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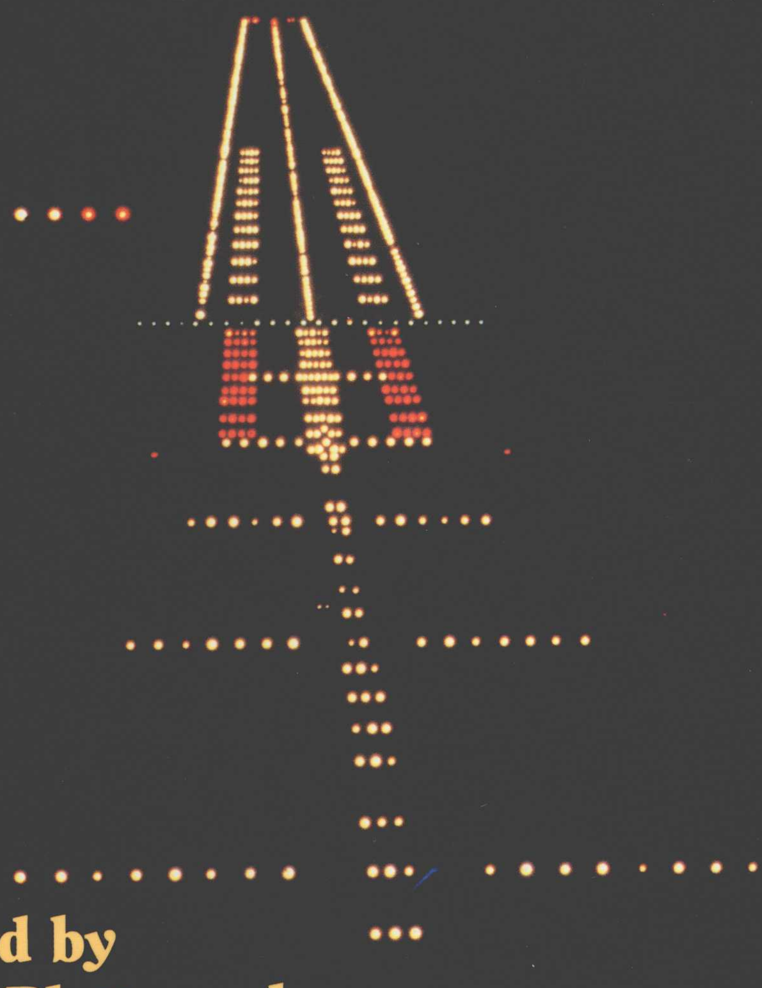
UNINTERRUPTIBLE POWER SUPPLIES



Edited by John Platts and

UNINTERRUPTIBLE POWER SUPPLIES

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Foreword

'Uninterruptible Power Supplies' is intended to be a fundamental guidebook related to the various systems available and how they may be usefully specified and employed.

While we have come to expect reliability and continuity of supply from the electricity supply utilities, this cannot be guaranteed absolutely and outages and disturbances must be expected at some time. Such outages and disturbances can be quite disastrous in the case of sensitive loads, such as computers, which are now extensively used in modern commerce and industry. Equally, such electronic equipment is often dependent on a clean electricity supply.

Thus, a continuous supply of clean electrical power has become a necessity for many functions within business and manufacturing organisations, and this book outlines what is involved in the design, construction, installation and operation of suitable supply equipment.

After setting the scene in the first two chapters, the next five chapters describe a range of equipments and systems used for uninterruptible power supplies. These are followed by chapters on the application of UPS equipment in active operation in two typical important fields where security of supply is vital.

Finally there are three chapters dealing with, respectively, harmonic distortion, reliability and specification of equipment.

The authors who have contributed to this book represent leading manufacturers, authoritative designers and consulting engineers, and professional engineers of user organisations.

Each author has written his particular chapter based on knowledge and experience gained in day to day involvement with UPS systems. Consequently, the book should be regarded not so much as an academic theoretical treatise, but more as sound engineering logic from experienced practical Chartered Engineers. Therefore, it should prove to be helpful for professional engineers who have a requirement to specify, design, install and subsequently make use of the facilities available from UPS systems.

The Editors wish to acknowledge and give full credit for the initial conception of this book to Alec King and Bill Knight.

The complete team of authors are separately listed; all are expert in their respective aspects and fields of endeavour. Both the IEE and the Editors are grateful for their contributions. Acknowledgment to HM Stationery Office is given in relation to permission to quote extracts from the Electricity Regulations in Chapter 1.

The Editors have tried to produce a unified text, and hope it will fulfil a long felt need.

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Chapter 1

Why the need arises

J. R. Platts

1.1 Reliability of electricity supply

The objective of an electricity supply utility is to provide a wide range and variety of customers with a supply of electrical energy. The purpose is to meet the variable and instantaneous demand for electricity at the most economic cost, and to achieve customer satisfaction by a good standard of reliability and quality, typically in terms of voltage and frequency. Over the last 100 years the customer, whether a householder or a major commercial organisation, has increasingly developed an expectation that electricity will always be available like water from the tap.

In the UK and most other industrial countries total outage of the electricity supply network is an extremely rare occurrence. Reliability is overwhelmingly good except in situations such as very adverse weather conditions. These can be hurricane winds with resultant falling of trees onto overhead distribution lines; flooding due to excessive rainfall with rivers overflowing their banks; and in some countries the build up of ice on overhead distribution lines under conditions known as freezing rain. Freezing fog and rain can produce flashovers on the insulators of overhead lines particularly if they have been previously affected by salt and other pollutants carried by on-shore winds. In economic terms it is totally impossible to safeguard the electricity supply network against sporadic system failures. The majority of disturbances to the continuity of electricity supply are caused by external factors beyond the control of the utility's operating staff. However, through careful design and planning the probability of some disconnections may be reduced, but generally at a price. The balance of costs and benefits of such provision of increased security of supply is a matter for judgment and assessment by the customer.

It is unrealistic to expect the electricity supply utility to plan the generation, transmission and distribution systems such that supplies of electricity are never interrupted. To achieve this ideal would entail investment costs which would make electricity prohibitively expensive, judgments have to be made by the utility related to provision of adequate capacity and the relative trade-off between quality and security of the service for the main body of customers and the costs of providing that service. Although customers have an expectancy that electricity will be available at all times, this availability stems from a myriad of difficult decisions; for example, in the areas of planning, sizing, engineering, control and location of plant and equipment within the composite system.

Most electricity consumers in the United Kingdom experience very rare interruptions in the continuity of electricity supplies. Whilst it is clear that averages can be misleading, the situation is that on average each customer experiences supply interruptions totalling about only one hour 30 minutes per annum (i.e. out of 8760 hours in the year). This average figure has been reduced from one hour 44 minutes per annum applicable in 1965–66, and is inclusive of planned outages. Interruptions are caused not only by adverse weather conditions but also by planned maintenance of distribution networks, of which advance notice is provided by the local distribution company. Needless to say industrial disputes can catastrophically affect outage times.

The Annual Report of Electricité de France indicates that the average outage time for low voltage customers in that country has been reduced from about 11 hours per annum in 1965 to 5 hours 22 minutes in 1986. The figure increased to 6 hours 26 minutes in 1987 due to the effect of the October hurricane. The average outage time due to planned work was 1 hour 15 minutes, due to accidental interruptions was 4 hours 35 minutes and due to generation and transmission difficulties it was 36 minutes.

Outage times of customers in other European countries vary quite considerably. Typically they have been about 18 minutes per annum in West Germany, 38 minutes per annum in Stockholm (Sweden), and 74 minutes for Denmark. Understandably the outage times in rural areas tend to be higher than in urban areas. For Japan it is said that one power company has an average outage time of 6 hours 52 minutes, comprising 46 minutes unplanned and 6 hours 6 minutes for planned work. In the United Kingdom there is a wide variation across the country with average times in the South West and South Wales being about twice as high as in the Midlands, and with London considerably lower than the national average.

1.2 Electricity Supply Regulations 1988

The Electricity Supply Regulations impose requirements regarding the installation and use of electric lines and apparatus of suppliers of electricity including provisions for connections with earth. Part VI contains provisions relating to supply to a consumer's installation, and in particular Regulation 30 imposes a requirement to give information regarding the type and quality of supply with specific limits.

It is equally important to be aware that these Regulations cover provision for 'Discontinuance of supply in certain circumstances' including the causing of undue interference with the supplier's system or with the supply to others. The pertinent extracts are Regulations 27 and 28 which are quoted in this text by kind permission of HM Stationery Office.

1.2.1 *Extracts from Electricity Supply Regulations*

General conditions as to consumers
27(1): No supplier shall be compelled to commence, or, subject to regulation 28, to continue to give a supply to any consumer unless he is reasonably satisfied that each part of the consumer's installation is so constructed, installed, protected and used, so far as is reasonably practicable, as to prevent danger and

not to cause undue interference with the supplier's system or with the supply to others.
27(2): Any consumer's installation which complies with the provision of the Institution of Electrical Engineers Regulations shall be deemed to comply with the requirements of this regulation as to safety.
Discontinuance of supply in certain circumstances
28(1): Where a supplier, after making such examination as the circumstances permit, has reasonable grounds for supposing that a consumer's installation or any part of it, including any supplier's works situated on the consumer's side of the supply terminals, fails to fulfil any relevant requirement of regulation 27, paragraphs (2) to (7) shall apply.
28(2): Where, in an emergency, the supplier is satisfied that immediate action is justified in the interests of safety, he may without prior notice discontinue the supply to the consumer's installation and notice in writing of the disconnection and the reasons for it shall be given to the consumer as soon as is reasonably practicable.
28(3): Subject to paragraph (2), the supplier may, by notice in writing specifying the grounds, require the consumer within such reasonable time as the notice shall specify to comply with one or both of the following:

(*a*) to permit a person duly authorised by the supplier in writing to inspect and test the consumer's installation or any part of it at a reasonable time
(*b*) to take, or desist from such action as may be necessary to correct or avoid undue interference with the supplier's supply or apparatus or with the supply to, or the apparatus of, other consumers.

28(4): In any of the circumstances specified in paragraph (5) the supplier may, on the expiry of the period specified in the notice referred to in paragraph (3), discontinue the supply to the consumer's installation and shall give immediate notice in writing to the consumer of the discontinuance.
28(5): The circumstances referred to in paragraph (4) are:

(*a*) that, after service of a notice under paragraph (3) (*a*), the consumer does not give facilities for inspection or testing; or
(*b*) in any other case:
  (i) after any such test or inspection the person authorised makes a report confirming that the consumer's installation (or any part of it) fails to fulfil any relevant requirement of regulation 27; or
(ii) the consumer fails to show to the reasonable satisfaction of the supplier within the period so required that the matter complained of has been remedied or is the responsibility of the supplier.

28(6): Any difference between the consumer and the supplier in relation to the grounds or the period specified in any notice of the kind mentioned in paragraph (3)(*b*) shall be determined in the manner provided by regulation 29.
28(7): The supplier shall not discontinue the supply in pursuance of paragraph (4) pending the determination of any difference of the kind mentioned in paragraph (6), and shall not discontinue the supply to the whole of the consumer's installation where it is reasonable to disconnect only a portion of that installation in respect of which complaint is made.

28(8): Where in pursuance of this regulation a supplier has disconnected the supply to a consumer's installation (or any part of it) the supplier shall not recommence the supply unless:

(*a*) he is satisfied in respect of the consumer's installation that the relevant requirements of regulation 27 have been fulfilled; or
(*b*) it has been determined in the manner provided by regulation 29 that the supplier is not entitled under regulation 27 to decline to recommence the supply,

and if he is so satisfied or it is so determined, the supplier shall forthwith recommence the supply.

Regulation 30 reads as follows:
Declaration of phases, frequency and voltage at supply terminals
30(1): Before commencing to give a supply to a consumer, the supplier shall declare to the consumer:

(*a*) the number and rotation of phases;
(*b*) the frequency; and
(*c*) the voltage,

at which it proposes to deliver the supply and the extent of the permitted variations of those values:
Provided that, unless otherwise agreed between the supplier and the consumer, the frequency to be declared shall be 50 Hz and the voltage to be declared in respect of a low voltage supply shall be 240 V between the phase and neutral conductors at the supply terminals.
30(2): For the purposes of this regulation, and unless otherwise agreed by the consumer, the permitted variations are:

(*a*) a variation not exceeding one per cent above or below the declared frequency; and
(*b*) a variation not exceeding six per cent above or below the declared voltage at that frequency where that voltage is below 132 kV, and not exceeding 10% above or below the declared voltage where that voltage is 132 kV or above,

or the variation which may have been authorised by the Secretary of State under paragraph (3).
30(3): The Secretary of State may, on application by a supplier, authorise him to alter any of the declared values or any permitted variation if he gives such notice of his application as the Secretary of State may require.
30(4): The supplier shall forthwith give notice of any authorisation under paragraph (3) to every consumer to whose supply it may apply.
30(5): The supplier shall ensure that, save in exceptional circumstances, any supply he gives complies with the declaration under paragraph (1).
30(6): The polarity of direct current and the number and rotation of phases in any supply shall not be varied without the agreement of the consumer or, in the absence of such agreement, the consent of the Secretary of State who may impose such conditions, if any, as he thinks appropriate.

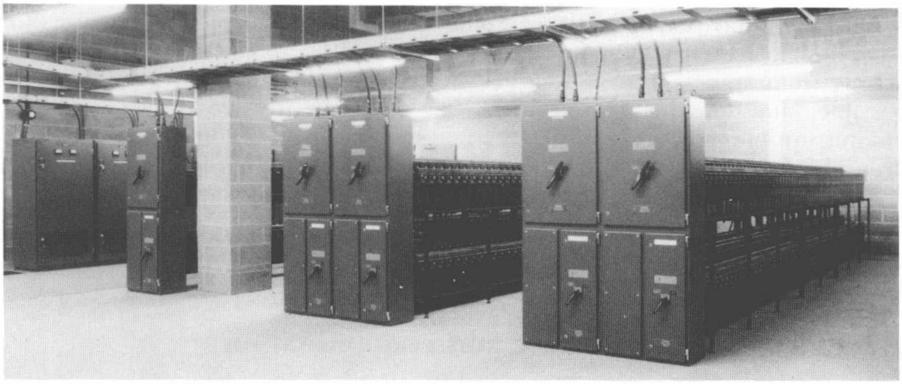

Figure 1.1 *The Halifax Building Society's Copley data centre is protected by an Anton Pillar uninterruptible power supply system backed by over 3000 Tungstone ultra high performance Planté cells. Power can be supplied for up to 20 min to allow a back-up supply from diesel generating sets to be brought on-line or, if the generators fail to start, for a controlled shut down of the computers to be completed. The data centre contains computers which control over 10 000 different terminals and automatic teller machines and are permanently on-line. The UPS systems are tested weekly*

1.3 The need to protect against power supply breaks and disturbances

Whilst the general standards of supply are completely adequate for most applications in industry and commerce, the contamination of the supply by relatively small disturbances can cause serious and unacceptable problems for sensitive loads — typically computers. The need is not just to provide standby power in the event of supply failure, but is also to make certain that the electrical input to valuable computer systems is as pure, clean and continuous as is required, to prevent any data or control signals being corrupted or lost entirely (Fig. 1.1).

Although from the information already provided it can be seen that total power outage from the electricity supply utility is infrequent, it should be recognised that the timing of a break is beyond the customer's control. It follows that a sudden break in power supply or even a mild fluctuation could occur at a critical time for the business. This might prove to be disastrous, since the computer's data could become corrupted or totally lost. The manifestation of the incident may become apparent through damage to computer hardware as well as sporadic and unexplainable errors occurring on the software.

Similarly, mains-borne electrical interference such as surges can adversely affect computers and process control equipment. Typically this electrical interference results from thunderstorms and lightning, from switching operations and from other electrical apparatus within the building (e.g. from thyristors within electronic devices utilised for controlling other essential electrical equipment).

One might have expected the computer and process control manufacturers to have designed their equipment to be less susceptible to electrical interference arising from spikes, dips and surges. Apparently, this has not proved to be possible, and for this reason there has been progressive development of uninterruptible power supply (UPS) systems. They become an economic proposition for organisations whose business and associated information technology demand a vital need to protect against power supply breaks and disturbances.

1.4 Electrical interference and contamination

Several forms of interference can cause problems for electronic instrumentation and information technology systems. Each form of electrical interference is separately considered in this section as follows:

1.4.1 *Spikes*

Lightning is the atmospheric condition which is the main external and unpredictable causes of spikes on the public electricity supply network. Lightning strikes which hit overhead lines can produce high voltages spikes of some considerable power. Also similar effects are the result of ground strikes of lightning by induction into power lines and cables.

Other major sources of spikes are switching operations and particularly those relatively close to the computer and other electronic equipment. Switchgear operating on heavy currents and HRC fuses are devices which are known to produce transient spikes when operating as designed and as intended under fault conditions.

Spikes with high amplitudes up to many hundreds of volts, and even in excess of 2 kV, are to be encountered with major electrical system faults. Being transient, they are of short duration and last for some 100 μs. They are oscillatory having a frequency in excess of 100 kHz. The rise time can be relatively short at about 1 μs.

A greater occurrence of spikes is attributed to semiconductor switches, and they can even be caused by electrostatic discharges from staff walking on office carpeting and subsequently touching metallic cabinets with a resultant spark. In particular, repetitive strikes are generated by thyristors and triacs used in control systems; by variable speed commutator motors as used on lifts and escalator drives; by sodium and mercury discharge lamps; by mercury arc rectifiers in various applications for the production of direct current; and also by the overhead collector or third rail collector on electric traction systems. Repetitive strikes attributable to semiconductor devices have amplitudes normally not exceeding 300 V and with a rise time in the range of 50 ns to 1 μs. Total duration time does not normally exceed a few tens of microseconds.

Other forms of spikes are generated by the switch starting and stopping of induction motors, which are typically used for driving pumps and fans. Random spikes commonly have amplitudes up to about 800 V and rise times as short as a few nanoseconds. Contact bounce of the contractors within the starter can result in a series of spikes; although each spike has a duration of less than 100 μs, the contact bounce will extend the incident over a longer period.

1.4.2 *Surges and dips*

Surges and dips in the electrical supply are generally brought about by the switching off (surges) and switching on (dips) of large loads. The criterion is the size of the load being switched in relation to the transformer rating at the local point of supply. The phenomenon of a surge is analogous to the momentum of inertia in a mechanical system, and a dip is a reverse concept to a surge. Typically, one can sense and become aware of surges and dips through variations in the luminance of lamps in lighting systems. Duration periods for both surges and dips can be in the range of a single half cycle of the electricity supply waveform through to several half cycles. The latter is the more usual duration period. The variation from the nominal voltage resulting from surges and dips can exceed the normal range of 6% above or below.

Types of loads to be switched within the building and fed from the same electricity supply point are usually electric motors. These may be as applied for motive power to drive lifts, escalators, refrigeration compressors, pumps or fans.

Beyond the local point of supply, voltage dips are sometimes caused by major variations on the high voltage supply network such as system faults or sometimes major load switching of industrial plant. Normally provision is made at the design stage to avert the adverse impact of industrial plant such as arc furnaces. The number and size of voltage dips due to disturbances beyond the point of supply is to a large extent dependent upon the robustness of the local network. Generally, the situation prevailing in a major city or urban area is better than in a rural area.

Fluctuating high power loads are encountered in industrial processes. For example, in steel works variable high power loads could arise from arc furnaces and from highly powered reversing mill motor drives. These types of installation can produce voltage fluctuations which, in transmission through to the supply network, may result in flicker. The flicker usually has frequency of a few hertz with voltage amplitudes within a few percent of the nominal voltage.

1.4.3 *Harmonics*

Thyristors, mercury arc rectifiers, discharge lamps, diodes, induction motors and variable speed commutator motors are all electrical devices which generate harmonics on the mains supply.

These may be relatively low on most distribution systems with the total harmonic content of the voltage in the range of 2—5%. Only under exceptional circumstances will higher total harmonic contents be experienced.

1.5 Criteria influencing the need for UPS

Uninterruptible power supplies are necessary for any business operation which requires a very high availability factor and purity factor for a key facility on which the core activities crucially depend. For applications where corruption of data or interruption of supply even for a fraction of a second cannot be tolerated, a UPS is needed.

A surge, dip, break, fluctuation, or other contamination can in some situations prove to be absolutely devastating. Such circumstances can result in disastrous loss of data. The most susceptible and vulnerable facilities are the whole range of computer and instrumentation processes.

The vulnerability of a computer system or information technology system to interference or mains supply disturbance is dependent upon the precautions built into the system by the designer.