HANDBOOK OF ELECTRICAL INSTALLATION PRACTICE

FOURTH EDITION

Edited by

Eur Ing GEOFFREY STOKES

BSc(Hons), CEng, FIEE, FCIBSE

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Editorial Offices:
9600 Garsington Road, Oxford OX4 2DQ
Tel: 01865 776868
Blackwell Publishing, Inc., 350 Main Street,
Malden, MA 02148-5018, USA
Tel: +1 781 388 8250
Iowa State Press, a Blackwell Publishing
Company, 2121 State Avenue, Ames, Iowa
50014-8300, USA
Tel: +1 515 292 0140
Blackwell Publishing Asia Pty Ltd,
550 Swanston Street, Carlton South,
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Tel: +61 (0)3 9347 0300
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Preface

My first task as editor is to acknowledge and thank my predecessors Alan Smith and Eric Reeves for their work in editing the three previous editions. It is to be hoped that they will not disapprove of this latest fourth edition.

Since the third edition was published in 1996, developments in many aspects of the electrical installation industry have continued apace, both on the technological and Standards fronts. The revolution in electronic microtechnology has made it possible to introduce more complex technologies in protective equipment and control systems. This, together with the rationalisation of national, European and international harmonised Standards, has led to the need to provide new guidance in some areas. So, after seven years, the time is ripe for an update to take account of such developments.

Additionally, since the third edition was published, the political and financial aspects of the supply industry have further escalated, with further fragmentation. Chapter 1 therefore was particularly difficult, trying to take account of the continuous change in practice. At the time of writing this book, the replacement of the Electricity Supply Regulations 1988 (as amended) was anticipated. The Electricity Safety, Quality, and Continuity Regulations came into force on 31 January 2003, but for the purposes of this book reference is made to the earlier Statutory Regulations.

The effect of changes in the industry over the last few years has meant the update of nearly all the 23 chapters. It is not possible to highlight here particular alterations for they are too numerous. Sections dealing with the safety aspects of electrical installations, most particularly Chapter 11, naturally take into account Electricity at Work Regulations. To a great extent these statutory requirements complement BS 7671: *Requirements for Electrical Installations*, known as the IEE Wiring Regulations. All chapters required some revision to take account of revisions and amendments to British and other Standards. It has to be recognised that, both on Standards and technology evolution, the target is continually moving. However, every effort has been made to bring the text as up-to-date as possible.

Over recent years lighting design development has continued. Extra-low voltage luminaires continue to be used extensively for display and feature illumination. Security lighting has now become an industry in its own right, and Chapter 18 takes all these factors into account.

The declared low voltage supply has for a number of years been harmonised across Europe to 400/230 V with tolerances of +10% and –6%. Further consideration of these tolerances is expected in 2008.

Geoffrey Stokes

CHAPTER 1

Power Supplies in the UK

D.C. Murch, CEng, FIEE

Revised by G.S. Finlay, BSc, CEng, MIEE
(Private Consultant)

In Great Britain the electricity supply industry was fully nationalised on 1 April 1948. Changes were made in 1957 which created a UK structure consisting of the Central Electricity Generating Board (CEGB) responsible for major generation and transmission throughout England and Wales, twelve Area Boards responsible for distribution within their areas in England and Wales, two Scottish Boards and a Northern Ireland board responsible for both generation and distribution within their areas, and the Electricity Council which had a co-ordinating role and performed special functions in relation to research, industrial relations and finance.

Privatisation of the supply industry was implemented in England, Wales and Scotland under the 1989 Electricity Act and in Northern Ireland by the Electricity (Northern Ireland) Orders 1992. The Area Boards were replaced by twelve Regional Electricity Companies (RECs) operating distribution networks under franchises. Two companies in Scotland and one in Ireland, having transmission and distribution networks, received franchises (see Fig. 1.2). A company which holds licences under the Act and Orders is designated a public electricity supplier (PES). Most of the industry is now owned by private investors following flotation on the stock market, and returns on capital investment are now made to shareholders instead of the Government. The Electricity Council was abolished by the Act but some of its engineering functions are now carried out by two new companies. EA Technology Ltd now offers a research and development service to the electricity industry (EI), while the Electricity Association (EA) operates as a trade association on behalf of all its member companies, most of whom are mentioned in the following text.

The structure of the UK electricity industry is shown in Fig. 1.1. In England and Wales approximately 33% of the system peak demand of 58 GW is met from thermal power stations, 41% from combined cycle gas turbine (CCGT) power stations and 20% from nuclear power stations. Powergen UK and Innogy, known in the UK as npower, own most of the thermal and CCGT power stations while British Energy plc and BNFL Magnox Generation, which is state owned, control all the nuclear power stations in the UK. The pumped-storage facilities at Dinorwig and Festiniog are owned by Edison Mission Energy, which is a subsidiary of Edison International.

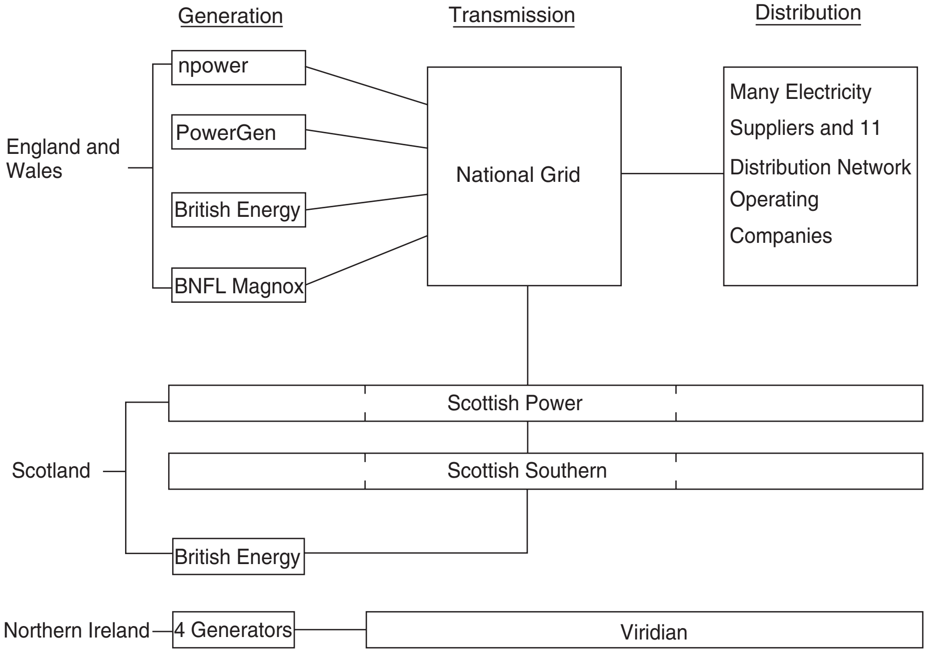

Fig. 1.1 Structure of the UK electricity industry.

When the National Grid Company (NGC) was sold by the twelve RECs to private investors in 1995, it retained its statutory duties to facilitate competition in the supply and generation of electricity and to develop and maintain an efficient, co-ordinated and economic transmission system. National Grid, as it is now named, is the only company holding a Transmission Licence for England and Wales. The 7000 route kilometres of circuits and approximately 300 substations which comprise the Grid are operated at 400 kV and 275 kV.

In Northern Ireland there are four major power stations with an aggregate capacity of 2300 MW and supplying a national peak demand of 1550 MW but also exporting to the Republic of Ireland. These power stations were sold to private investors in 1992, and Premier Power, a subsidiary of British Gas, now operates the largest at Ballylumford. NIGEN, a subsidiary of Tractebel and AES, operates two power stations and the fourth one at Coolkeeragh is operated privately by a management buy-out team. Northern Ireland Electricity (NIE) acts as the Independent System Operator with responsibility for both transmission and distribution systems, and responsibility for the purchase of electricity from Generators. A separate supply business has been established within the company, which facilitates competition and the unbundling of the core business. NIE became part of the Viridian Group in 1998.

In Scotland, the peak demand of approximately 4500 MW is met from 10 400 MW of generating plant owned and operated by British Energy, Scottish Power and Scottish and Southern Energy. The two latter companies operate as vertically integrated electricity companies and under their regulatory regime their generation, transmission, distribution and supply activities are treated as separate businesses and each is subject to separate regulation, which prevents cross-subsidy and excessive profit from manipulation of use-of-system charges.

There are two double-circuit connections, between the Scottish transmission network and that of National Grid, which are used to export power to England and Wales.

The original electricity supply franchise areas for distribution companies are shown in Fig. 1.2 and they now represent the areas under the control of Distribution Network Operating Companies (DNOs) which no longer have a monopoly to supply consumers connected to their networks. Some of the company names have changed since privatisation as a result of acquisitions and mergers.

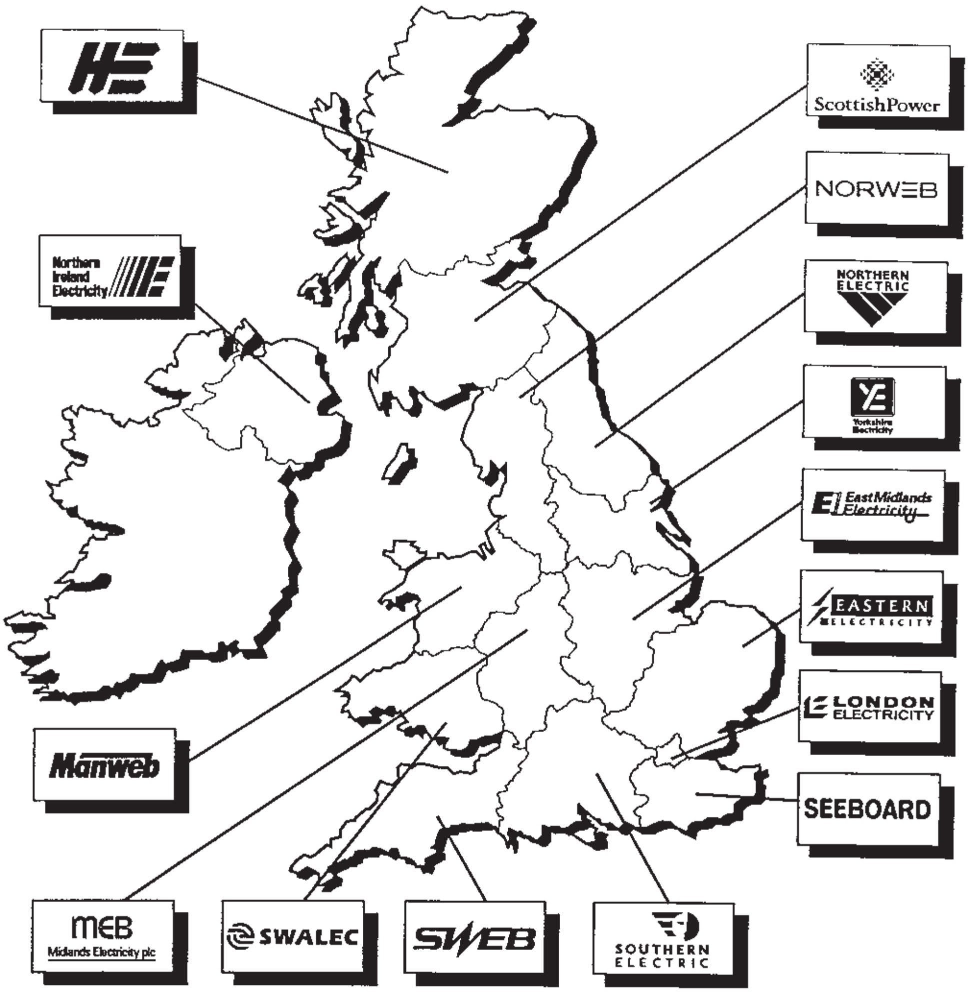

Fig. 1.2 The original franchised supply areas.

In 1999 the electricity supply and gas markets were liberalised so that now all customers in the UK are able to choose the company or companies from which to buy their supplies of gas and electricity, regardless of the company to whose network they are physically connected. These competitive markets have resulted in considerable savings to users. In the first year more than three million electricity users of the 22 million in England and Wales had switched supplier. Most of the original RECs still supply electricity to consumers and operate distribution networks but since liberalisation of the electricity market some RECs have either sold their supply businesses and only operate distribution networks, or have separated their supply and distribution businesses. There is an increasing tendancy for electricity supply to be integrated with generation.

The Office of the Gas and Electricity Markets (Ofgem) regulates the gas and electricity industries in Great Britain. Ofgem aims to bring choice and value to customers by promoting competition and regulating monopolies. Ofgem itself is governed by the Gas and Electricity Markets Authority (GEMA) and is organised into Directorates which have to report GEMA. The role of Ofgem's Director of Distribution and Financial Affairs is to oversee implementation of the Utilities Act 2000 and the Electricity Act 1989, particularly with regard to price regulation, protection of interests of customers by setting standards of service and promoting competition in electricity generation and supply, and gas markets.

The price of electricity is policed by Ofgem, which requires that the average use of system charge per unit distributed should not increase year on year by more than $RPI - x$, per cent after adjusting for an incentive to reduce electrical losses. The initial values for x were agreed between Government and individual supply companies, and range from 0 to –2.5%. In fact, increases in use of system charges have generally been kept well below the permitted limits.

The 1988 Electricity Supply Regulations and amendments, which were replaced by the Electricity, Safety, Quality and Continuity Regulations in late 2002, contain the statutory technical requirements for supplies to consumers in the UK. There are other technical requirements of a statutory nature in the Health and Safety at Work etc. Act 1989.

NGC was obliged to produce a Grid Code approved by the then Director-General of Electricity Supply, which defines the technical aspects of the working relationship between NGC and all those connected to its transmission system. Some generation embedded in distribution networks is subject to the provisions of the Grid Code. National Grid provides open access to the grid under terms which are non-discriminatory. However, all Generators and Distributors seeking connection must meet the appropriate standards to ensure that technical difficulties are not caused for others connected to the system.

The Grid Code covers items such as planning requirements, connection conditions, demand forecasting, coordination and testing requirements, together with the registration of appropriate data.

Each company operating an electrical distribution network is required to produce a Distribution Code, which establishes the basic terms of connection for users. In England and Wales the DNOs have a common Distribution Code as they all use the same preprivatisation Engineering Recommendations of the Electricity Council as technical references and the technical basis for managing their networks.

The Engineering Recommendations referred to in the Distribution Code are now published by the Electricity Association and are as follows:

(1) G5/4 *Planning Levels for Harmonic Voltage Distortion and the Connection of Non-Linear Equipment to Transmission Systems and Distribution Networks in the UK.*
(2) G12/3 *Requirements for the Application of Protective Multiple Earthing to Low Voltage Networks.*
(3) G59/1 *Recommendation for the Connection of Embedded Generating Plant to PES' Distribution Systems.*
(4) P2/5 *Security of Supply.*
(5) P25/1 *The Short Circuit Characteristics of PES' Low Voltage Distribution Networks and the Coordination of Overcurrent Protective Devices on 230 V Single Phase Supplies up to 100 A.*
(6) P26 *The Estimation of the Maximum Prospective Short Circuit Current for Three Phase 415 V Supplies.*
(7) P28 *Planning Limits for Voltage Fluctuations Caused by Industrial, Commercial and Domestic Equipment in the United Kingdom.*
(8) G75 *Recommendations for the Connection of Embedded Generating Plant to Public Electricity Suppliers' Distribution Systems Above 20 kV and with Outputs Over 5 MW.*
(9) S34 *A Guide for Assessing the Rise of Earth Potential at Substation Sites.*
(10) P29 *Planning Limits for Voltage Unbalance in the United Kingdom.*
(11) ER41–24 *Guidelines for the Design, Testing and Maintenance of Main Earthing Systems in Substations.*

Other recommendations referred to in this chapter are:

(12) G22/2 *Superimposed Signals on PES Networks.*
(13) G19/1 *Model Guidelines for Operations or Work on the Premises of Consumers Receiving H.V. Supply.*

All the documents listed above have been exempted from the requirements of the Restrictive Trade Practices Act 1976.

Distribution Code Review Panels comprised of representatives of Suppliers, Distributors, Generators and Users, as well as Ofgem, meet regularly to agree amendments to the Distribution Codes and their reference documents.

The Scottish companies operate under common transmission codes and separate distribution codes.

The biggest change in the electricity industry (EI), resulting from privatisation and Government incentives, has been the reduction of coal fired generation, the increase in gas fired generation, particularly combined cycle gas turbines (CCGTs), and the increase of generation embedded in DNO networks.

CCGTs are particularly attractive as they offer major environmental advantages over coal fired plant; they consume 27% less fuel, and emit 58% less CO_2 and 80% less NO_x for each kWh of electricity generated. Moreover they emit no SO_2 and so they do not contribute towards acid rain and global warming.

Also increasing are the numbers and size of wind farms connected to DNO networks. Schemes of 10 MW asynchronous generation are becoming common and development of photo-voltaic generation systems has just commenced. These non-fossil fuel systems are encouraged by Government financial incentives as they are environment friendly. In 1995 the completion of Sizewell B station added another 1250 MW of 'green' energy to the system and a similar station is proposed by British Energy for the same site.

NETA

Until 2001, trading of bulk generation and supply of electricity was carried out through the Electricity Pool of England and Wales (the Pool). This did not require bilateral contracts directly relating to supply between a Supplier or his customer and a Generator as the vast majority of all trading was carried out through the Pool. The Grid Operator was responsible for matching supply and demand by estimating the latter and dispatching generation to provide the former.

The New Electricity Trading Arrangements (NETA), which started in mid-2001, mean that Suppliers now contract directly with Generators for supplies; excesses or shortfalls are covered by a Balancing Market. This change has not affected the metering arrangements, which were previously in place for the Pooling arrangements (see Fig. 1.3 and the section on metering later in this chapter).

The Grid Operator continues to balance generation and demand in real time but now electricity is traded competitively between companies in 'forward' and 'futures' markets like any other commodity. In the first few months of operation, wholesale electricity prices fell by 20 to 25 per cent.

VOLTAGE AND FREQUENCY

The supply system in the UK was standardised at 240 V single-phase and 415 V three-phase with a frequency of 50 Hz following nationalisation in 1947 but was recently redeclared. The supply voltage for low voltage (l.v.) consumers is now 400 V + 10%, –6%, for three-phase supplies, and 230 V + 10%, –6%, for single-phase supplies at a frequency of 50 Hz ± 1%. In the year 2008 it is expected that all voltages in Europe will be redeclared within the range 400/230 V ± 10% in line with the Cenelec Harmonised Document, HD472, S. Distribution network design and voltage control will ensure that existing consumers' supplies will be unaffected by the new declaration and that their apparatus will continue to function satisfactorily. The greater part of electrical energy is sold at 230 V and used directly by most apparatus. Major generation is connected to the supergrid system which operates at 400 kV although some sections are at 275 kV. In England and Wales this network is owned and operated by NGC. The original 132 kV grid system which was started in 1926 was transferred from the CEGB to the area boards in the 1970s and is now the highest strata of distribution systems.

The major primary distribution voltage is 11 kV although a small proportion still operates at 6.6 kV. For most of the system there is an intermediate stage of 33 kV, but direct transformation between 132 kV and 11 kV is becoming common policy in city areas, where over 150 MW can be economically distributed

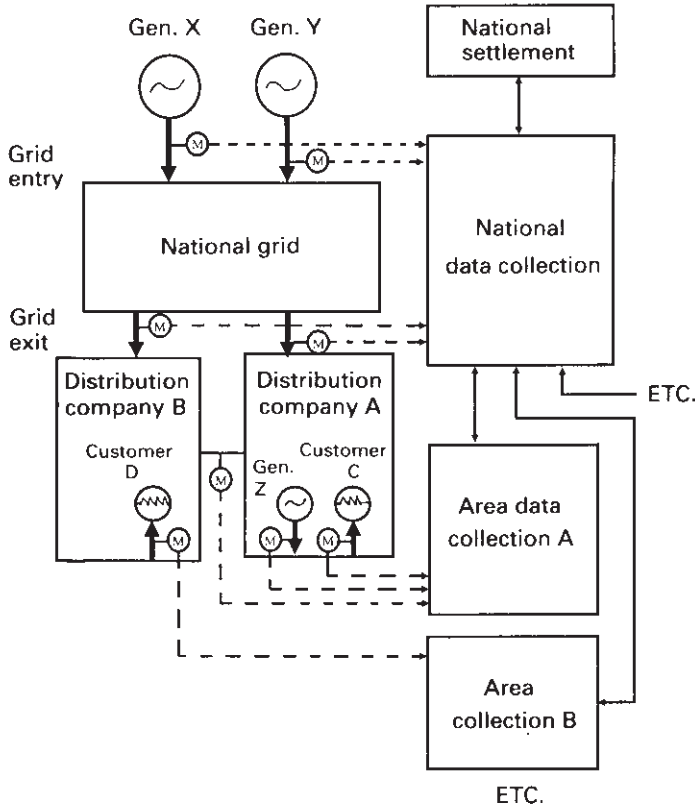

Fig. 1.3 Pool metering arrangements.

at 11 kV from one site. The frequency is maintained by NGC which regulates the input power to the generators to match the instantaneous load on the system and thus maintain their speed and thereby the frequency. This is manually controlled to very close limits, thus enabling synchronous clocks, time-switches and other motors to be used.

The voltage supplied to the consumers is mainly regulated by on-load tap-change gear on the transformers which supply the 11 kV system. Fixed tappings are used on the 11 kV to 433/250 V transformers as it would not be economic to put on-load tap-changing on these. For large machines or equipment, supply is at a higher voltage, usually 11 kV or transformed to 3.3 kV.

Apart from the size of the largest item, the need to bring a high voltage (h.v.) supply on to a consumer's premises is determined by the relative strength of the local network in relation to the total load. In order to determine what supply can be made available at any particular location, the local office of the appropriate DNO should be consulted at an early stage. While generators produce a near perfect waveform and the on-load tap-change gear maintains voltage at the 11 kV source within fine limits, all load on the system creates some distortion. The extent to which the various types of consumer load can be connected to the system depends on the distortion they are likely to create and the nuisance this disturbance causes to other consumers. This subject is dealt with more fully in a later section.

SYSTEM IMPEDANCE AND SHORT-CIRCUIT LEVELS

From the consumer's point of view another important parameter of the supply system is its impedance as viewed from his terminals. On the one hand, the lower the impedance the greater will be the stress on his switchgear and protective devices, but on the other hand, the higher the impedance the greater will be the risk of annoyance due to distortion caused by either the consumer's own load or by that of a nearby consumer. High network impedances are troublesome to installation designers because they result in low values of fault current, which severely limit the number of series graded protection devices and cause an increase in the I^2t energy let through of inverse characteristic devices such as fuses. The 16th edition of the IEE Wiring Regulations, BS 7671, requires installation designers to have a knowledge of the limits of system impedance to which the supply will be kept in order that they may install the necessary protective devices to an appropriate rating and to operate within the required time. All supply systems are dynamic and many DNO staff are continually employed laying cables and moving and installing plant in order to ensure that the system configuration meets the demands of the customers. For this reason it is not possible to give an exact impedance figure for any one location, but the appropriate local area office should be able to give installation designers the maximum and minimum likely to be encountered for a particular location. A maximum earth loop impedance figure of 0.35 Ω is quoted nationally for l.v., single-phase, PME system supplies of 100 A or less. An appropriate maximum prospective short-circuit current of 16 kA is quoted for many urban supplies; further information may be gained from Engineering Recommendation P25/1.

For many years it has been common practice to express the energy available on short-circuit in terms of 'short-circuit MVA'. This is simply $\sqrt{3}\,VA \times 10^{-6}$ where V is the normal system voltage between phases and A the symmetrical component of the short-circuit current.

In 1971 the International Electrical Commission (IEC) introduced a standard for switchgear ratings (IEC 56) which specified that the working voltage rating should be expressed in terms of the system maximum, for example 12 kV for an 11 kV system, and that short-circuit ratings should be expressed in terms of the maximum symmetrical fault current. A range of ratings was specified, for example 12.5, 16, and 25 kA for 12 kV gear.

For any three-phase system voltage the short-circuit level and the system impedance are inverse functions of each other, $\mathrm{kA} = \mathrm{kV}/\sqrt{3}\,Z$.

On l.v. systems the cables will generally be the major contributors to the system impedance as the h.v./l.v. transformers are of low impedance. The governing factor is thus the distance of the consumer from the nearest substation.

On DNO h.v. systems the short-circuit ratings of the switchgear have a considerable economic significance and, therefore, system designers aim at keeping these to as low a figure as practicable. A common method of achieving this is to employ high impedance 33/11 kV or 132/11 kV transformers. The high impedance is achieved by judicious spacing of the windings and does not increase the transformer losses or costs to any appreciable extent. The high impedance does not affect the voltage output as the tap-changer regulates accordingly. At 11 kV the impedance of the cables is generally much less significant.

Until the publication of IEC 56 many 11 kV systems were designed for a maximum level of 250 MVA which is equal to 13.1 kA. The new rating method therefore poses a problem where new or additional switchgear is required on an existing system, since the 16 kA switchgear is more expensive. In general, however, UK manufacturers can supply switchgear tested to 13.1 kA at similar to 12.5 kA prices. With the low growth of demand, these 250 mVA systems will remain for many years.

LOADING EFFECTS ON THE SYSTEM

Any normal load causes a voltage drop throughout the system. This is allowed for in the design, and the cost associated with the losses incurred is recovered in the related unit sales.

Unbalanced loads

Unequal loading between the phases of the network causes an unequal displacement of the voltages. Extreme inequality causes motors and other polyphase equipment to take unequal current and perhaps become overloaded on one phase. For this reason DNOs impose limits on the extent to which they accept unbalanced loads at any particular location in order to ensure that other consumers are not adversely affected. Installation designers need to ensure that the same problem does not arise due to an unbalanced voltage drop within the consumer's installation itself.

While most voltage unbalance is caused by single-phase loading, the effect on a three-phase motor can best be assessed in terms of the negative phase sequence component of the voltage thereby created. Providing that this is less than 2% the inequality of current between phases should not be more than the motor has been designed to withstand. Engineering Recommendation P29 aims to limit continuous levels of voltage unbalance to 1%.

Power factor

Many types of apparatus such as motors and fluorescent lighting also require reactive power and thereby take a higher current than is necessary to supply the true power alone. This extra current is not recorded by the kWh meter but nevertheless has to be carried by the distribution system and uses up its capacity thereby. It also increases the losses on the system. A power factor of 0.7 means that the current is 1/0.7 = 1.43 times as great as absolutely necessary and thus doubles the losses ($I^2 R$). If all the loads in the UK were permitted to have as low a power factor as this, the additional cost of the losses (if the system could stand the burden) would be in the order of £200 million per annum.

It will readily be seen, therefore, why DNOs are keen to ensure that their consumer's power factors are near to unity. Where practical, some penalty for poor power factor is built into the tariff or supply agreement.

Power factor correction is therefore an important aspect in the design of installations, although too often forgotten at the outset (see Chapter 23). The most simple and satisfactory method is to have each equipment individually corrected as this saves special switching and reduces the loading on such circuits. Bulk correction of an installation is, however, quite commonly used, particularly where it is installed as an afterthought. There are then problems of switching appropriate blocks of capacitance to match the load, as overcorrection again increases losses and, in addition, creates voltage control problems at light load.

Switching transients

One of the primary uses of electricity is for general lighting and the local DNO must ensure that its supply is suitable for this purpose. Repeated sudden changes in voltage of a few per cent are noticeable and are likely to cause annoyance. The local DNO must ensure that these sudden variations are kept within acceptable levels and this means placing limits on consumers' apparatus which demands surges of current large enough to cause lighting to flicker.

In order to evaluate flicker in measurable terms, two levels have been selected: the threshold of visibility and the threshold of annoyance. Both are functions of frequency of occurrence as well as voltage change. Since both these thresholds are subjective it has been necessary to carry out experiments with various forms of lighting and panels of observers to ascertain consensus relationships between frequency of occurrence and percentage voltage change for the two thresholds. The DNOs have used this information in setting the planning levels for flicker contained in Engineering Recommendation P28, which govern motor starting currents, etc.

The network impedance from the source to the point of common coupling between the lighting and the offending load is of paramount importance and thus the local office of the DNO should be consulted in cases where the possibility of creating an annoyance arises.

Intermittently loaded or frequently started motors, such as those on lifts, car crushers, etc., together with instantaneous waterheaters, arc welders and furnaces, are all potential sources of disturbance. Large electric furnaces present a particular problem and it is frequently necessary to connect them to a higher voltage system than is necessary to meet their load in order to achieve a lower source impedance.

Fluctuations occurring about ten times a second exhibit the maximum annoyance to most people, but even those as intermittent as one or two an hour will annoy if the step change is of sufficient magnitude.

CENELEC Standard EN61000-3-3, limits voltage fluctuation emissions from equipment rated less than or equal to 16 A and EN61000-3-11 limits emissions from equipment rated from 16 A to 75 A.

Harmonics

Harmonics on the supply system are becoming a greater problem due to the increasing use of fluorescent lighting and semiconductor equipment. Cases have been known where large balanced loads of fluorescent lighting have resulted in almost as much current in the neutral as in the phases. This current is almost entirely third harmonic. The use of controlled rectifiers and inverters for variable speed drives, as used on many continuous process lines, can also be a problem and DNOs have frequently to insist that 6- or 12-phase rectification be used. It is another case for local consultation to determine what the system will stand. Even a multiplicity of small equipment can summate to create a big problem, for example television set rectification, and for this reason international standards have been agreed. Engineering Recommendation G5/4 sets out the limits of harmonic voltage distortion which are acceptable to the supply industry for the connection of load at various voltage levels. CENELEC Standard EN61000-3-2 limits harmonic emissions from equipment rated less than or equal to 16 A and IEC TR61000-3-4 is applicable to equipment rated at more than 16 A.

SUPERIMPOSED SIGNALS

For many years load control systems which superimposed signals on the normal supply system have been in use. The earlier ones were usually at a higher frequency and were referred to as ripple control, though one system used a d.c. bias. Tuned relays respond to the appropriate signal and switch public lighting, change various tariffs according to time of day or system load, switch water or space heating according to tariff availability or weather conditions, and perform various other functions, even to calling emergency staff.

Although these did and still do perform satisfactorily, they did not come into universal use, probably because the full expenditure on signal generators was necessary to cover the system even though initially there were only a few receivers, and this caused cash flow problems.

Equipment came on the market which could communicate from one premises to another over the supply system. The EI predicted severe interference problems if bandwidths were not allocated for specific types of usage. Self regulation has evolved under the guidance of TACMA and the EI has produced its own working document Engineering Recommendation G22/2. The British Standards Institution has published BS 6839 on the subject.

With the advent of the thyristor and the transistor, supply companies started experimenting with them on their network as a communication media, using pulse techniques both for one-way and two-way communication. Practical installations have been developed and a number of one-way systems installed to perform similar functions to those carried out by the earlier ripple control method.

One such system developed by London Electricity was a range of codes transmitted by short pulses injected at the zero point of the 50 Hz wave (Fig. 1.4). Injection at this point requires less power and thus enables smaller transmitters to be used. This method has been taken up by a major UK manufacturer and several one-way systems called Cyclocontrol are now controlling over 150 MW of off-peak load in London. The two-way communication objective is to read meters remotely and a workable system has been in use for several years, but only as a pilot scheme because it was not economically viable using discrete components.

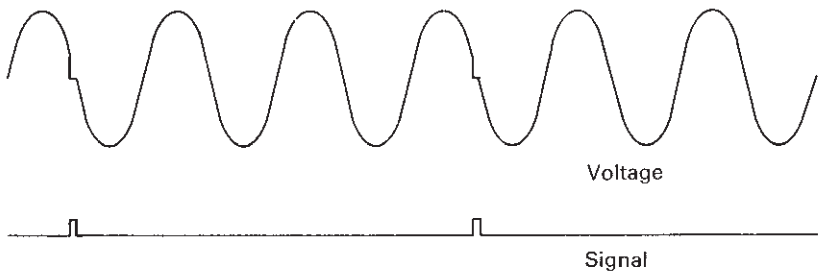

Fig. 1.4 Cyclocontrol signals.

The advent of the microprocessor and its relatively low cost in quantity production has widened the development field and made many schemes attractive. Solid state metering with sophisticated control and tariff regulating functions will definitely be in use in the near future. Deciding what these 'black boxes' should be made to do is the big problem facing the EI, remembering that there are some 20 million energy meters in the UK alone and the task of changing these is a mammoth one. If the changes were carried out as part of the normal recertification programme it would take 15–20 years to complete. Consumers who had to wait this long for an attractive tariff or control function to be available to them would be far from happy.

There is another side to the picture. Sophisticated control systems which are already available for use within a consumer's premises enable a master programme controller to send signals over the main conductors to slave controllers on appropriate apparatus. The master controller being flexibly programmed via a keyboard and display is even capable of responding to signals sent via the telephone.

Interference, both accidental and wilful, is a problem which needs careful consideration and rejection circuits may be needed where such systems are in use on both sides of the supply terminals.

While the use of the network itself, as a control medium, is attractive to a DNO, it has its drawbacks and other methods using superimposed signals over the radio or telephone are being used. The radio is attractive for one-way communication as the transmitter cost is minimal and full coverage is available. The telephone is attractive for two-way communication as the addressability exists within the telephone system.

From the electrical contractor's point of view this expanding field of superimposed control is likely to extend the range of his work and so add to the complexity of some installations.

RADIO TELESWITCHING

The EI in collaboration with the BBC investigated the possibility of superimposing digital data on BBC long-wave transmissions for the purposes of sending information and control signals from its offices to its customers' premises. Suitable technology to enable this was developed and the radio teleswitching (RT) system was approved by the relevant authorities. An important requirement was that the superimposed signals should not impair the reception of normal audio (Radio 4) programmes transmitted on long-wave band. Fully operational facilities became available in 1984.

The EI holds a patent on the development and issues licences to approved manufacturers of RT devices. The RT device consists of three essential components – a radio receiver capable of satisfactory performance under low signal strength and high noise level areas, a microprocessor which decodes the received signals and includes a time clock and memory, and a set of contacts or switches which are controlled by the microprocessor.

Companies supporting the RT system use it for one-way communication with load and metering apparatus in their customers' premises. The system does not need routing or rerouting of signal paths. Nationwide broadcast coverage and the use of unique codes enables a user company to send signals to its customers no matter where they are located in the UK and prevents one company's data affecting customers of another company. A company can store an entire week's programme for all its groups of RT devices in the central computer of the RT system or, through the same computer system, it can send immediate command control signals addressed to any of its groups. This central teleswitch control unit (CTCU) is managed by the Electricity Association which also manages the development and operational arrangements of the whole RT system. The CTCU converts the programme information into the required codes, minimises the signals required and schedules and despatches them for transmission at the appropriate times. Off-air monitors are installed for each transmitter area, and the signals from these are fed back to the CTCU as a check that all despatched messages have been broadcast and therefore should have been received by all RT devices.

The most common type of RT device used by companies has a 24-hour clock and a memory which stores programme messages for a day. The RT device then controls customer load and tariff according to the received and stored 24-hour programme. The problem of inaccuracy and drifting of load and tariff switching times is eliminated by the broadcasting of time signals every minute. A stored programme can be removed and replaced by an entirely different 24-hour programme at any time, or it can be gradually changed to the following day's programme on a rolling basis. A programme may also be suspended and replaced by an immediate command broadcast at any time. The devices have a standard fallback programme which they follow under certain conditions. To keep new devices updated and help ensure reception, broadcast messages are repeated as a routine. If a device misses a programmed broadcast and its repeats it will follow the last programme it received.

By being first in establishing radio teleswitching as a fully operational cost effective option for use in energy management on a national scale the EI has given the UK a world lead in this field. Further developments of the RT system are intended to increase its data carrying capability, enable weather and cost related information to be broadcast as energy management parameters and allow the system to be integrated with other developing technologies, such as smart cards, so that the full potential of the system can be realised.

SYSTEM AND INSTALLATION EARTHING

In the UK the Electricity Supply Regulations have governed the way systems are connected to earth. The successor Regulations, The Electricity Safety, Quality and Continuity Regulations 2002, came into force on 31 January 2003. For the purposes of this book reference will be made to the earlier Statutory Regulations.

Low voltage systems

For many years the Regulations required that each l.v. system should be solidly connected to earth at only one point, that being the neutral of the source transformer. Special permission was necessary to earth at more than one point. The Regulations also required that cables buried in the highway must have a metallic sheath. Systems earthed at only one point require the neutral conductor to be electrically separate and are now known as SNE (separate neutral and earth).

It was, and still is, the responsibility of each consumer to provide the earth connection for his own installation. This was commonly achieved by connection to a metallic pipe water main. The growing use of PVC water mains makes this impossible for new installations and causes problems with existing ones when water mains are replaced. Gradually, supply companies developed a practice of providing consumers with an earth terminal connected to the sheath of their service cable. This is, of course, a very satisfactory arrangement but it is not universally practical as many cables laid in the 1920s or earlier are still in use and many of these are not bonded across at joints. The arrangement is not practical on most overhead systems.

In Germany and elsewhere in Europe an earthing system known as 'nulling' grew up. This employed the principle of earthing the neutral at as many points as possible. It simplified the problem of earthing in high resistance areas and by combining the sheath with the neutral conductor permitted a cheaper cable construction. These benefits were attractive and during the 1960s the official attitude in the UK gradually changed to permit and then encourage a similar system known as PME (protective multiple earthing). Blanket approvals for the use of this system, and the required conditions to be met, were finally given to all area boards in 1974. In BS 7671 – the 16th edition of the IEE Wiring Regulations this system is classified as TN-C-S.

Providing the consumer with an earth terminal which is connected to the neutral conductor ensures that there is a low impedance path for the return of fault currents, but without additional safeguards there are possibilities of dangerous situations arising under certain circumstances.

If the neutral conductor becomes disconnected from the source of supply then the earthed metalwork in the consumer's premises would be connected via any load to the live conductor and thus present an electric shock hazard from any metalwork not bonded to it, but which has some connection with earth. In order to eliminate this rare potential hazard the Secretary of State, in his official Regulations, requires that all accessible metalwork should be bonded together as specified in the IEE Wiring Regulations and so render the consumer's premises a 'Faraday cage'. This is the reason for the more stringent bonding regulations associated with PME.

Under the extremely rare circumstances of a broken service neutral and intact phase conductor, there may be a danger of electric shock on the perimeter of the