supply the electric propulsion motors and the extensive hotel services on board. A cargo ship may have two main generators typically rated from 350 to 1000 kW which are sufficient to supply the engine room auxiliaries while at sea and the winches or cranes for handling cargo while in port. The limited load required during an emergency requires that an emergency generator may be rated from about 10 kW for a small coaster to about 300 kW or more for a cargo liner. The shipbuilder must estimate the number and power rating of the required generators by assessing the power demand of the load for all situations whether at sea or in port.

Electrical power on board ship is commonly generated at 440 V, 60 Hz (sometimes 380 V, 50 Hz). Ships with a very large electrical power demand will require generators that operate at a *high voltage* (3.3 kV, 6.6 kV or 11 kV) to limit the size of normal load current *and* the prospective fault current.

The British Standard (BS) and International Electrotechnical Commission (IEC) definition of *low voltage* is 50 V a.c. to 1000 V a.c. (the IEC give this definition to harmonise British and European standards).

Lighting and other low power ancillary services usually operate at 110 V or 220 V, single-phase a.c. Transformers are used to reduce the 440 V system voltage to these lower voltage levels.

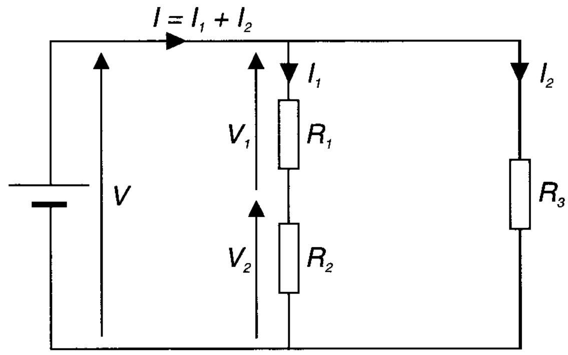
Where portable equipment is to be used in dangerous, hot and damp locations, it is advisable to operate at 55 V or even 24 V supplied again by a step-down transformer. Occasionally, transformers are also used to step-up voltages, e.g. supplying a large 3.3 kV bow thruster motor from a 440 V switchboard supply.

Batteries for various essential services operate at 12 V or 24 V d.c. but sometimes higher voltages are used if such loads require a large power supply.

1.2. Circuit Calculations

The following gives a brief revision of d.c. and a.c. circuits and calculations.

d.c. circuit



$$R_T = R_1 + R_2 + R_3 + \ldots \text{ (in series)}$$

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots \text{ (in parallel)}$$

$V = I.R$ (Ohms Law)

$\Sigma emf's = \Sigma pd's$ (Kirchhoff)

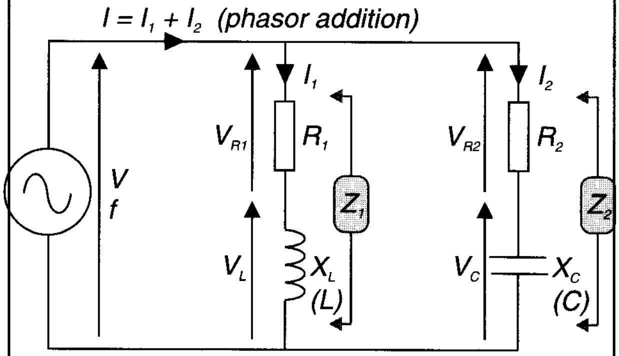
$\Sigma I_{IN} = \Sigma I_{OUT}$ (Kirchhoff)

$P = V.I = I^2.R$

Example:
Using the above circuit with a 110 V d.c. supply and $R_1 = 6\ \Omega$, $R_2 = 5\ \Omega$, $R_3 = 5.5\ \Omega$: Calculate all currents, supply power and p.d. across the 6 Ω resistor.

Determine as,
$I_1 = 110/(6+5) = \underline{10\ A}$ *and* $I_2 = 110/5.5 = \underline{20\ A}$
so supply current is $\underline{I = 30\ A}$.
Supply power is $P = V.I = 110 \,.\, 30 = \underline{3.3\ kW}$
[check with $P = \Sigma(I^2R)$*]*
p.d. across 6 Ω resistor is $I_1.6 = 10 \,.\, 6 = \underline{60\ V}$

Single phase a.c. circuit



$$X_L = 2\pi fL\ (\Omega) \qquad X_C = 1/2\pi fC\ (\Omega)$$

$$Z = \sqrt{R^2 + X_L{}^2} \quad or \quad Z = \sqrt{R^2 + X_C{}^2}$$

$$I = V/Z$$

$$power\ factor = cos\phi = R/Z = P/S\ (lag\ or\ lead)$$

$$P = V.I.cos\phi\ or\ P = I^2R\ (W)$$

$$Q = V.I.sin\phi\ or\ Q = I^2X\ (VAr)$$

$$S = V.I\ or\ S = I^2Z\ (VA)$$

Example:
Using the above circuit with a 220 V, 60 Hz a.c. supply and $R_1 = 6\ \Omega$, $R_2 = 5\ \Omega$, $L = 0.1$ H, $C = 100\ \mu$F:
Calculate all currents, supply power, overall power factor and p.d. across the 6 Ω resistor.

Determine as,

$X_L = 2.\pi.f.L = 37.7\ \Omega$ *and* $X_C = 1/2.\pi.f.C = 26.5\ \Omega$

Then $Z_1 = 38.2\ \Omega$ *at* $81°$ *(lagging)*

and $Z_2 = 27\ \Omega$ *at* $79.3°$ *(leading)*

So, $I_1 = 220/38.2 =$ <u>5.76 A</u> *lagging V by 81°*

and $I_2 = 220/27 =$ <u>8.15 A</u> *leading V by 79.3°*

The total supply current is the <u>phasor</u> sum of I_1 and I_2 which must be resolved into "in-phase" (horizontal) and "quadrature" (vertical) components before adding, the result (for you to check) is $I =$ <u>3.34 A</u> *at 43.8° leading*

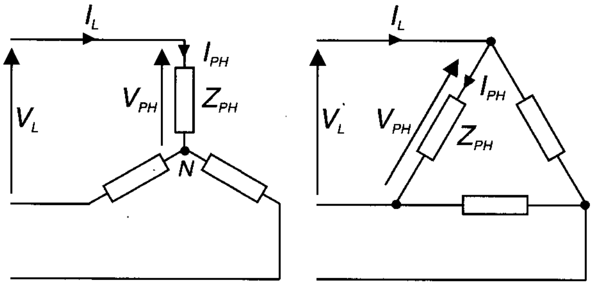
Supply Power is $P = 220 . 3.34 . cos43.8° =$ <u>531 W</u>

[check with $P = \Sigma(I^2R)$*]*

Overall power factor is $cos43.8° =$ <u>0.72 leading</u>

p.d. across $6\ \Omega = I_1 . 6 = 5.76 . 6 =$ <u>34.56 V</u>

three phase a.c. circuit



$$V_L = \sqrt{3}.V_{PH}\ and\ I_L = I_{PH}\ (in\ STAR)$$

$$V_L = V_{PH}\ and\ I_L = \sqrt{3}.I_{PH}\ (in\ DELTA)$$

$$P_{PH} = V_{PH}.I_{PH}.cos\phi = I_{PH}^2.R$$

$$Balanced\ 3\text{-}phase:\ P = \sqrt{3}.V_L.I_L.cos\phi$$

Example:
Using the above circuit with a 440 V, 3-phase, 60 Hz a.c. supply and $Z_{PH} = 10\ \Omega$ at p.f. = 0.8 lagging (balanced load)
Calculate phase and line currents and supply power when connected as:
(a) STAR and (b) DELTA

Determine as,

(a) in Star, $V_{PH} = 440/\sqrt{3} = 254$ V

so $I_{PH} = 254/10 =$ <u>25.4 A</u>

and $I_L = I_{PH} =$ <u>25.4 A</u> *also*

$P = \sqrt{3} . 440 . 25.4 . 0.8 =$ <u>15.49 kW</u>

(b) in Delta, $V_{PH} = V_L = 440$ V

so $I_{PH} = 440/10 =$ <u>44 A</u>

and $I_L = \sqrt{3}.44 =$ <u>76.2 A</u>

$P = \sqrt{3} . 440 . 76.2 . 0.8 =$ <u>46.46 kW</u>

(notice this power is three times the value in star)

1.3 Electrical Diagrams

There are various types of diagram which attempt to show how an electrical circuit operates. Symbols are used to represent the various items of equipment. The shipbuilder provides a complete set of ships' electrical diagrams. It is important that you study these diagrams to be able to read and understand them competently, and to use them as an aid in locating electrical faults.

A *block diagram* shows in simplified form the main inter-relationships of the elements in a system, and how the system works or may be operated. Such diagrams are often used to depict control systems and other complex relationships. The block diagram in Fig. 1.2 describes the main functions of an overcurrent relay (OCR) used for protection. Its *circuit diagram* shows one way of realising the overall OCR function.

Diagrams like this state the function of each block but usually do not give any information about the components in each block or how the blocks are actually interconnected.

A *system diagram*, as in Fig. 1.3, shows the main features of a system and its bounds, without necessarily showing cause-to-effect. Its main use is to illustrate the ways of operating the system. Detail is omitted in order to make the diagram as clear as possible, and so, easily understood.

A *circuit diagram* shows, *in full*, the functioning of a circuit. All essential parts and connections are depicted by means of graphical symbols arranged to show the operation as clearly as possible but

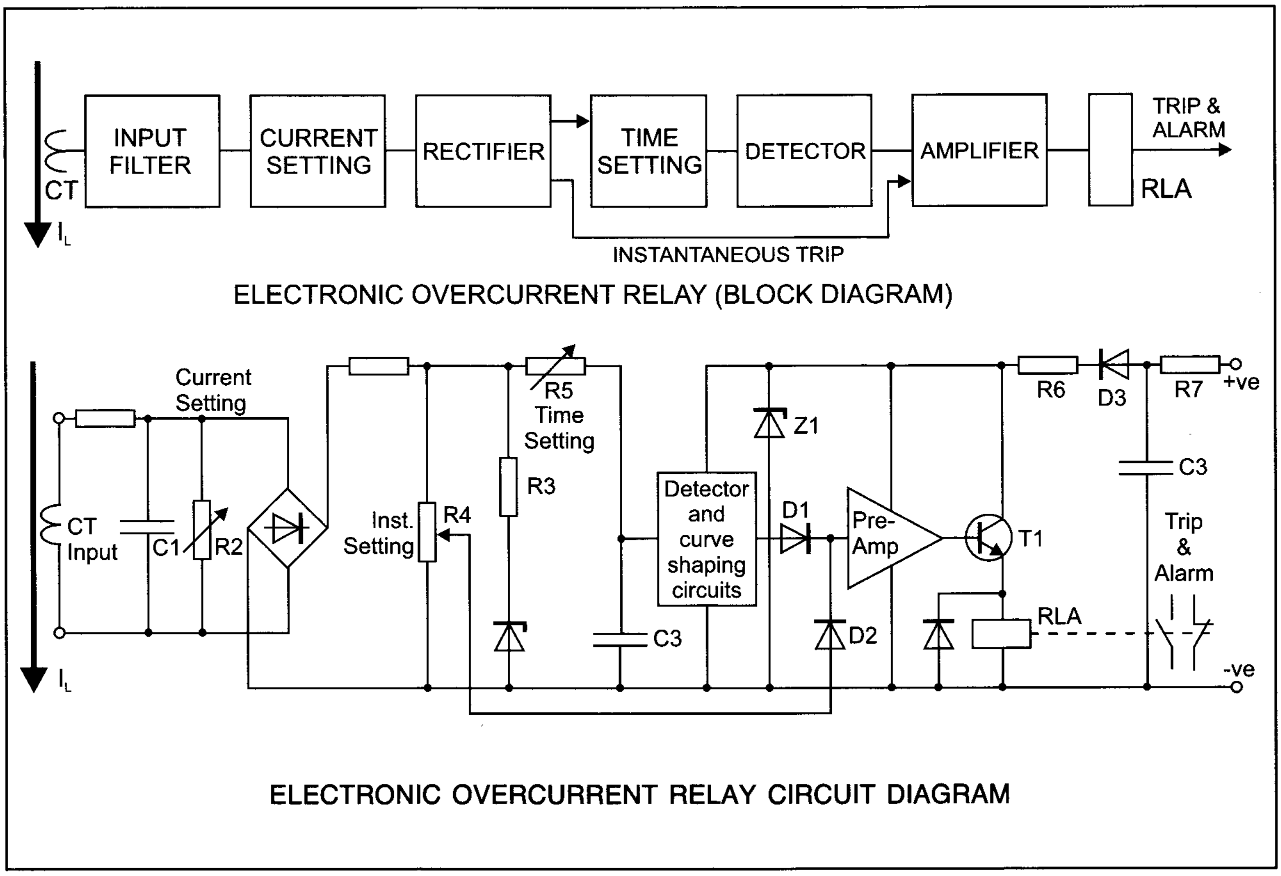


Fig. 1.2 Block and circuit diagrams.

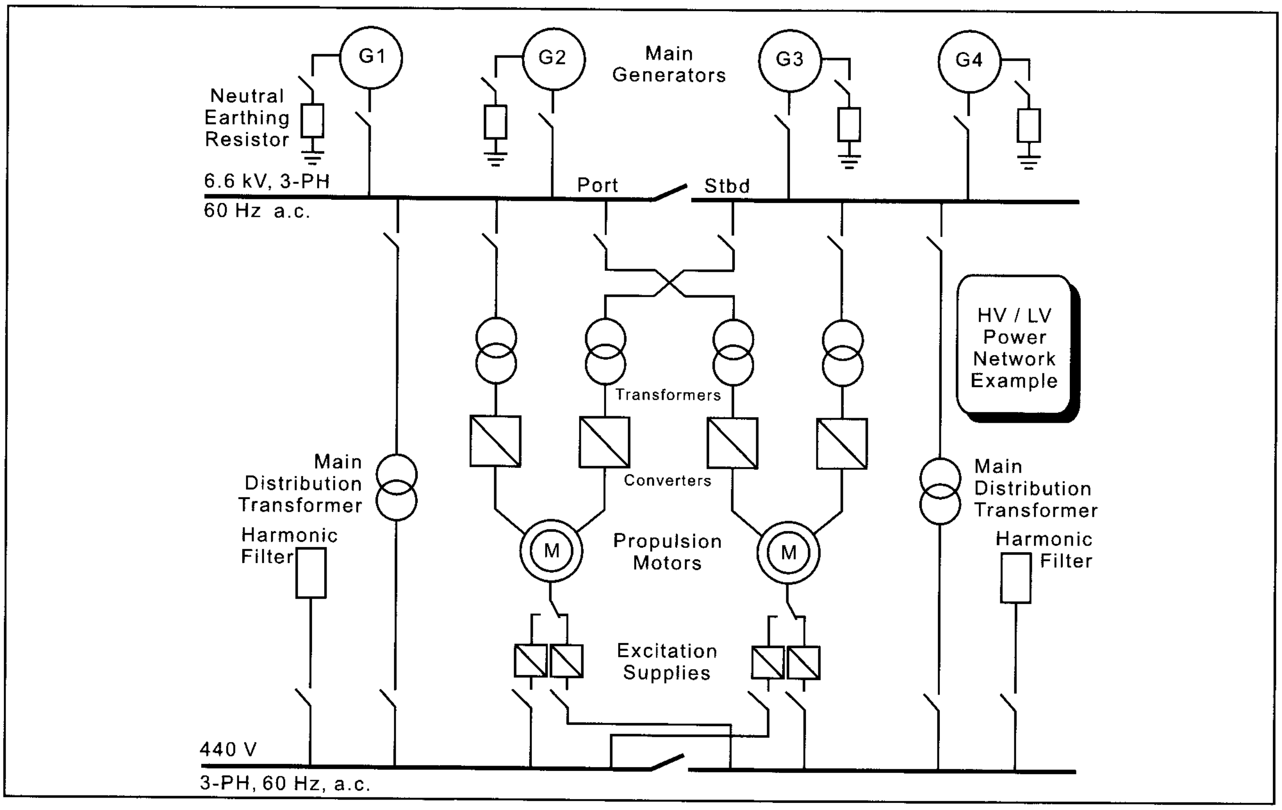


Fig. 1.3 Power system diagram.

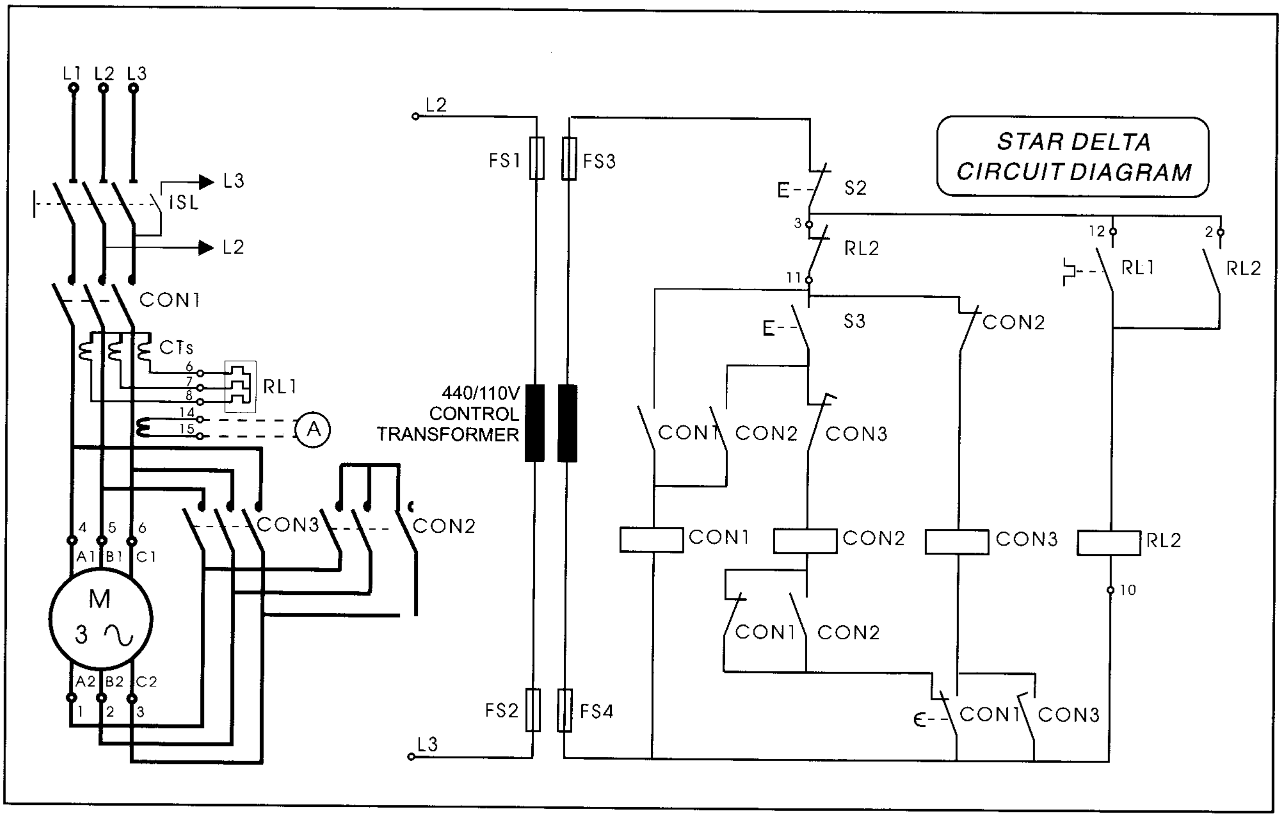


Fig. 1.4 Power and control circuit diagram.

without regard to the physical layout of the various items, their parts or connections.

The electrical connections in Fig. 1.4 for a motor starter are clearly shown in the simplest possible way. A most important point is that no attempt is made to show the moving contacts of a relay or contactor alongside the coil that operates them (where they are actually physically located). Instead, the coil and its related contacts are identified by a common number or letter. Although there are international agreements as to the symbol to be used to represent electrical components you must be prepared to meet various different symbols representing the same component.

The use of a circuit diagram is to enable the reader to understand the operation of the circuit, to follow each sequence in the operation from the moment of initiating the operation (e.g. by pressing a *start* button) to the final act (e.g. starting of the motor). If the equipment fails to operate correctly, the reader can follow the sequence of operations until he comes to the operation that has failed. The components involved in that faulty operation can then be examined to locate the suspect item. There is no need to examine other components that are known to function correctly and have no influence on the fault, so the work is simplified. A circuit diagram is an essential tool for *fault finding*.

A *wiring diagram* shows the detailed connections between components or items of equipment, and in some cases the routeing of these connections. An equipment wiring diagram shows the components in their approximate positions occupied within the actual enclosure. The component may be shown complete (e.g. a contactor coil together with all the contacts it drives) or may be simply represented by a block with the necessary terminals clearly marked. A different thickness of line can be used to differentiate between power and control circuit connections. The wiring diagram in Fig. 1.5 is of the same starter shown for the circuit diagram of Fig. 1.4.

A wiring diagram may be of a fairly simple circuit, but its layout makes it quite difficult to use and to understand the sequential operation of the circuit. The purpose of a wiring diagram is mainly to instruct the wiring installer how to construct and connect the equipment. It is of little use in trouble shooting apart from identifying the exact position of suspect components, terminals and wires.

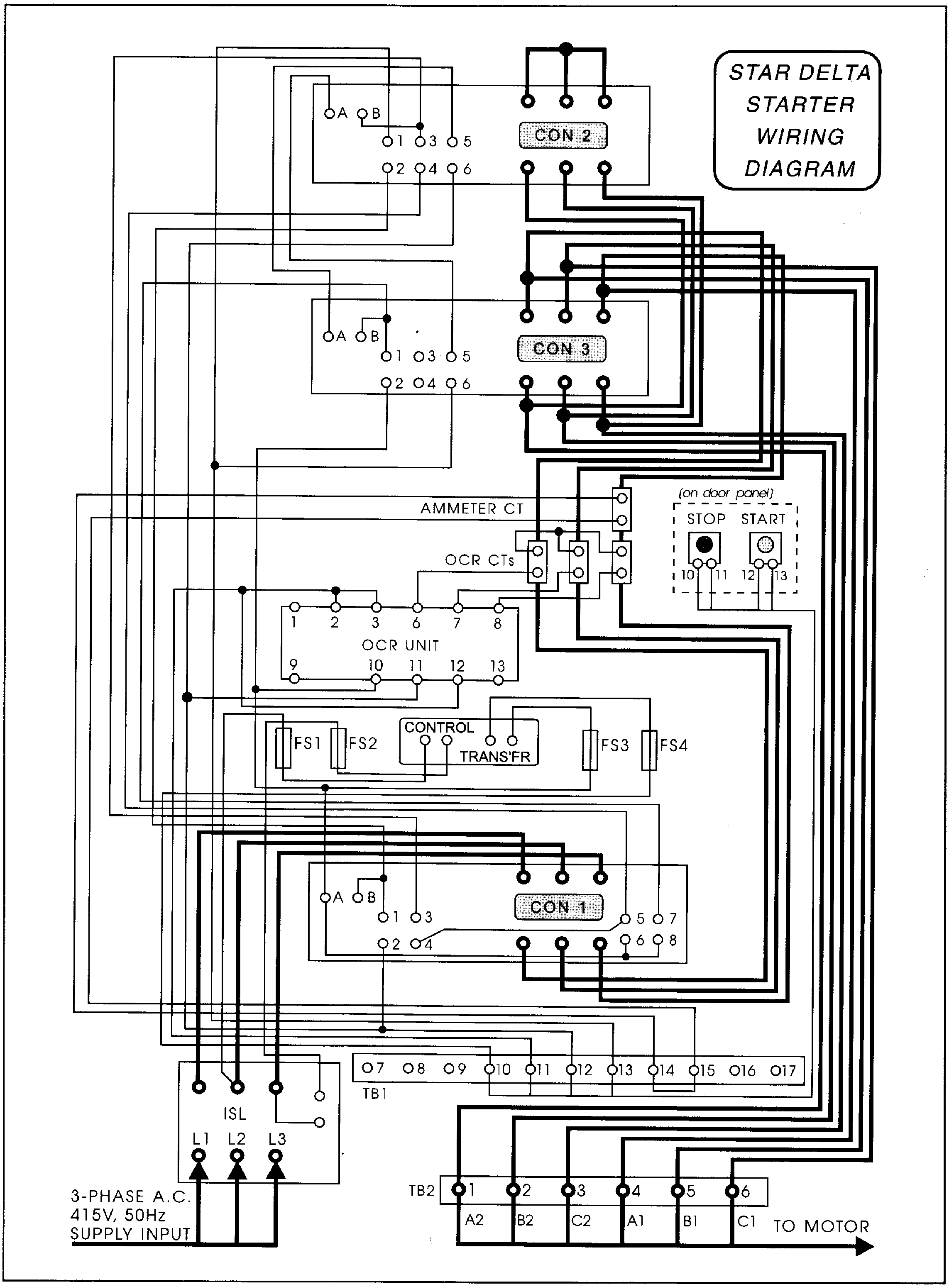


Fig. 1.5 Power and control wiring diagram.

QUESTION

What are you to do if difficulties arise in locating a fault on an item of equipment and only a *wiring diagram* is available?

ANSWER

It may well save time and trouble to convert the wiring diagram into a much simpler and more useful *circuit diagram*. When converting a wiring diagram into a circuit diagram certain basic rules and conventions should be followed.

- Every sequence should be drawn from left to right and from top to bottom (where possible).
- Each stage should be in order of occurrence from left to right.
- All contacts and components which are in series should be drawn in a straight line (where possible) with the component they control.
- All contacts and components which are in parallel should be drawn side by side and at the same level to emphasise their parallel function.
- All major components operating at bus-bar voltage should be drawn at the same level (or aligned horizontally) to help identify the required components quickly.
- All contacts should be shown *open* or *closed* as in their *normal* or de-energised condition.

There are other conventions but these cover the main points of good systematic diagrams. *Block, system, circuit and wiring diagrams* are the main types in general use for electrical work. Other types of diagram are sometimes used to give information for which the basic types are unsuitable (e.g. a pictorial view of a component).

You should study the ship's electrical diagrams to gain an understanding of equipment operation prior to carrying out maintenance or fault finding. Diagrams should be regarded as an essential tool when carrying out work on electrical equipment.

1.4. Electrical Safety

Large power equipment and processes utilise high forces. Electrical, mechanical, thermal and chemical changes produce the desired operation. Very high values of voltage, current, power, temperature, force, pressure etc. create the possibility of danger in an engineering system.

To minimise the safety risk to personnel and equipment a system must be designed and manufactured to the latest high standards and be correctly installed. During its working life the equipment must be continuously monitored and correctly maintained by professionally qualified personnel who understand its operation and safety requirements.

Before attempting any electrical work, there are some basic safety precautions you must bear in mind. The possible dangers arising from the misuse of electrical equipment are well known. Electric shock and fire can cause loss of life and damage to equipment.

Regulations exist to control the construction, installation, operation and maintenance of electrical equipment so that danger is eliminated as far as possible. Minimum acceptable standards of safety are issued by various bodies including national governments, international governmental conventions (e.g. SOLAS), national and international standards associations (e.g. BS and IEC), learned societies (e.g. IEE), classification societies (e.g. Lloyds), etc. Where danger arises it is usually due to accident, neglect or some other contravention of the regulations.

Ships' staff must operate equipment in a safe manner and maintain it in a safe condition at all times. Failure to do so will cause danger with serious consequences arising. Keep in mind an essential list of *DO's* and *DO NOT's* when working with electrical equipment:

- ✓ *DO* get to know the ship's electrical system and equipment. Study the ship's diagrams to pinpoint the location of switches and protection devices supplying distribution boards and essential items of equipment. Write down this information in a note book. Become familiar with the *normal* indications on switchboard instruments so that abnormal operation can be quickly detected.
- ✓ *DO* operate equipment according to the manufacturer's recommendations.
- ✓ *DO* maintain equipment according to the manufacturer's recommendations or the shipowner's maintenance procedures.
- ✓ *DO* ensure that all guards, covers and doors are securely fitted and that all bolts and fixings are in place and tight.
- ✓ *DO* inform the Officer of the Watch before shutting down equipment for maintenance.
- ✓ *DO* switch off and lock-off supplies, remove fuses, and display warning notices before removing covers of equipment for maintenance.
- ✓ *DO* confirm that circuits are *DEAD* (by using an approved voltage tester) before touching conductors and terminals.
- ✗ *DO NOT* touch live conductors under any pretext
- ✗ *DO NOT* touch rotating parts.
- ✗ *DO NOT* leave live conductors or rotating parts exposed.
- ✗ *DO NOT* overload equipment.
- ✗ *DO NOT* neglect or abuse equipment.

You should think ***SAFETY*** at all times and so develop a *safety conscious attitude*. This may well save your life and the lives of others. Most accidents occur due to a momentary loss of concentration or attempts to short-circuit standard safety procedures.

DO NOT let this happen to YOU.

1.5 Electric Shock

Nearly everyone has experienced an electric shock at some time. At best it is an unpleasant experience, at worst it is fatal.

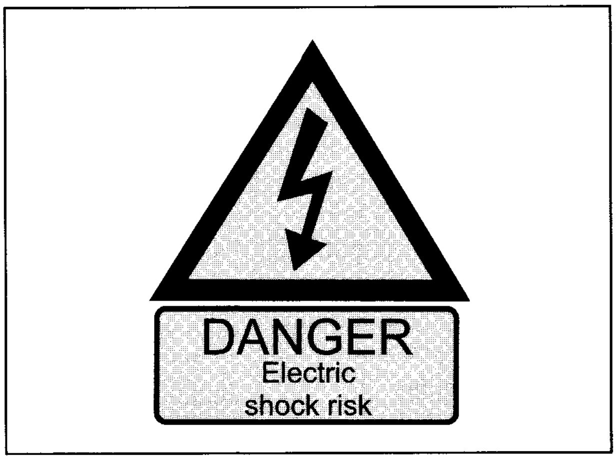


Fig. 1.6 Electrical safety warning.