

Electrical Power Equipment and Measurements

**With heavy current
electrical applications**

Alan Symonds

second Edition

Electrical power equipment and measurements: with heavy current electrical applications

Second edition

Alan Symonds

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**Electrical power equipment and measurements: with heavy current
electrical applications**

Second edition

Preface to the first edition

The primary purpose of this book is to provide Electrical Technician students with a textbook covering Electrical Power Equipment. The book is intended to cover two years' work, but in order to preserve subject continuity no attempt has been made to divide either the book or the individual chapters into two distinct parts.

Much of the subject matter is descriptive and illustrated by drawings, circuit diagrams, and phasor diagrams. In general, the theory and mathematics have been limited to that necessary to give an understanding of the principles, characteristics, and practical uses of particular pieces of equipment. From this point of view the practical technician in industry, whose days of studying may be behind him, may find the book helpful.

SI units have been used, although some units, for example the horsepower, have not been completely omitted since old machines will still carry the old rating on their nameplates.

Although based upon a particular syllabus, much of the book will be found useful for Electrical Installation students and students taking Electrical Craft Study courses.

The author wishes to thank the City and Guilds of London Institute for permission to use their Electrical Technician Course syllabus as a basis for the contents of this book and for the inclusion of questions from past examination papers; the East Midland Education Union for permission to use questions from past examination papers; the Institution of Electrical Engineers for permission to use information contained in their *Regulations for the Electrical Equipment of Buildings*; and Her Majesty's Stationery Office for permission to use material quoted in the 1969/70 Annual Report of the Central Electricity Generating Board.

Questions from past examination papers are printed in an Appendix. The order in which the questions appear corresponds with the sequence of chapters. The source of the questions is indicated but where numerical answers are given these are the author's, and the relevant examination body is in no way responsible for their accuracy.

In writing this book, the author has been helped by the reading of scripts and the constructive comments of several of his colleagues and wishes to thank Mr S. Busby, Mr D. V. Miles, Mr F. G. Vivian, and Mr R. Wilson for their help, and also Mr J. Cleveland and Mrs E. Cleveland for typing the scripts.

Alan Symonds

Preface to the second edition

Since the first edition was published in 1971 considerable changes have taken place in the structure of technical education courses. Many colleges are now offering courses based upon syllabuses issued by the Technical Education Council. In revising this book much material has been added to enable the book to give a complete coverage of the TEC Level III Syllabus Unit U76/362. The title of this unit, 'Heavy Current Electrical Applications', is used as a sub-title for this present edition.

Inevitably, some of the original material has had to be condensed to give space for the new and some material has been rearranged. This new edition will now appeal to students taking a number of TEC courses, but particularly Unit U76/362, and also to technicians, installation and craft students who have previously used the book.

Basically the chapters follow the same general order as in the first edition although some chapter headings have been changed and new chapters introduced, particularly on three-phase rectification and control systems.

Many colleges today introduce basic electronic theory at an early stage and in most cases students will be familiar with this work before reaching Level III. For this reason much of this basic work has now been omitted from the new edition.

Questions in the Appendix have now been placed under chapter headings.

The author wishes to thank those colleagues who have helped with this second edition by reading the scripts and making constructive comments. In particular he wishes to mention Mr S. Busby, Mr R. Wilson, Mr C. S. J. Evens, and Mr R. Taylor.

Alan Symonds

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1. Consumer's supply

1.1 From the grid to the consumer

Since the initial 132 kV network was completed in 1936 the Grid has been extended until it now covers virtually the whole of Great Britain. The *Grid System* consists of an extensive interconnected transmission network supplying the whole country and is controlled by the Central Electricity Authority. When the supply industry was nationalized in 1948 generation also became part of the system. The Grid network is now supplied from a small number of very large and highly efficient power stations strategically placed where fuel (usually coal) and water are easily available. The basic networks are still 132 kV but increasing demands and the necessity to supply bulk power over long distances has brought about the introduction of the Super Grid. This consists of transmission lines with voltages of 275 kV and 400 kV forming the main 'arteries' of the supply system.

Figure 1.1 is typical of the Grid supply system from the generating plant to the consumer. Most consumers receive supplies from the medium-voltage (415/240 V) distribution system, but it will be seen from the diagram that supplies to some large industrial consumers may be given at 11 kV or even 33 kV.

The advantages of the Grid system can be summarized as follows:

1. The whole country is linked by a common e.h.v. network.
2. Best use is made of large, highly efficient generating stations built upon the most advantageous sites.
3. Load flow is under a centralized control, enabling generating plant to be operated at its highest efficiency.
4. Small and inefficient stations are eliminated.
5. Standby plant and spares are kept to a minimum.
6. Supply frequency and voltage can be standardized.
7. Loss of supply due to breakdown is minimized.
8. Electricity is more readily available to isolated communities.

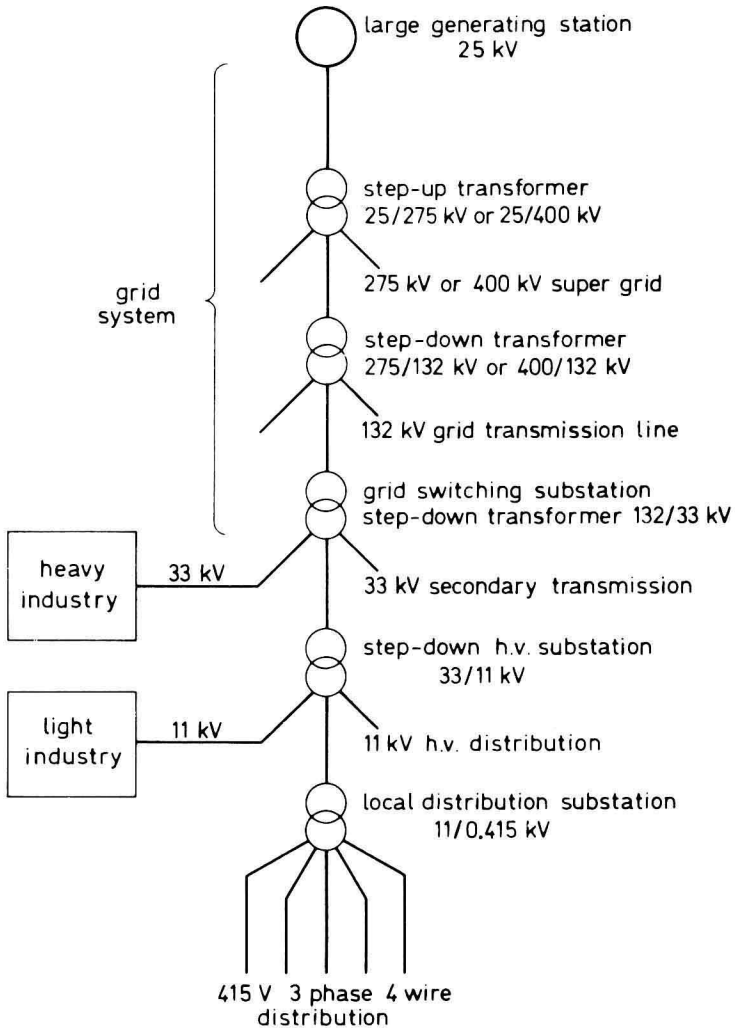


Fig. 1.1 Typical supply system

1.2 The local distribution system

The main substation feeding a particular area is usually placed as close to the load centre as possible. This substation will be supplied from the Grid transmission line, probably by means of a 33 kV secondary transmission line or underground cable. From the main substation there will be high-voltage distribution cables radiating outwards to feed the local distribution substations. This will probably be at 11 kV. The local substations

will also be interconnected by means of further 11 kV cables, so that a ring system of feeders is formed. By employing this ring system, it is possible to isolate any one of the cables without interrupting the supply to any substation. In the case of a fault, this may be done automatically by the use of suitable protective equipment at the substations. Transformers at each substation feed into a network of low-voltage distributors which radiate from the substation and to which the consumers' supplies are connected. These low-voltage cables may also be interconnected by means of link pillars or underground boxes, the use of which enables faulty cables to be isolated, feeds to be changed, and even a substation to be taken out of commission for maintenance work to be carried out, usually with no interruption to the consumer's supplies.

Figure 1.2 shows a typical arrangement for such a distribution system.

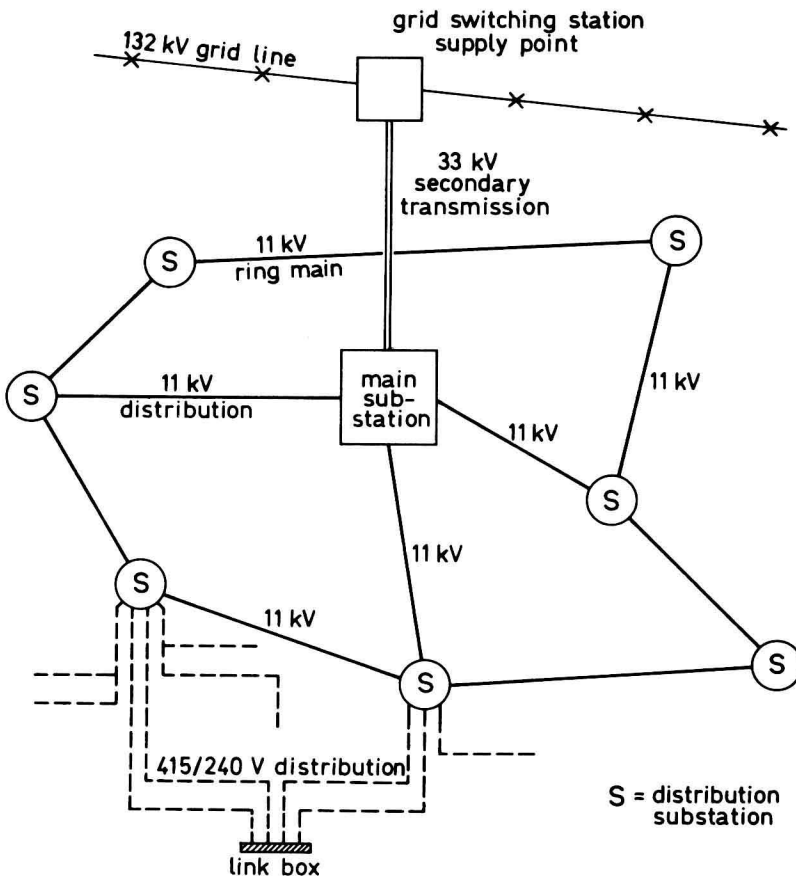


Fig. 1.2 Layout of distribution system

1.3 Operating voltages

On long transmission lines, the losses can be high. By raising the operating voltage, thereby reducing the current for a given power being delivered, the losses can be reduced and the efficiency of transmission increased. For any given line there is also a definite voltage which will give the minimum cost. This is the 'economic voltage' for the line. To find this voltage, a number of factors have to be taken into account, including local conditions, but a rough guide is 1000 V per mile of line. However, in order to standardize in the manufacture of equipment, certain standard voltages are used. These are:

- 400 kV and 275 kV for the Super Grid;
- 132 kV for the original Grid;
- 66 kV and 33 kV for secondary transmission;
- 11 kV, 6.6 kV, and 3.3 kV for h.v. distribution.

The standard distribution voltages for consumer's supplies are 415 V three-phase 50 Hz a.c. for power, and 240 V single-phase 50 Hz a.c. for lighting and heating supplies.

The voltages of consumer's circuits are normally classified as follows:

<i>Extra-low voltage</i>	Not exceeding 50 V between conductors, and not exceeding 30 V a.c. or 50 V d.c. between any conductor and earth.
<i>Low voltage</i>	Between 50 V and 250 V.
<i>Medium voltage</i>	Over 250 V and not exceeding 650 V.
<i>High voltage</i>	Over 650 V and not exceeding 3000 V.
<i>Extra-high voltage</i>	Over 3000 V.

The above voltages are either between conductors or between one conductor and earth.

1.4 Consumer's supplies

Nowadays, the supply to the consumer is almost always a.c. However, there is still a need for d.c. for specific processes and even if the supply is a.c. there may still be a d.c. network within a factory supplied through either rectifiers or a motor-generator set. The following outline of supply systems includes both a.c. and d.c. supplies. The voltages shown are for standard supplies.

The main form of lighting is by means of the filament lamp. As it is uneconomical to manufacture such lamps much above a 250 V rating, this gives a limit to supply voltages for lighting circuits. Since such supplies are required in domestic premises there is also the safety aspect to be considered. Thus, the standard voltage for supplies to lighting circuits is limited to 250 V or less.

For power purposes, a higher voltage leads to greater efficiency. It will be seen below that by developing the three-wire and three-phase systems a higher voltage can be provided for power circuits while the lower voltage for lighting circuits is still maintained.

D.C. Two-wire System. This is the simplest system, consisting of two conductors known as the positive and negative leads (Fig. 1.3a). The voltage is limited to under 250 V for both lighting and power loads. Higher voltages may be used for power supplies only, as for traction where 1000 V or more may be used.

D.C. Three-wire System. By adding a third conductor, called the *middle wire* or *neutral*, the voltage of the system can be doubled for the supply of

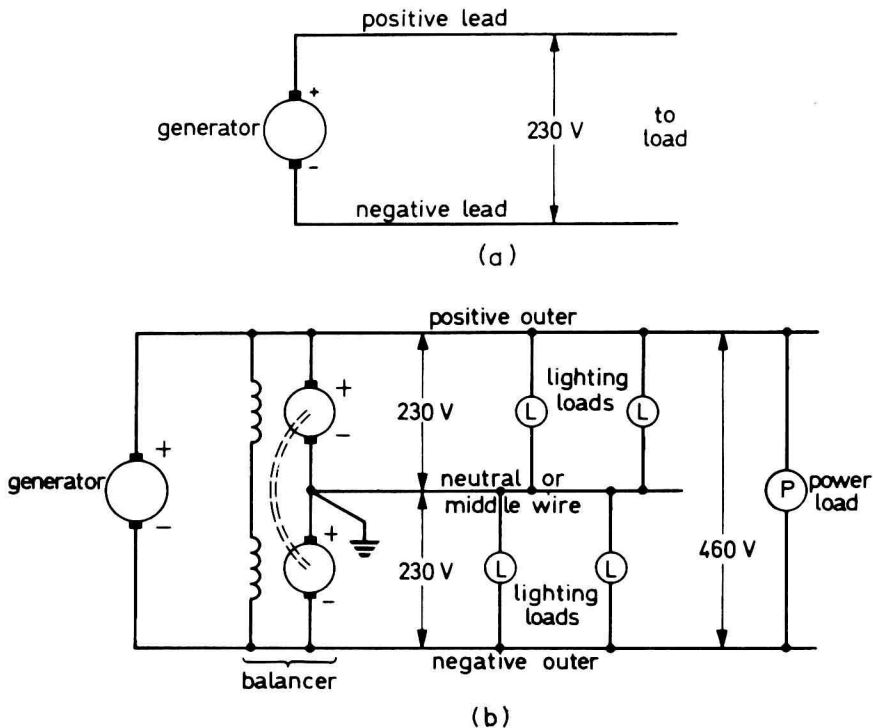


Fig. 1.3 D.C. systems: (a) two-wire system, (b) three-wire system

power loads. The full voltage will exist between the two *outers*, with half the voltage for lighting circuits between one of the outers and the middle wire. One problem with this system is that any out-of-balance between the positive and negative lighting loads will cause a rise in voltage on the lightly loaded side, with a corresponding reduction of voltage on the heavily loaded side. To overcome this, a *balancer*, consisting of two similar shunt machines coupled together, is connected into the circuit, as shown in Fig. 1.3b. The machine connected in the lightly loaded side operates as a motor to drive the other machine as a generator, thereby transferring power from one side to the other and thus reducing the out-of-balance and equalizing the voltages.

A.C. Single-phase Two-wire System (Fig. 1.4a). This is similar to the d.c. two-wire system, except that in this case the supply is normally from the secondary of a transformer at the distribution substation. One side of the secondary is always earthed, and the conductor connected to this side is

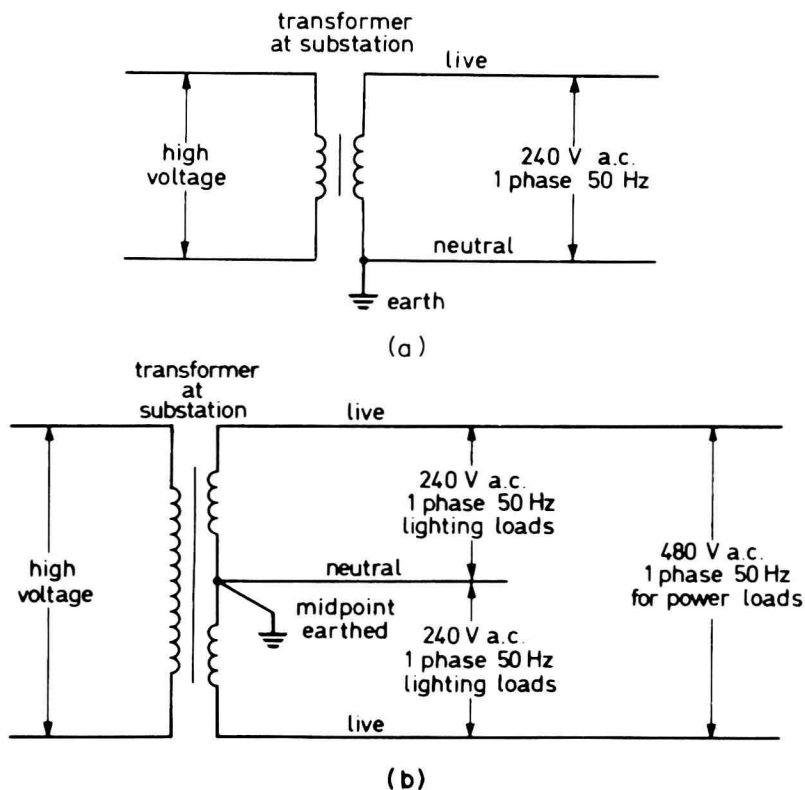


Fig. 1.4 A.C. single-phase systems: (a) two-wire system, (b) three-wire system