THE HONG KONG

INSTITUTION OF ENGINEERS

ELECTRICAL DIVISION

One day Symposium

Friday, 8th November 1985

Effective Use of Electricity in Hong Kong

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Symposium Programme

08.30 Registration and Coffee

09.00 Introduction
- Symposium Chairman: Mr. A. D. Longmore BSc(Eng), DipMS, CEng, FIEE, FHKIE, MBIM.
  Welcomed by: Mr. Y. C. Tong, MSc, DipEE, FHKIE, CEng, FIEE, MITD.

90.05 Opening Address
- President: HKIE Mr. W. S. Y. Chan, BSc, DLC, FHKIE, CEng, FICE, FInst Petroleum.

1. <u>Quality of Electricity</u>

09.10 'Reliability of the Electrical Supply Systems'
- Speaker: Mr. J. Gibson, BSc(Eng), CEng, MHKIE, MIEE, Supplies Engineer, CLP.

09.30 'Pollution in the Electrical Environment'
- Speaker: Dr. S. K. Tso, BSc(Eng), PhD, CEng, MIEE, Sen MIEEE, MHKIE, Senior Lecturer, HKU.

09.50 'Reliability of Electrical Supply in Hospitals'
- Speakers: Mr. S. S. Fung, BSc, MHKIE, CEng, MIEE, Sen. B. S. Engineer, EMSD,
  Mr. W. K. Fan, MIEE, MHKIE, CEng, Sen. B. S. Engineer, EMSD,
  Mr. R. S. Chin, BSc, CEng, MIEE, MIEEE, MHKIE, B. S. Engineer, EMSD.

10.10 Discussion

10.30 Coffee

2. <u>Computerized Energy Management</u>

10.50 'Use of Computer in Energy Saving Study'
- Speaker: Mr. Deryck Thornley, FCIBSE, FHKIE, MASHRAE, Partner, JRP.

11.10 'Conserving Electrical Energy in Buidlings by Computerized Control'
- Speaker: Mr. Eric L. H. Ho, DipEE, MHKIE, MIEE, CEng, MCIBSE, Manager, Johnson Control Hong Kong.

11.30 'The Application of Microprocessor based Equipment for Energy Saving and Consumption Optimisation in Industrial Installations'
- Speaker: Mr. M. C. S. Simposn, BSc (Eng), CEng, MIEE, Technical Director, GEC Meters Ltd, UK.

11.50 Discussion

12.10 Lunch

TAI Tak-him

3. Means for Effectiveness

14.10 'Uplighting & Energy Saving Techniques'
– Speaker: Mr. L. Bedocs, CEng, MIEE, FCIBSE, Research and Development Manager, Thorn EMI Lighting Ltd, U.K.

14.30 'The Control of Lighting-A Business Management Service'
– Speaker: Mr. K. Hughes,, Manager, Allenwest P.L.C. Systems Division, Simplex Electrical Ltd.

14.50 'Energy Conservation – The role of Electrical Accessories and related equipment'
– Speaker: Mr. C. J. Stares, Senior Product Manager, MK Electric, London.

15.10 Coffee

15.25 'Power Capacitors for Financial Saving'
– Speaker: Mr. G. Martin, MISE, Regional Sales Manager, London, Johnson & Phillips (Capacitors) Ltd.

15.45 'Practicable, Practical & Practised'
– Speaker: Mr. S. T. Tam, MHKIE, CEng, MIEE, Vice President, Hong Kong & Kowloon Electrical Contractors Association Ltd.

16.05 Discussion

16.30 Summing up: Symposium Chairman
Closing Address
– Mr. S.P.W. Wong, FHKIE, CEng, FIMechE, FCIBSE, FIEE, Principal Partner, Associated Consulting Engineers.

Acknowledgement

The Electrical Division of the Hong Kong Institution of Engineers would like to express its sincere appreciation and gratitude to the following persons and organizations for their contribution to the Symposium:

Symposium Speakers

Mr. W. S. Y. Chan
Mr. S.P.W. Wong
Mr. J. Gibson
Dr. S. K. Tso
Mr. S. S. Fung
Mr. W. K. Fan
Mr. R. S. Chin
Mr. Deryck Thornley
Mr. Eric L. H. Ho
Mr. M. C. S. Simpson
Mr. L. Bedocs
Mr. K. Hughes
Mr. C. J. Stares
Mr. G. Martin
Mr. S. T. Tam

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Ryoden Electric Engineering Co., Ltd.
Tridant Engineering Co. Ltd.
Johnson Control Hong Kong Ltd.
BBC Brown Boveri Ltd.

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1. Quality of Electricity

Paper No. 1
Reliability of the Electrical Supply Systems

Speaker: Mr. J. Gibson, BSc(Eng), CEng, MHKIE, MIEE, Supplies Engineer, CLP.

RELIABILITY OF THE ELECTRICAL SUPPLY SYSTEMS

Introduction

Asking an electricity consumer what he or she expects from the supply of electricity one would probably obtain:

i. 'It must be there when I want it.'

ii. 'It must be controllable, I want to switch it on or off to suit my needs.'

iii. 'It must not be expensive.'

Apart from the consumer's control, the other answers refer to a requirement of the Electricity Supply Company to provide a reliable and inexpensive supply. Varying degrees of reliability can obviously be provided, from the least reliable – a single supply from the consumer back to the generator, to the optimum – a full duplicate supply.

How should reliability be expressed? If one says a 99% reliability, does that mean that there is a risk of 1 in 100 of the supply being wanted but is not available or that for 99% of the time the supply is available. If the latter is so, with 8,760 hours in a year, 1% represents 88 hours off supply – a generally unacceptable figure.

Electricity Supply Companies therefore devise Standards of Security of Supply to define affordable reliable supplies dependent on number of consumers possibly affected.

Such Standard of Security of Supply or Security Standards cannot be used in a mandatory sense but rather as a guideline, where local circumstances are also taken into account to determine that real improvements are worthy of the costs involved.

This paper describes some of the reasoning behind the CLP Security Standards as applied to the transmission and distribution systems.

Parameters of Security

No Electricity Supply Company can guarantee a continuous supply at all times. It can endeavour to provide a supply voltage and a supply frequency within predefined limits. In Hong Kong, low voltage supplies are currently stated as 200V ± 6% for single phase supplies, with an A.C. frequency of 50Hz ± 2%. These are practical parameters and can be measured. Hence the first parameter that the quality or observance of predefined limits should be maintained wherever practical during other system disturbances.

Should any one consumer receive preferential treatment over another? Within any given tariff range, the answer must be, "No". The tariff is structured to reflect the costs of provision and of maintenance of supplies at different voltages and in different quantities. The essential nature of an electricity supply can only be assessed by the individual consumer in examination of his own needs and it is his requirements which justify an alternative supply or a standby system of supplies and he must meet the costs thereby involved. However, number of affected consumers is a reasonable criterion to be used in the development of security standards, and with average load demands per consumer, a parameter can be expressed in load or MVA. This point requires to be stressed, when a supply company refers to MVA in its security standards, it is really refering to an average number of consumers whose total diversified demand equals that MVA value.

The third parameter is time of resotration. Whereas the optimum would be a zero lapse of time between interruption and restoration, provision of automatic features again costs money which is the fourth and overriding parameter.

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Before these four parameters are put in the mixing bowl, a fifth consideration comes into play. The experience gained in plant performance, the fault or outage rates of certain types of equipment must also be considered in determining what is an affordable, reliable item of and how long would it take to repair.

Distribution Classes of Security Standards

The following table is typical of range of demand, number of supply circuits and resotration times adopted by many Supply Companies, within economic cost criteria. It can be proved that marginal improvements in security can only be achieved at substantial and uneconomic increments of cost.

Table 1

Range of Demand	No. of Supply Circuits	Demand able to be met after 1st Outage	Restoration Time
Up to 1.5 MVA	1	Nil	Repair time
1.5MVA – 4.5 MVA	2	Nil	Switching time
4.5 MVA – 20 MVA	4	Full demand	Nil

It can be deduced that as the amount of demand increases, i.e. the number of consumers x average load per consumer, an improved security of supply can be afforded, and for any group demand in excess of 4.5MVA, a single outage on the network will leave supplies unaffected. Load flow, voltage drop and fault level studies are made to ensure quality of supply is also maintained under single outage conditions.

'First outage' requires explanation. The word 'outage' is used to cover both planned and unplanned (fault) interruptions to supply. Planned interruptions are required to connect new installations, repair faulted equipment and to maintain certain equipment. It is the endeavour of all Supply Companies to combine new connections and maintenance outages to obtain minimum overall interruption but maintenance outages present a dichotomy for the Supply Company. Which is best, annual outages of 8 hour duration, or bi-annual (every 2 years) of say 10 hours, or do nothing and risk a repair time of 45 days if a catastrophic incident occurs? In reality, planned maintenance allows one to sleep at nights, and maintenance frequencies are determined by experience and the local conditions.

Taking the first of the three categories shown, demand range not greater than 1.5MVA, interruptions of supply will exist whilst work is being done.

For the second range 1.5MVA – 4.5MVA, restoration will be within 'switching time'. Usually this requires a visit to site, identification of faulted equipment, and isolation prior to restoration. The target for switching time is not greater than 2 hours. Similarly, a fault subsequent to a planned outage can usually be isolated also within 2 hours, with the exception of a portion of demand which would fall into the first category.

The third range is relatively secure, though portions of demand may fall in second or first categories.

Abnormal Faults

Reference has been made earlier to plant performance which should be taken into account in devising Security Standards.

It follows that the design of a distribution system using the Security Standards as a guideline must also allow for the local circumstances, e.g. the urban underground cable distribution system has

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a high design and performance integrity but is at risk from third party damage.

However, certain faults are rare and they cannot be catered for in the Table I above. A typical exception is the busbar fault. Although the consequential effect is extensive, the fault rate is exceptionally low and provision to cater for such an eventuality would be inordinately expensive. However, with careful design, it usually is possible to restore supplies by switching to substations other than the seat of the problem.

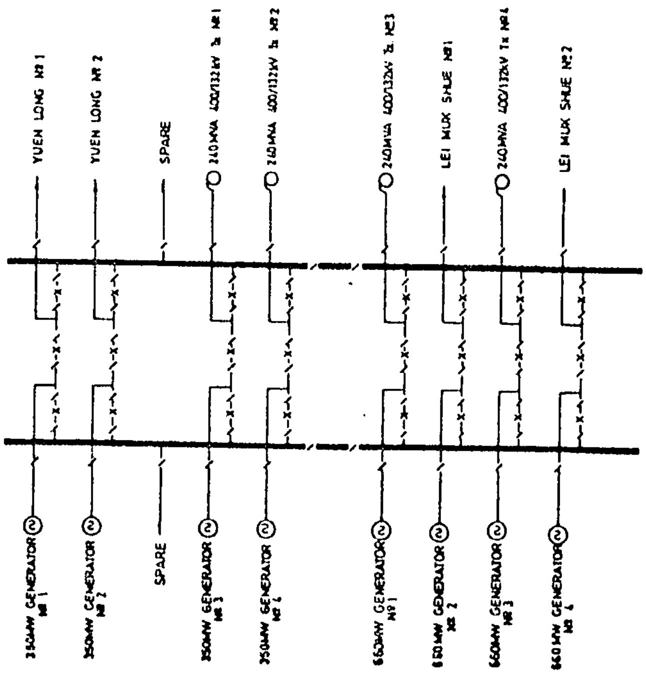
Transmission Security

The security of the distribution system in many ways depends on the degree of security of the system supplying it, i.e. the transmission system.

The transmission system supplies electrical energy in bulk to the main distribution points from the generating stations. Thus the security standards as well as catering for the supplies to the distribution system must also recognise the economics of generation.

Thus the theme of increased security as the amount of load increases is carried through to the transmission Security Standards where circuit breaker faults, busbar faults and specific double circuit outages are taken into account when considering integrity of generation infeeds.

As an example of application of transmission security standards to the aspect of switchgear configurations, the 1.1/2 switch substation provides high security.



It can be seen that three switches are shared by two circuits, hence the 1.1/2 nomenclature, but the whole arrangement is secure from a busbar fault, a single circuit breaker fault or isolation for maintenance will not affect any supply. A very flexible operational arrangement is obtained at no higher cost than a conventional double busbar arrangement.

Conclusion

This paper has described the philosophy adopted by Electriicty Supply Companies to take sensible and economic safeguards against outage requirements, both planned and unplanned, in order to give as reliable a supply of electricity as practicable to all their consumers.

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— Notes & Questions —

Paper No. 2
Pollution in the Electrical Environment

Speaker: Dr. S. K. Tso, BSc(Eng), PhD, CEng, MIEE, Sen MIEEE, MHKIE, Senior Lecturer, HKU.

POLLUTION IN THE ELECTRICAL ENVIRONMENT

Abstract

The quality of the electrical environment is often taken for granted by the consumer. However, power system pollution of one kind or another cannot be entirely avoided. For effective use of electricity, particularly in complex systems, this must be suitably monitored and contained. Equipment connected to the system should be provided with adequate immunity to its effects.

Introduction

Once connected to the supply system, electrical loads, large or small, will all assume satisfactory system environment to prevail that will sustain their uninterrupted healthy operation. When it is realised that hundreds and thousands of apparently different users are simultaneously involved, the capability of the system to provide consistent and reliable service is truly remarkable. Nevertheless 'perfect' conditions can never be expected. The nature and problems of pollution in the electrical environment must be properly understood in order that the electrical resources so vital to the modern society will be more effectively exploited for the benefit of continued rapid progress without at the same time jeopardising the overall interests of the electrical utilities, equipment suppliers and consumers.

Harmonic Sources

One major source of pollution in the power system orginates from the widespread use of non-linear loads[1] . Since the very beginning of the electricity supply history, the moderate non-linearities associated with transformers, generators and induction motors have been known and generally tolerated. The introduction of discharge lamps, fluorescent lighting included, (Fig. 1) and rectification products has further magnified the flow of non-sinusoidal currents in the network. It is, however, the application of fast-responding and efficient power semiconductor equipment including the various forms of solid-state drives (Fig. 2) and static reactive power compensators, (Fig. 3) in increasing numbers and power ratings, which has called for yet greater concern. The economic advances which we have witnessed would certainly have been impeded had the various non-linear loads mentioned been excluded from use.

These loads have been well integrated into the system, but not without realising that the non-sinusoidal currents thus flowing will lead to the presence of harmonic voltage components superimposed on the normal fundamental components. The harmonic magnitudes depend on the type of non-linearities and the size of the loads.

The existence of voltage harmonics at various points in the system may be measured in terms of the r.m.s. amplitude of the individual harmonics or, as sometimes preferred for convenience by a single index – the total harmonic distortion THD defined as

$$\mathrm{THD} = \sqrt{\sum_{h=z} \left(\frac{V_h}{V_1} \right)^2}$$

where V_h is the harmonic voltage of order h and v_1 is the fundmental. For the majority of cases, it is not necessary to sum to beyond the 20th harmonic. The acceptable limits of either the individual harmonics or THD depend on the system voltage under consideration and the prevailing load types in the particular system, but do not exceed a few percents in any case.

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Harmonic Effects and Assessment

The presence of harmonic voltages distorts the voltage waveform so that even when the fundamental voltages are within satisfactory limits the peak values may become excessive. Consequently, protective circuits may be inadvertently tripped; and certain metering and relay equipment may malfunction. Equipment designed to work according to specific points in the voltage wave are particularly vulnerable; included in this category are the many power electronic systems that are synchronised periodically to the voltage zero crossing instants.

The flow of harmonic currents naturally implies additional losses. Power devices such as capacitors and motors may thus tend to overheat and their insulation may be subject to unexpectedly fast deterioration as a result.

In systems where reactive power compensation or filtering capacitors are employed, the associated harmonic energy may even lead to the development of damaging resonance voltages at the harmonic frequencies. An example is illustrated in Fig. 4, where it can be shown that the connection of a capacitor having impedance z_c at the frequency hf_o (f_o being the mains frequency) gives rise to a harmonic voltage at the same frequency at the bus, its amplitude being

$$V_h = \left(\frac{Z_c Z_h}{Z_c + Z_h}\right) I_h$$

where I_h is the harmonic current injected at the bus and Z_h (hf_o) is the corresponding system impedance as seen from the bus. In practice Z_h is a rather complex function of frequency and resonance can occur when the imaginary parts of Z_c and Z_h are conjugates. For an assessment of V_h, Z_h must hence be predicted from a consideration of the power components (e.g. transformers, reactors, transmission lines) and major load characteristics. Alternatively, measurement can be made based on the controlled injection of harmonic currents or, if spectral analysis is instead used, transient currents switching. It is of course imperative that transducers and instruments used in these tests must provide sufficiently wide bandwidth. Fig. 5 shows the plot of Z_h in the R – jx plane for an imaginary HV network. Because of their increasing importance, harmonic analysis programs have been developed for investigating the propagation of harmonics in large, complex power systems, when more straightforward analysis made possible by the simplified models as used above cannot easily apply.

Harmonic problems when and where identified can be reduced at source by equipment improvement[2] or otherwise contained by suitably designed power filters[1]. Over-voltage protective circuits are necessary for vulnerable equipment or components. Sensitive important loads may also have to be safely buffered from the contaminated supply.

Harmonic Interference

Harmonic voltages falling within the acoustic frequency range can interfere with telephone and communication lines running close to a power line carrying the harmonic currents. The electromagnetic coupling effect may be reduced with cable screening and attempts at balancing either the power circuits (e.g. transposition of three-phase conductors) or the telephone wires with respect to earth (e.g. using twisted pairs), but the extent of disturbance should be monitored whenever the two systems share the same right of way for considerable distances. A commonly used measure of the effect is the telephone interference factor TIF defined as[3]

$$\text{TIF} = \sqrt{\sum_h \left(\frac{k_h T_h Z_h I_h}{V_1}\right)^2}$$

where k_h is the coupling coefficient (equated to $5hf_o$ by convention) and T_h is the telephone interference weighting factor, both corresponding to the frequency hf_0. The weighting factor takes into account the non-linear frequency response of the 'average' human ear, a plot of which is presented in fig. 6. Instruments designed to read the TIF directly are commercially available.

It is somewhat empirical in setting the limits on the acceptable TIF but a figure less than 20 is usually considered necessary to provide safe margins. This index is of course not applicable when a carrier is used or a data communication channel is under consideration.

Voltage Notches

One type of distortion found in thyristor converter systems not conveniently measured in terms of the harmonic generation is associated with the formation of notches in the voltage wave resulting from current commutation overlap (when a momentary short-circuit occurs between supply phases via the normally small source reactances.) The phenomenon is illustrated for a 6-pulse thyristor converter in Fig. 7.

The energy associated with the notches, though small, can lead to resonance effects in the audio frequency range under unfavourable conditions.

With their sharp wavefronts these notches could easily affect neighbouring control and digital circuits at signal levels through inductive or capacitive coupling.

If the voltage waves are utilised for timing purposes in control circuits, the notches have to be suitably suppressed by smoothing circuits.

It would be good practice in any case to segregate thyristor converters from the main bus to which other major loads are connected; the notch depth would then appear materially reduced at the main bus. A useful indirect estimate of the possible notch effect on other loads is hence afforded by the impedance ratio of the total system impedance as seen from the thyristor unit to the source impedance alone as seen from the connection bus.

Voltage Fluctuation and Flicker

When loads fluctuate because of the basic nature of their operation, the voltage at the connection bus will tend to vary accordingly. For the same current magnitude, the voltage variation will be more severe the greater the relative proportion of the reactive component in the load current[1]. In this respect welders, excavators, reversing drives, traction loads and especially electric arc furnaces are notable offenders. Furthermore, solid-state a.c. controllers or regulators of larger and larger ratings are finding wider applications in recent years and as seen in fig. 8 the integral cycle type presents a modulating effect on the system insofar as the load current switches between the extreme limits[4].

Voltage fluctuations have a deleterious effect on some instrumentation, computer, and communication equipment. The tolerable limits can be specified in terms of the percentage deviation from the nominal value. The limits adopted depend on the system voltage levels and the relative duration of the disturbance.

A readily noticeable effect of appreciable voltage fluctuations is the flicker phenomenon exhibited by incandescent lamps (and to a less extent fluorescent lamps) and television sets, as their brightness undergoes corresponding variation. The most irritating range of modulation for the human eye lies between 3Hz and 15Hz and the threshold amplitude of perceptible voltage fluctuation varies in a non-linear fashion with frequency.

Because of the serious annoyance effect, flicker measurement has come to be accepted as a means to assess the tolerance level of voltage fluctuation. However, the difficulty of establishing standards is evident when it is realised that people do not generally respond to the irritation in the same way and the response of the same person may also change depending on the person's physiological and psy-

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chological conditions as well as possibly the prevailing environmental conditions. Statistical means have thus to be resorted to. The Disturbance Study Committee of the International Union for Electroheat (UIE) have drawn up the specifications for a flickermeter to meet the need for more independent, objective studies[5].

The normalised weighting on voltage fluctuation as a function of simple harmonic modulating frequencies that take into account the combined response characteristics of the tungsten filament lamp, the human eye and brain is plotted in fig. 9. The curve reflects that the human flicker sensitivity is by no means uniform for different modulating frequencies, exhibiting a maximum at 8.8Hz. Flicker level is then interpreted as the integrated voltage fluctuation weighted according to the sensitivity factor.

To increase its utility, the flickermeter usually allows for the measurement of the more basic percentage voltage fluctuation and facilitates the quantitative evaluation of probability measures of flicker.

It is seen that minor voltage fluctuations are unavoidable in normal practice. Whenever the disturbing effects of the offending load are likely to be severe, consideration should be given to connecting them to points in the system of lower effective impedance (i.e. higher system voltages), locating them farther from the more sensitive loads or introducing voltage stabilising equipment in the form of static reactive power compensators[6].

Conclusion

Electrical pollution, like other forms of pullution, has its economic ill-effects. The healthy operation and working life of equipment (some more susceptible than others) will be at risk of a proper electrical environment is not maintained. It is with a view to drawing attention to the nature and effects of the major polluting problems in power systems of increasing size and complexity that the short paper is prepared. While phase unbalance can create yet another type of pollution of its own[1] and calls for a different type of counter-measure[7], limited coverage does not permit its elaboration here; suffice it to say that the distortion, flicker and interference problems can well be worsened by unbalanced conditions existing in the network.

Only through an understanding of significant polluting sources and corresponding precaution taken in equipment design, selection and operation taking cognizance of the non-ideal environment, will more realistic and effective use be made of the electrical resources at our disposal. Practicality clearly dictates that permissible disturbance levels be imposed to protect the majority of users. While possible offenders have to exercise self-restraint to meet the standards, other users will also have to recognise the imperfection and provide the necessary immunity to their own more sensitive equipment in accordance with the limits.

It is expected that in the years ahead, with the enhanced awareness of the polluting problems, more concerted efforts will be made in monitoring the various forms of electrical pollution, in reconciling the interests of the various parties concerned, and in preserving the high quality of our shared electrical environment of increasing diversity and sophistication.

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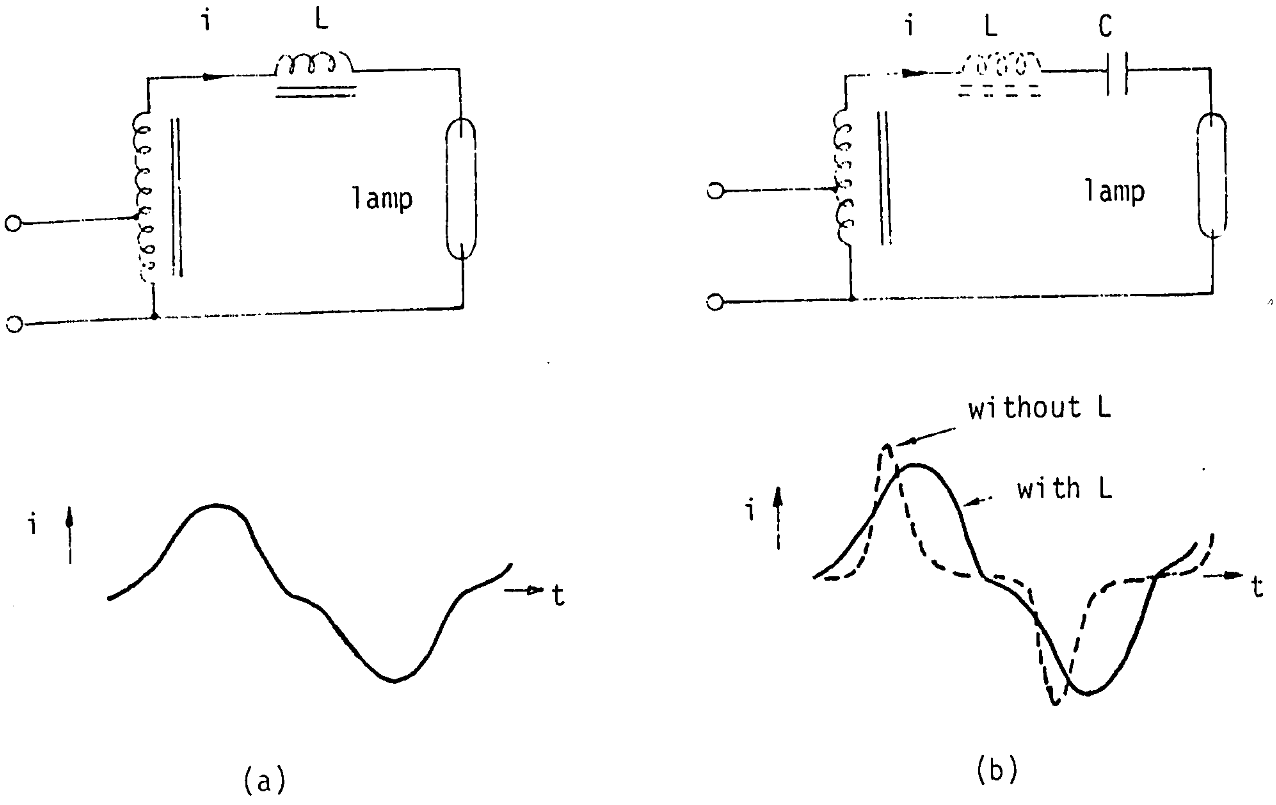

Fig. 1 Typical discharge lamp circuit and current

(a) with inductive ballast

(b) with "lead" ballast

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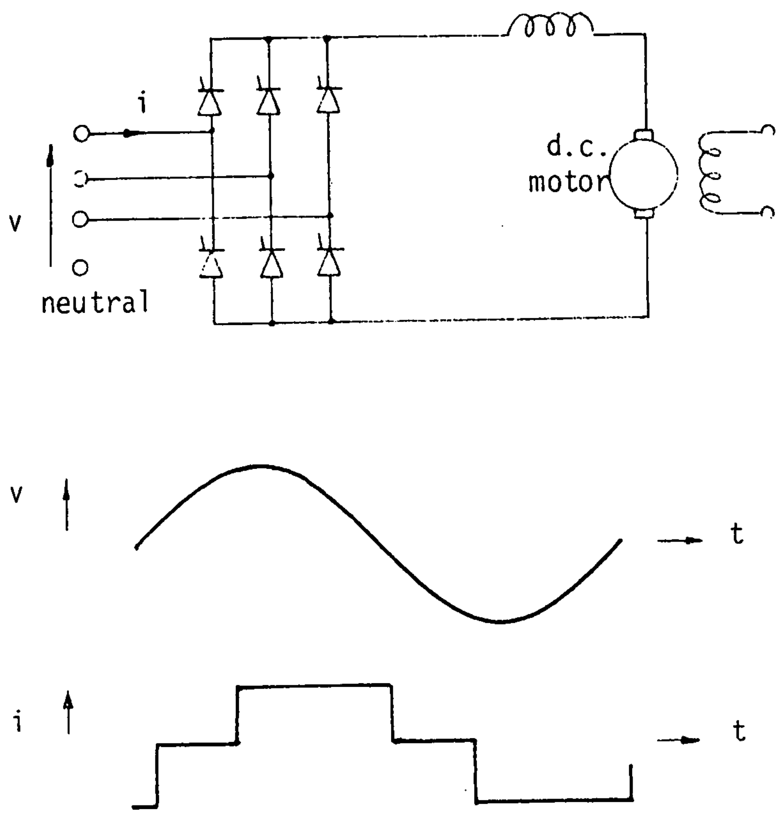

$$I_h = \left(\frac{1}{h}\right) I_1$$

$$h = kp \pm 1, \quad k = 1, 2, 3, \ldots\ldots \quad (p = 6)$$

Fig. 2 Six-pulse converter drive

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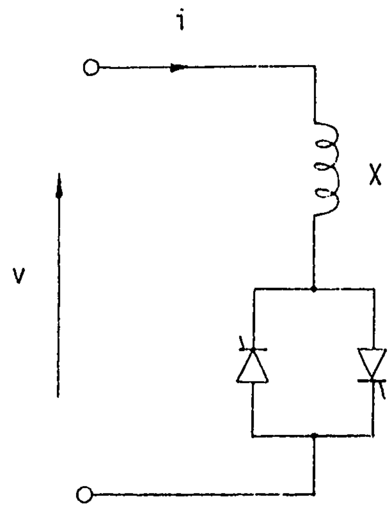

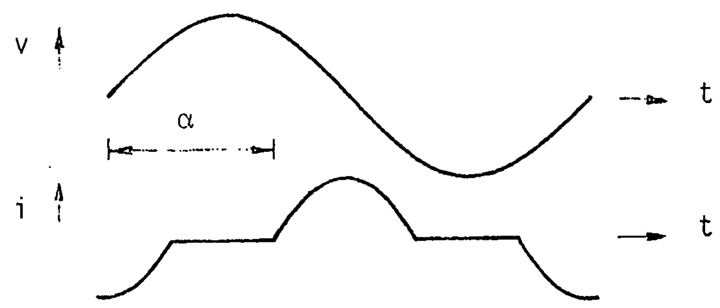

$$I_h = \frac{4V}{\pi X}\left[\frac{\sin(h+1)\alpha}{2(h+1)} + \frac{\sin(h-1)\alpha}{2(h-1)} - \frac{\cos\alpha \sin h\alpha}{h}\right]$$

$h = 3, 5, 7 \ldots\ldots\ldots$

Fig. 3 Thyristor-controlled reactor compensator

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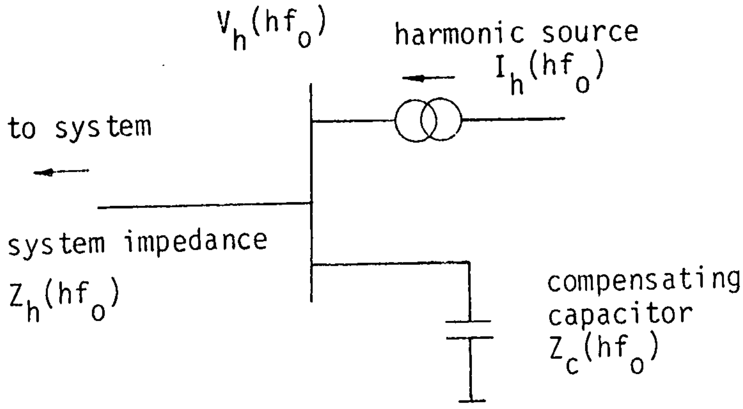

$$V_h = \left(\frac{Z_c Z_h}{Z_c + Z_h} \right) I_h$$

Fig. 4 Harmonic bus voltage (harmonic order h)

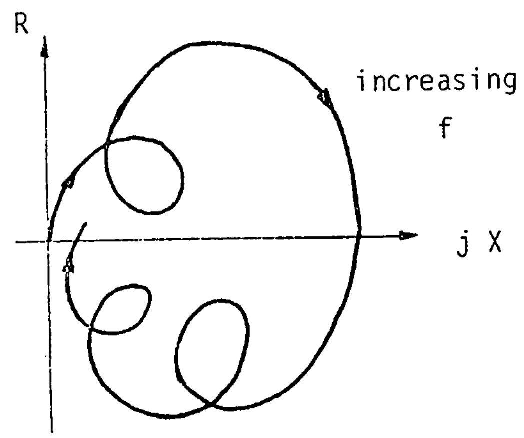

Fig. 5 Typical system impedance plot in complex plane

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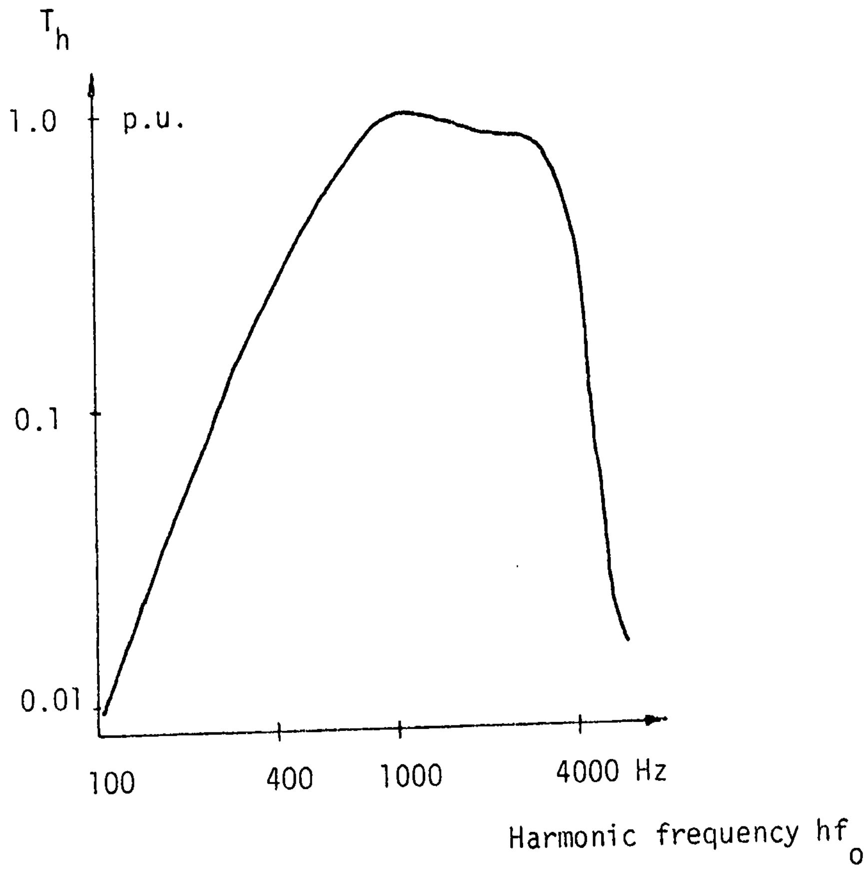

Fig. 6 Frequency response of interference weighting factor (T_h)

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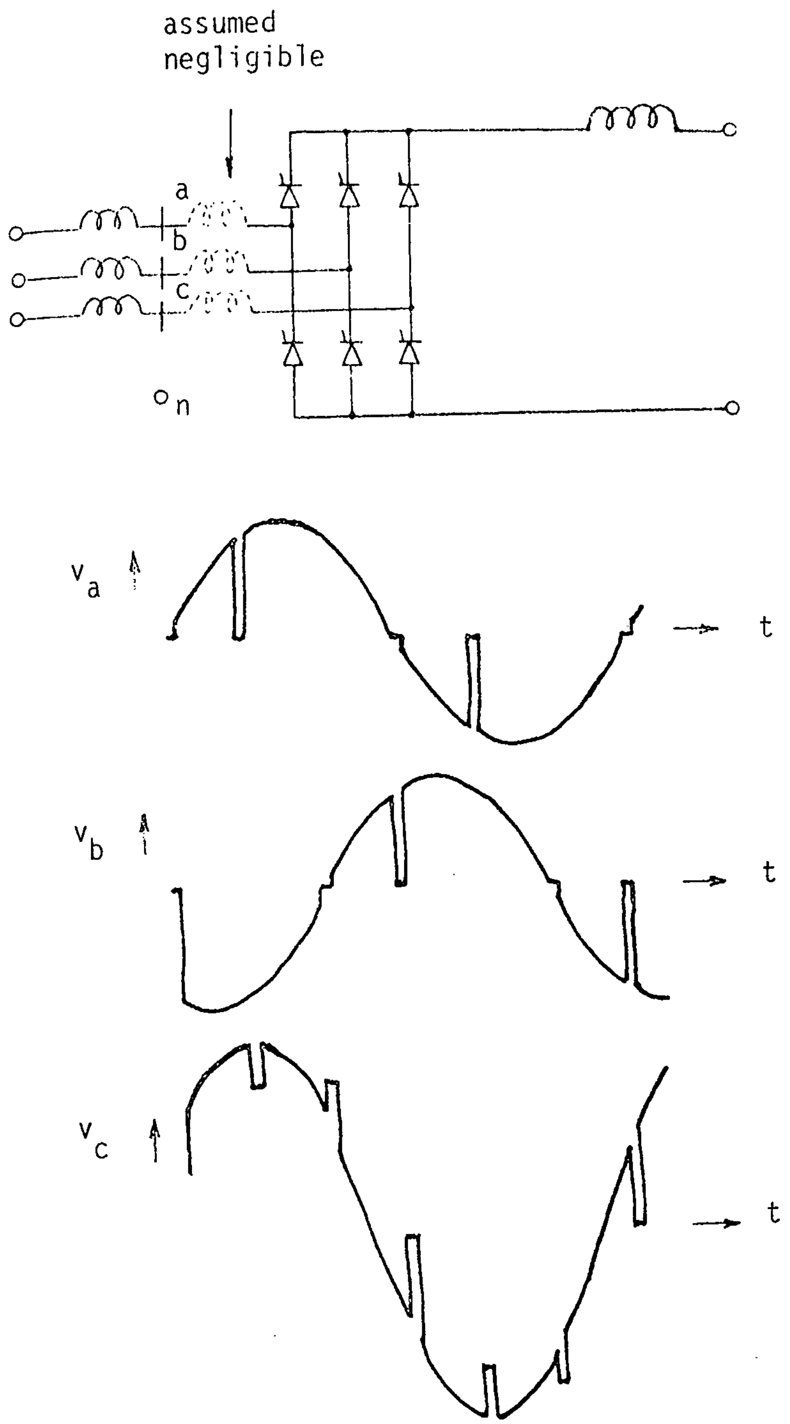

Fig. 7 Commutation notches in 6-pulse converter bus voltage

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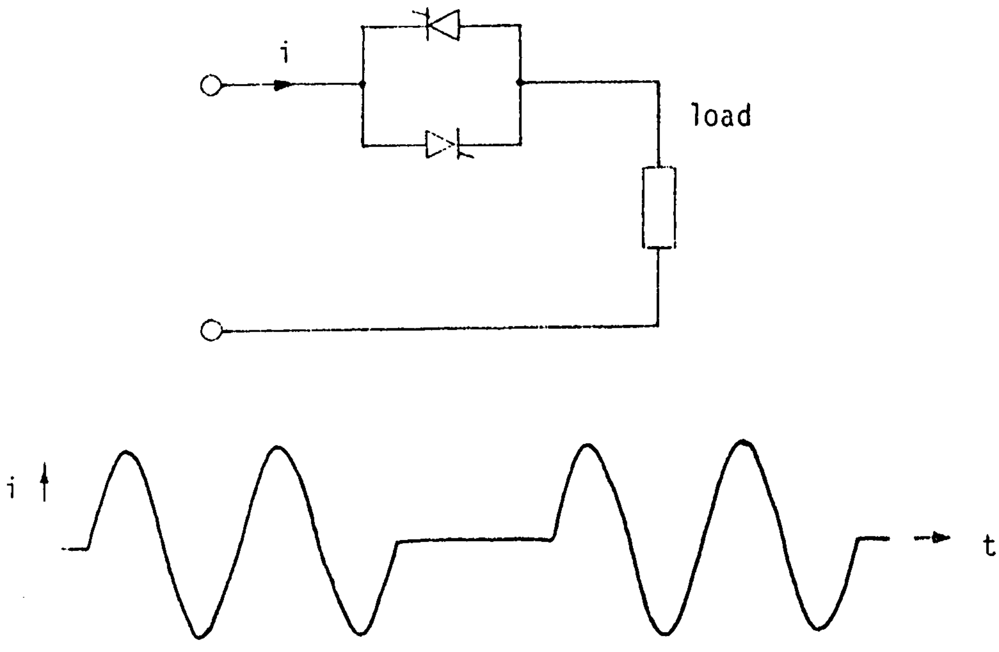

Fig. 8 Integral-cycle controlled regulator

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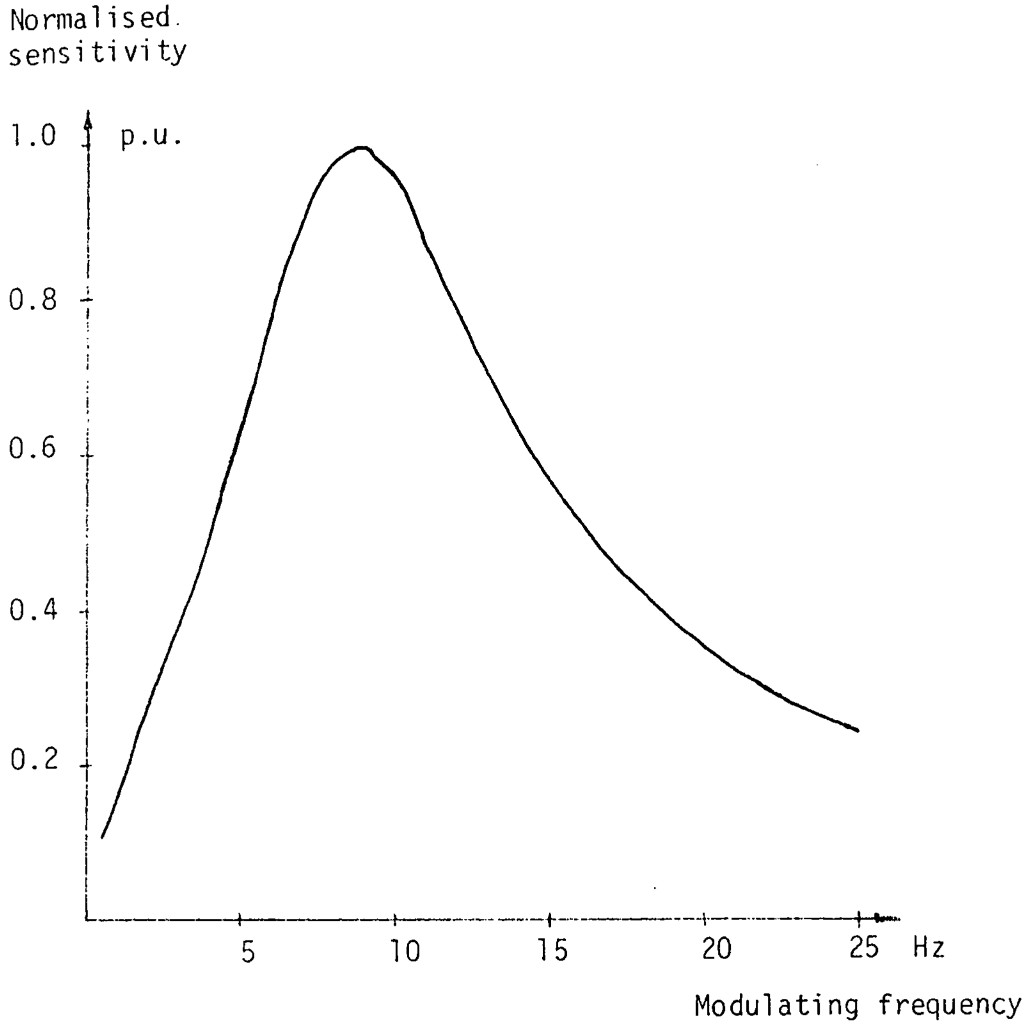

Fig. 9 Dependence of eye sensitivity to flicker on modulating frequency

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— Notes & Questions —

Paper No. 3

Reliability of Electrical Supply in Hospitals

Speaker: Mr. S. S. Fung, BSc, MHKIE, CEng, MIEE, Sen. B. S. Engineer, EMSD,
Mr. W. K. Fan, MIEE, MHKIE, CEng, Sen. B. S. Engineer, EMSD,
Mr. R. S. Chin, BSc, CEng, MIEE, MIEEE, MHKIE, B. S. Engineer, EMSD.

RELIABILITY OF ELECTRICAL SUPPLY IN HOSPITALS

Introduction

This paper intends to describe the development of the design of a reliable electrical supply in hospitals built for the Hong Kong Government. The various major electrical systems which make up the overall electrical supply in these hospitals will be covered and finally a note on the probable future trend in the design is also included in respect to the reliability aspects.

Utilities Incoming Supplies

In the design of Government hospitals, there existed basically those hospitals built from the outset with limited air-conditioned accommodations and those built or currently under construction and planning incorporating fully air-conditioned accommodations. This general distinction will be the major criterion upon which the electrical supply capacity and thence the ensuing complexity and reliability requirements emenates. Another factor which affects the design of electricity supply to a hospital is the ever-increasing demand for electricity due to the use of sophisticated medical equipment, e.g. specialist organ imaging equipment, computerised tomography whole body scanner, linear accelerators, etc.. Some of these items consume large amount of electricity, e.g. computerised tomography whole body scanners.

In the existing Government hospitals, such as the Queen Mary Hospital (QMH), the Queen Elizabeth Hospital (QEH), the Princess Margaret Hospital (PMH) etc., only part of the accommodations are air-conditioned. These included the operating theatre suites, the intensive care units, the administration offices and other essential areas and the requirements for electricity are much less. Take the existing QMH as an example, the supply system involves a single feeder supply to two 1500 KVA transformers making a total capacity of 3 MVA for the Ward and Administrative Block, i.e. excluding the Pathology Department, the Clinical Building and the medical staff quarters. The two transformer supplies are interconnected through a L.V. switchboard with manually controlled coupler switches. The interconnection is to allow any one of the transformers to supply the Essential loads in case of a failure of the other.

In the case of the fully air-conditioned hospitals beginning with the newly completed Prince of Wales Hospital (PWH) in Shatin New Town and followed by the Tuen Mun Hospital (TMH) now under construction and also in the up coming Shaukeiwan Hospital, the utilities incoming supplies cater for 10.5 MVA for the PWH supplied from a single 11KV feeder. In the case of the TMH where the total electrical supply capacity will be 22 MVA, two duplicate utilities incoming 11KV feeders each capable of providing the total capacity will be supplying the requirement of this hospital. In the case of the Shaukeiwan Hospital, which is anticipated to have a requirement for an incoming utilities supply of 23 MVA, a similar attempt will be made to secure an electricity supply to the hospital from two different zone sub-stations. This feature of providing the required duplicate utilities feeders from two different main substations is entirely dependent on the availability of these supplies based on the planning policy of the Supply Companies.

The 11KV distribution network provided in the PWH is via radial feeders to 1500 KVA substations located in the North and South ends of this hospital. Whereas in the TMH a 11 KV ring distribution network will provide this hospital's various load centres as can be seen Fig. 1.

Low Voltage Main Distribution

Generally the earlier designs of Government hospitals were based on the radial risers and sub-mains distribution boards all being fed from a L.V. Main Switchboard incorporating segregated Essential and Non-Essential busbars, as illustrated in Fig. 2 for the Queen Elizabeth Hospital and Fig. 3 for the Queen Mary Hospital. This trend was developed in the case of the PWH into radial L.V. feeders feeding from the Site Main Switchboards to the load centres Main Switchboards both incorporating segregated Essential and Non-Essential busbars suitably interlocked as depicted in Fig. 4. This concept is now the basis of newer designs of the more complex fully air-conditioned hospitals. Worthy of a mention here is the development of a separate "silent" earthing system which is independently installed from the normal electrical installation earthing system to cater for the earthing requirements of sensitive electronics equipment for medical and telecommunications purposes in the TMH.

Non-Essential and Essential Distribution

In the earlier Government hospitals including the PWH, the general concept of load distribution from the Main Switchboards with segregated Non-Essential and Essential busbars was through dedicated risers and sub-mains feeders either fed from the Essential or the Non-Essential sections of the Main Switchboards to the sub-mains distribution boards. Whether an area is fed from the Essential board or Non-Essential board depends on the function of the area. For example, in the QMH, the Operating Theatre Block is fed from the Essential section of the switchboard through a vertical riser within the building.

Each floor is fitted with a tap-off point and individual local distribution board. With this arrangement all final circuits on a floor is supplied from the same distribution board. The advantage of this arrangement is simplicity. However, it suffers from the disadvantage in the respect that whenever there is any thing wrong with the distribution board, the entire operating theatre suite of that floor will be without electricity supply.

In addition, if there is a need to modify or service the Essential riser, then the supply to the whole Block would have to be shutdown or an alternative supply must be provided well in advance. Because of this disadvantage, later designs would always divide all Essential final circuits into two separate riser/distribution board arrangement in order that at least half of the supply will be available at all times. However, in order to provide a reliable supply to the most essential areas, such as the Operating Theatre suites, a three-tier concept has been developed. This is exactly what has been designed for in the TMH, in which the load requirements will be met from two duplicate sub-mains cables fed from two separate Main Switchboards and the Essential and Non-Essential loads will be segregated at the point of the sub-mains distribution board through contactors controlled by the Central Control and Monitoring System (CCMS), this is clearly illustrated in Fig. 5. The less critical areas will be served from dedicated sub-mains feeders with the Essential and Non-Essential loads segregated through contactors also controlled by the CCMS as shown in Fig. 6. The third category of distribution system follows the concept of dedicated Essential or Non-Essential sub-mains feeders as used in the earlier hospitals.

In the PWH design dedicated cable risers were used for high capacity loads whereas the smaller capacity and higher rise loads were served by a system of cable risers and link boxes arrangement. In the case of the TMH, all loads will be fed from a system of dedicated cable risers and then further distributed into the three-tier arrangement described earlier.

Stand-by Generation Plants

In all Government hositals stand-by generation plants are provided to cater for the individual needs of the hospital under design. The Essential loads would generally be required for firefighting, personnel movement/evcuation, life-support, medical operation and any other specific functions critical for the operating personnel. Again in his generalised load types there are differing toleration requirements for power outage times ranging from the no-break to those for the air-conditioning systems' which are normally in terms of tens of minutes. In these respects the designs of Government hospitals have developed in line with the ever demanding requirements of the above two creiteria and this can be illustrated in the graph of the stand-by generation capacity plotted against the capacity of the transformers, excluding those serving centrifugal chillers, for the various major Government hospitals in Graph 1. Another consideration in the design of the stand-by generation plant was the important criterion of the location of the sensing points for the start-up of the stand-by generation plants. The generally adopted location is at the incoming terminals of the Main Switch-board and upon persisted utilities power supply failure the sensor would activate the start-up of the relevant stand-by generation plant. This consideration was not critical in the case of the earlier Government hospitals, As pointed out before, the earlier Government hospitals consume much less electricity and the supply system is rather simple. Take our previous example of the QMH where there are two 1500 KVA transformers inter-connected through manually operated busbar couplers. As shown on the schematic diagram in Fig. 3, the Essential section of the Main Switchboard is connected to Transformer A under normal conditions. The stand-by generation plant will only start-up when there is a signal indicating a persistent power failure of Transformer A. However, with the more recent Government hospitals, the large demand for electricity has made such simple operations impracticable. In the PWH, the locations of these sensing points had been further expanded to include critical sub-mains feeders. In all Government hospitals battery systems were incorporated in the design to provide the no-break requirement for Operating Theatre Lighting and personnel evacuation lighting. These battery systems comprises centralised battery charger/batteries systems located adjacent to the Operating Theatre Suites and Nickel-Cadmium batteries are provided in these applications. In the evacuation lighting systems, these are normally achieved by self-contained battery luminaires located throughout critical evacuation accesses.

Overview of Development

The progressive development of a reliable power supply in Government hospitals had evolved from the simple two-transformer bus-tie arrangement in the limited air-conditioned hospitals to those fully air-conditioned hospitals containing complex multiple distribution sub-stations as described in the foregoing.

In future hospitals, while the present fully air-conditioning concept will still be a major factor influencing the standard of electricity supply reliability, the increasing application of computer technology in the medical field coupled with the ever increasing introduction of sophisticated equipment for more accurate medical diagnosis and efficient medical treatment will probably stimulate a higher standard of electricity supply reliability in future hospitals. Up to the present, there is a very limited demand for "no-break" supplies in hospitals and these are being entertained by means of individual small battery back-up static inverter units attached to each critical local application. Future hospitals may have a more extensive and stringent "no-break" supply requiements which warrant the consideration of a more global type of "no-break" supply system design in hospitals. Another point which is worthwhile to be noted is that the present focus of electrical design with respect to reliability seems to be directed more around the source and originalıof distribution. As in line with the foreseeable trend of reliability standard evolution, it is anticipated that in future hospitals, more concern will be made as to ensure the same high standard of reliability is to be maintained throughout the entire distribution network commencing from the source right up to the point of application.

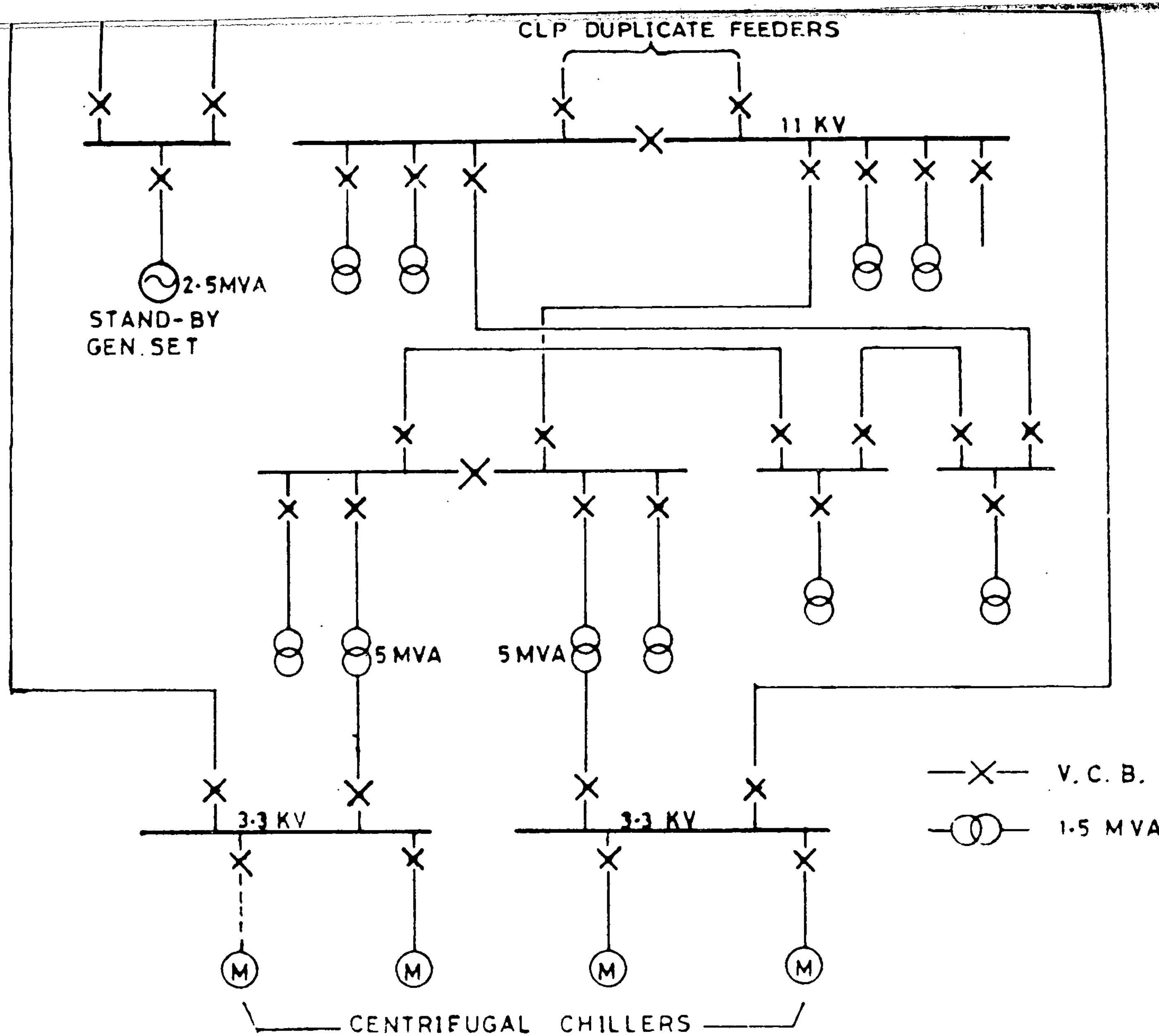

FIG 1– 11 KV & 3·3 KV DISTRIBUTION SCHEME FOR TUEN MUN HOSPITAL

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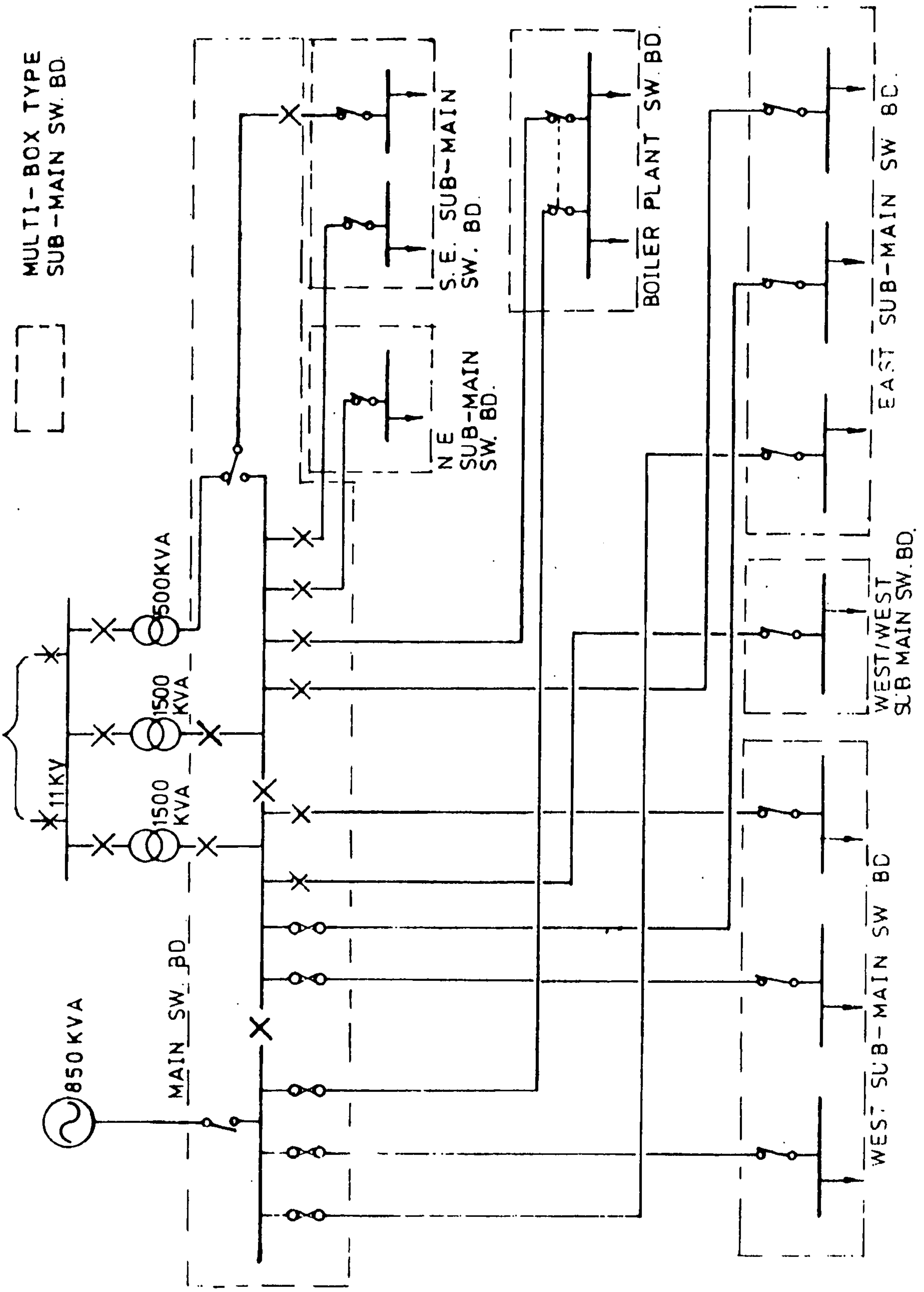

FIG 2— L V. DISTRIBUTION SCHEME FOR THE QUEEN ELIZABETH HOSPITAL

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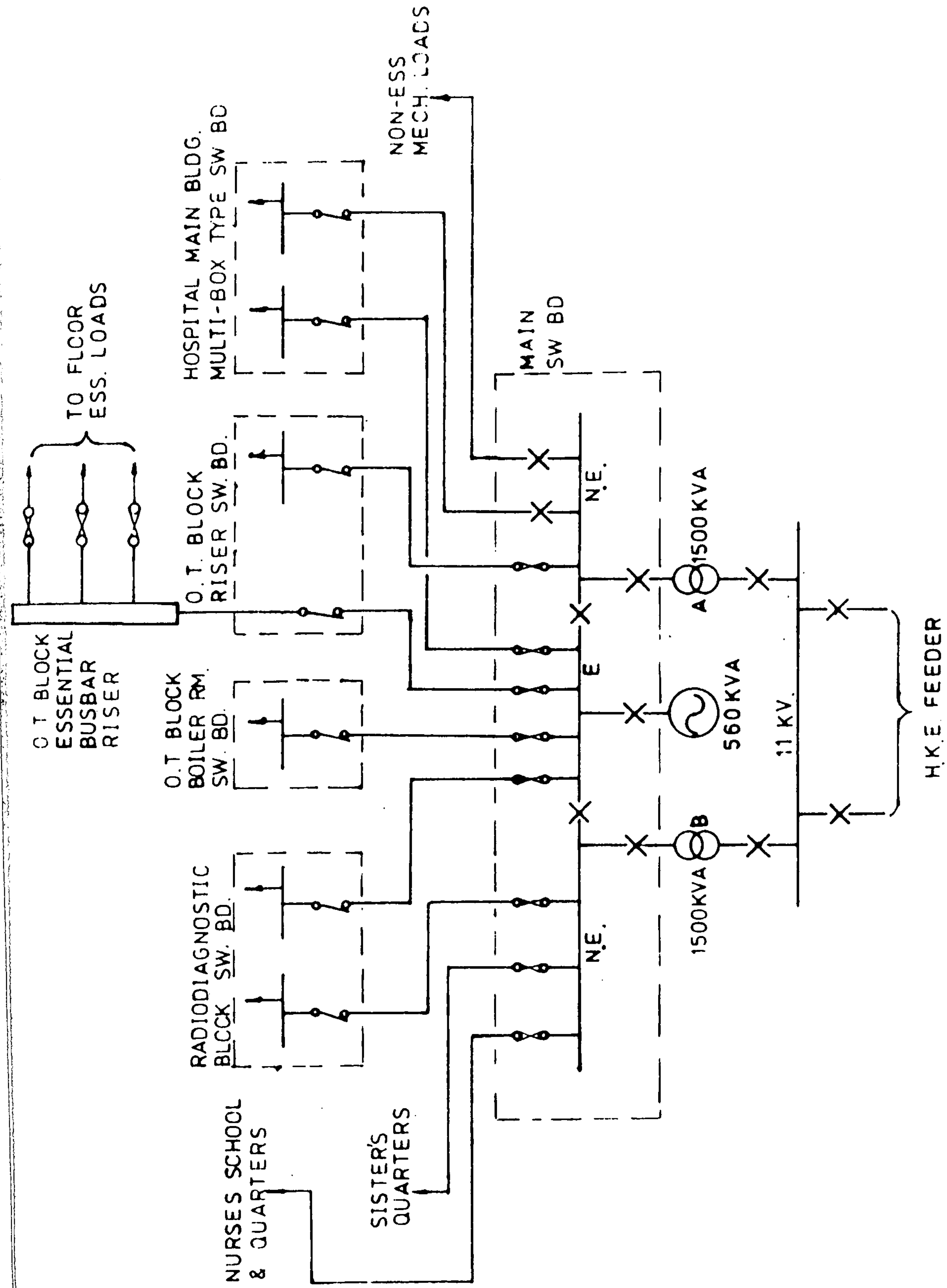

FIG. 3 – L. V DISTRIBUTION SCHEME FOR THE QUEEN MARY HOSPITAL

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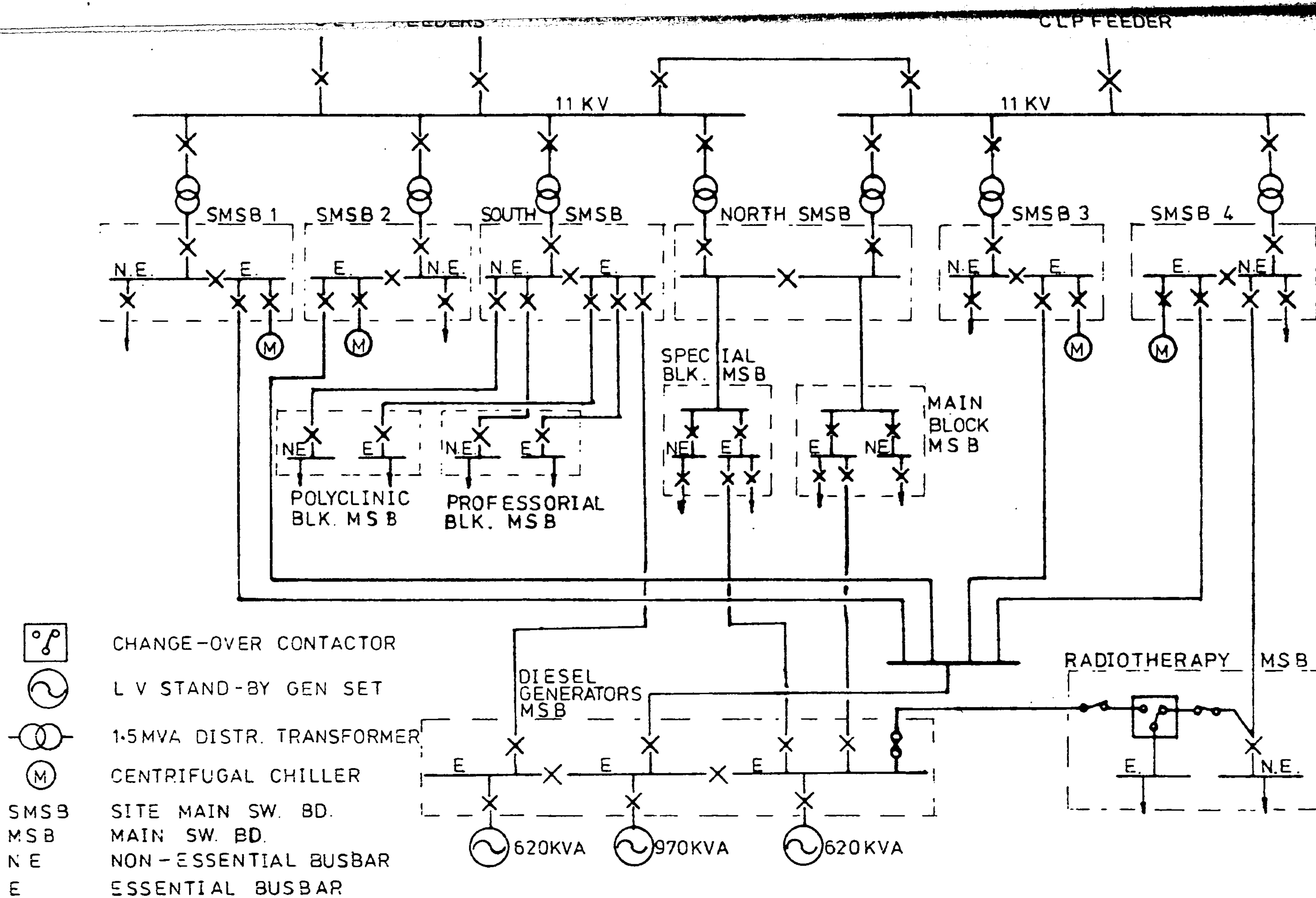

FIG. 4 – MAIN DISTRIBUTION SCHEME FOR THE PRINCE OF WALES HOSPITAL

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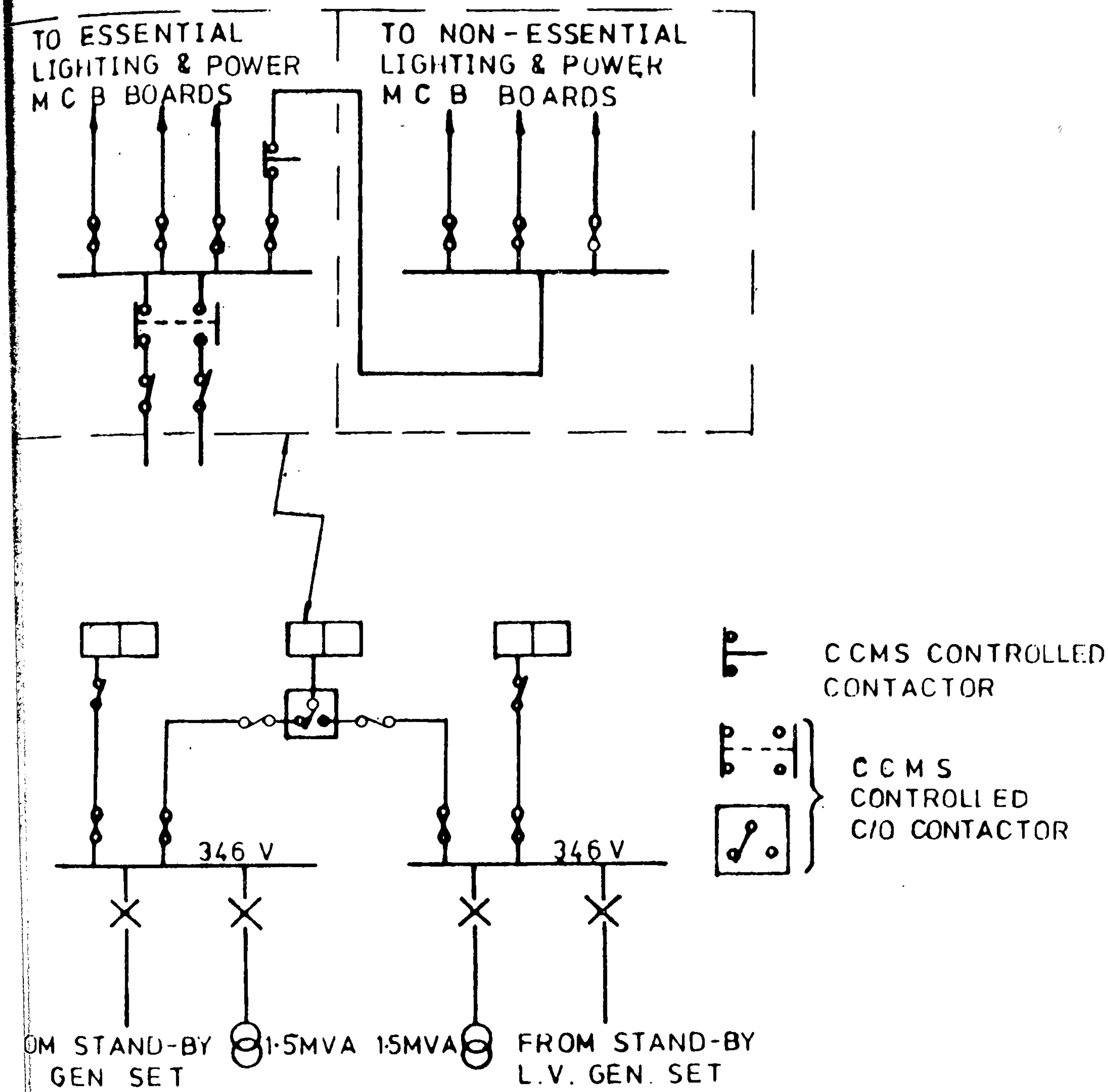

FIG 5 — TYPICAL FLOOR DISTRIBUTION SCHEME FOR MOST CRITICAL AREAS IN TUEN MUN HOSPITAL

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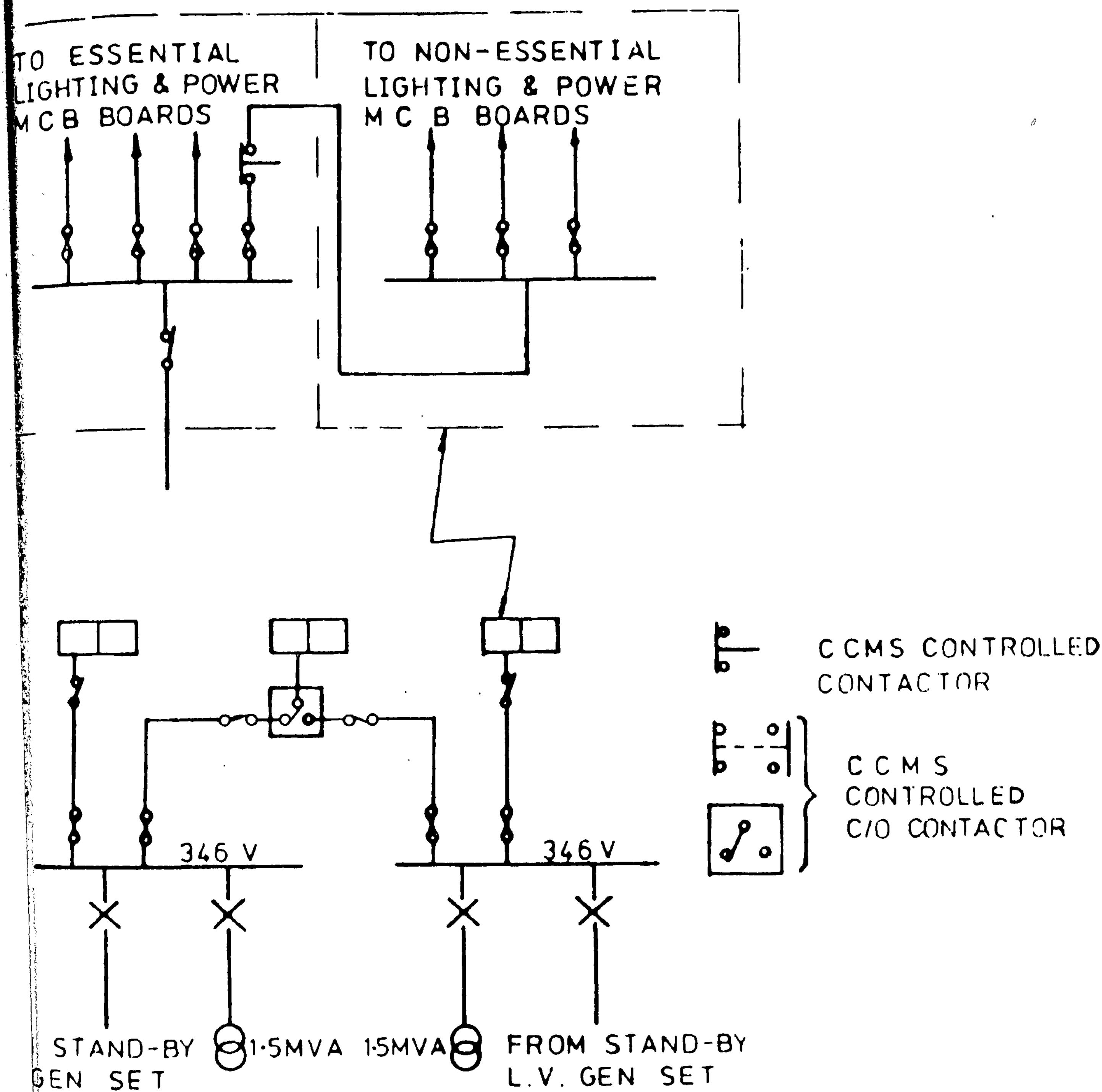

FIG 6 – TYPICAL FLOOR DISTRIBUTION SCHEME FOR LESS CRITICAL AREAS IN TUEN MUN HOSPITAL

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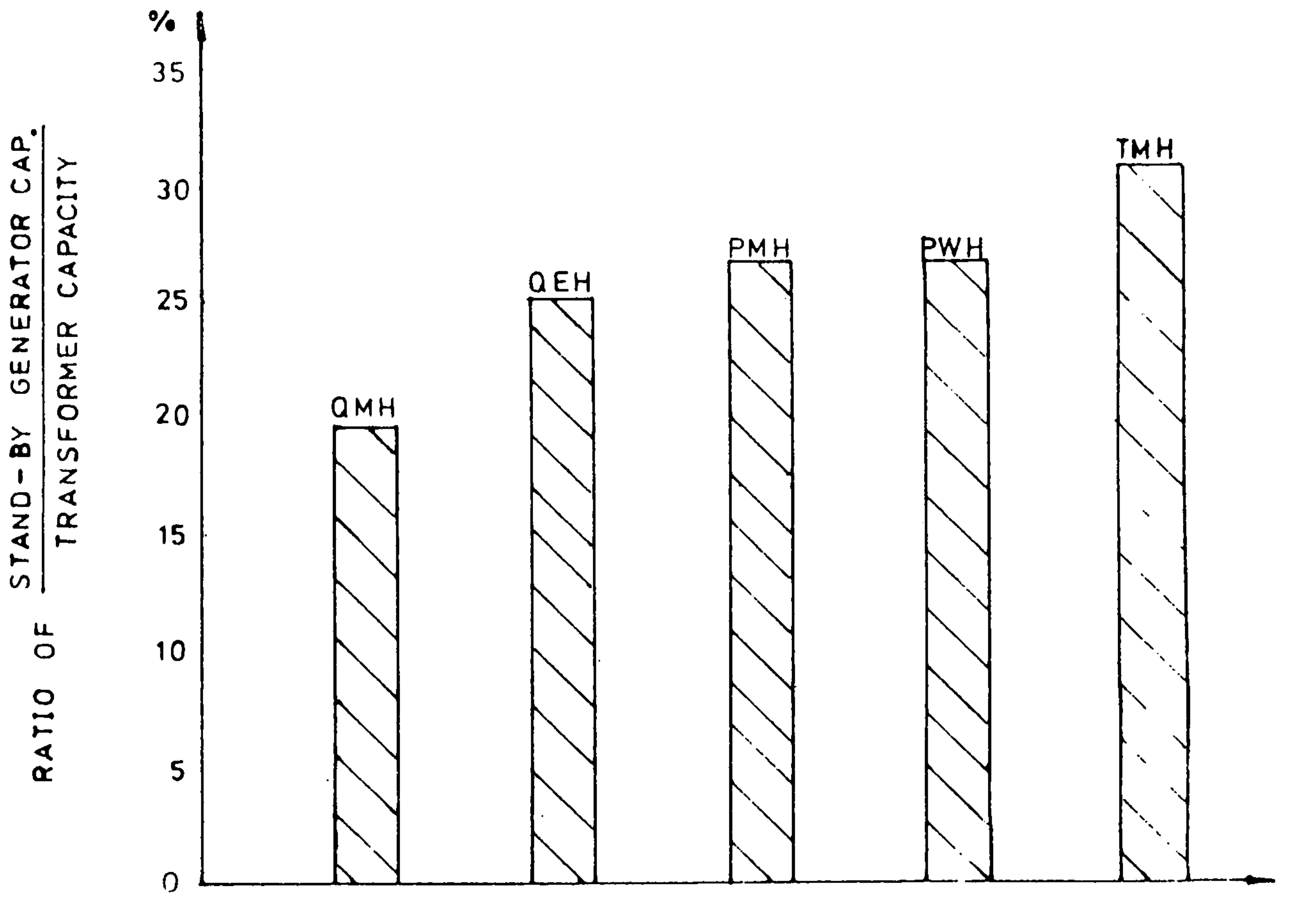
HOSPITAL	STAND-BY GENERATION CAPACITY (KVA) A	TRANSFORMERS CAPACITY (KVA) B	RATIO OF STAND-BY GENERATOR CAP / TRANSFORMER CAPACITY (PERCENT)
QUEEN MARY (QMH)	560	3,000	19
QUEEN ELIZABETH (QEH)	860	3,500	25
PRINCESS MARGARET (PMH)	850	3,000	28
PRINCE OF WALES (PWH)	1,240 *	4,500 *	28
TUEN MUN (TMH)	3,900 *	12,000 *	32

* EXCLUDING CAPACITY FOR CENTRIFUGAL CHILLERS



GRAPH 1 — GRAPH OF STAND-BY GENERATION TO TRANSFORMER CAPACITIES FOR MAJOR GOVERNMENT HOSPITALS.

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— Notes & Questions —

2. Computerized Energy Management

Paper No. 4

Use of Computer in Energy Saving Study

Speaker: Mr. Deryck Thornley, FCIBSE, FHKIE, MASHRAE, Partner, JRP.

USE OF A COMPUTER IN ENERGY SAVING STUDY
(A CASE STUDY RELATING TO THE NEW HONGKONG BANK HEADQUARTERS)

Introduction

The building services consulting engineer is increasingly concerned with energy. In the past, this has concentrated on the efficient design of the services – the point at which energy is consumed. Today, it is recognised that the building itself requires as much (if not more) attention – the primary cause of the need to consume energy. In our experience, the Architect looks to the consulting engineer to provide this service, which most readily accept. This presents the opportunity to integrate the design of the services with the building structure leading to improved environmental conditions and lower energy consumption.

Nevertheless, not even the rapid escalation in fuel costs during the last 12 years has resulted in energy being the only (perhaps mjaor) consideration in the design of the building structure and services. Yet this is hardly surprising if one reflects upon the reason for constructing new buildings. They are built to meet specific needs and invariably consume energy. The task is to design to achieve low energy consumption without detriment to the objectives of the building. The phrase "energy conservation" is a misnomer. Perhaps "energy optimisation" would be more accurate.

The role of the building services consultant engineer can be summarised to encompass the following duties:

(i) Co-operation in the design of the building structure (e.g. envelope, shape) to optimise energy requirements with others.

(ii) Design of the services to improve efficiency in providing this energy.

(iii) Ensuring the building user is equipped with the means to carry out energy management functions effectively.

This approach was enthusiastically employed from the vary outset when we were commissioned by the Hongkong and Shanghai Banking Corporation. This paper attempts to outline the path by which the design was developed, with emphasis on the role of energy optimisation.

Our original brief called for a very high standard of building, using the latest (and innovative) technology as necessary to carry the building into the 21st century. The long-term projected use (particularly by Hong Kong standards) required that great flexibility be incorporated to take account of future trends.

The size and complexity of the project, coupled with the use of latest technology offered great scope for energy optimisation. This was actively encouraged by the client.

A great many man-hours have been spent in the pursuit of energy optimisation, utilising a suite of programs developed by ourselves. Much has been discovered in putting the theory into practice, and has been partly responsible for enhancements made by our computing department. To this end, we are indebted to the project.

The building

Little introduction is needed for such a highly publicised building. Details of the building and its services are well documented (refs. 1, 2, 3, 4, & 5).

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For the purpose of this paper, four particular aspects of the project are considered:

i) The glazing system.

ii) The VAV air distribution system.

iii) The refrigeration and sea water systeym.

iv) The building management system.

(I) The Glazing System

The site of the New Hongkong Bank building commands superb views to the south of Hong Kong harbour, and to the north Victoria Peak. Likewise, the prominent position in front of Statue Square and Chater Gardens puts it in the eyes of the population and visitors to Hong Kong. Not surprisingly, the Architect was keen to exploit these features.

This resulted in a three-tiered tower with the principal facades facing north and south, and being virtually 100% glazed.

To accommodate such a large expanse of glass a system of external shading was designed providing solar shading but still allowing a view out. By reducing the ingress of solar radiation, energy consumption by the air conditioning system was reduced, though the primary intention was to protect occupants from high radiant temperatures. Throughout the development of the glazing system, thermal comfort was given high priority.

Figure 1 summarises the five initial glazing systems studied. Unlike dry resultant (comfort) temperatures, annual energy consumption could be quoted at this stage only as percentage of some suitable standard. This was achieved by comparison to a fictituous podium/tower design typical of Hong Kong. The reasons for this are three-fold.

i) Unlike such parameters as comfort temperature, there are no recognised upper limits for energy consumption in Hong Kong.

ii) Quoting energy consumption in physical units (MJ/annum) or annual cost gives no immediate indication of performance.

iii) The actual energy consumption depends upon the design of the building services, which were unknown at this stage. In the comparison, both building types were analysed using the same model for the air conditioning system. (A four-pipe fan-coil system was modeled – this being the simplest to simulate).

This work was carried out using a suite of computer programs previously developed by ourselves, based on the CIBSE/BRE admittance technique. Hourly cooling and heating loads are calculated for a twenty-four hour period, and by simulating the (pseudo-dynamic) response of the plant the energy consumed by the various items of equipment (fans, pumps, refrigeration machines etc.) is determined. The process is repeated to give annual consumption using either a full 365 day analysis or two days per month (one typical cold and one typical warm day).

The glazing solution initially adopted consisted of single silver reflective glass (option E).

No account was taken of possible energy reduction using photoelectric lighting control at this stage, though it was intended from the outset to employ such a system should this prove feasible. The decision to disregard the useful contribution of daylight at this stage was not taken

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lightly. Indeed, much investigative work was undertaken, but was severely limited by the lack of suitable daylight data. In our experience, this is a problem encountered whenever energy calculations are performed. The difficulty arises not merely from the lack of information on a specific weather condition – e.g. available daylight – but more importantly on integrating this with other variables.

As an example, instantaneous cooling load is influenced by the intensity of solar radiation (direct and diffuse), outdoor air dry bulb and wet-bulb temperature and internal heat gains such as artificial lighting. The importance of each will vary with time (and with the design of the building services). There is no simple relationship between such factors.

The initial choice of glazing was eventually discarded, though the external shading and glazed area was retained. Despite the fact that the single reflective glass yielded the lowest energy consumption and radiant temperatures, it failed to meet all the architect was seeking to achieve. A more transparent envelope was required, exposing the inner workings of the building and accentuating the structure to the general public when viewed from outside. The excellent properties of the original choice in terms of cooling load (and hence energy consumption) proved impossible to match, and some relaxation of performance was necessary.

(II) The Variable Air Volume Distribution System

No computer calculations of energy consumption were carried out during the initial stages to optimise the design, though once the details had been established such calculations were undertaken to update predicted energy consumption, and to compare these with the original studies (bearing in mind the revised glazing system).

The same suite of programs was used, using a mathematical model of the VAV system in place of the original 4-pipe fan coil. Whilst the same problems existed in chosing suitable weather data, information was now available on the duty and performance of fans which constitute a large poroportion of electrical energy consumed, even in a VAV system. Table 1 gives a breakdown of the energy forecast.

One interesting feature of energy ensumption calculations applied to a particular system materialises at the permieter of the building. As has been stated earlier, the large glazed areas tended to increase mean radiant temperatures at the perimeter. External shading was designed to reduce these, but at low solar altitudes direct solar radiation still impinged on the glazing. A low overall glazing transmittance reduced the ingress of short-wave radiation further by absorption, but with the penalty of higher glass surface temperatures and hence longwave re-transmitted radiation. These processes were taken into account in calculating dry resultant temperatures (ref. y) and were found to be barely acceptable. Given the excellent views from the building, and high building costs in Hong Kong, it was imperative that perimeter areas could be utilised to the maximum. This required that the high standard of comfort conditions specified for the building should extend as near as possible to the glazing line.

The solution was to supply conditioned air to the very perimeter, directing the air across the face of the glazing thereby removing the heat at source and lowering the glass temperature. (In winter, the supply air to the perimeter is heated, the temperature being scheduled to the outdoor air temperature). It was appreciated that this would increase the cooling (heating) load and lead to an increase in energy consumption, though the advantage of improved comfort conditions was paramount. Consideration of the higher heat transfer coefficients and greater temperature potentials suggested that peak heating and cooling loads at the perimeter would increase in the order of 20% for the double glazing system finally proposed. (The increase as a fraction of the total building load was very much less than this).

The opportunity to test this estimate presented itself when BSRIA were commissioned to exa-

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TABLE 1

FORECAST OF ANNUAL ENERGY

Electrical Energy	KW Hours x 10^6	Percent of Total
Refrigeration cooling and heat pumps	5.50	16.8
Pumping include seawater intake	5.23	16.0
Basement AC	0.90	2.7
Fans for AC and ventilation	5.46	16.7
Computer suite cooling	2.19	6.7
Sub Total for AC and associated equipment	19.28	59.0
EDP	4.40	13.5
Small Power	1.05	3.2
Lighting include circulation	5.28	16.0
Signs, decorative lighting and accommodation	0.50	1.5
Kitchens	0.25	0.8
Docuemnt Handling	0.02	0.1
Seawater Chlorination	0.23	0.7
Lifts + Escalators	1.20	3.6
Water boosting, drainage pumping + DHWS pumping	0.14	0.4
Refuse System	0.30	1.0
TOTALS	32.65	100%

mine the thermal properties of the glazing system. The use of mid-pane blinds required the inner pane of glass to be openable. Given the size and ceiling profile (see fig. 2) this necessitated that the inner glazing consist of separate panes of glass. This led to problems in sealing the horizontal mating edges of the inner panes.

The question was posed as to the effect of not sealing these joints – a solution mid-way between single and double glazing. The impact on cooling and heating loads could only be determined by testing, to which end BSRIA built a full-scale model using actual components. The effect of the

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horizontal gaps (about 6mm) was surprisingly small and could be accommodated. As a by product we were pleased to see our computer estimate of loads due to the perimeter supply validated.

(III) Refrigeration and Sea Water System

Very early in the concept stage of the project, the cooling load requirement for the building was estimated to be 12,500 kW, and methods for rejecting this considerable amount of heat were investigated.

Various schemes were examined. The first utilised sea water pumped from the harbour to titanium plate heat exchangers on the condensing side of the refrigeration plant in the basement. The second involved the use of air-cooled condensing units at the top of the building. A third scheme utilised high level air cooled radiators feeding clean condenser water to the basement refrigeration plant. Annual energy calculations were performed for all schemes, taking due regard of the greater pump duties required by the sea water scheme, but lower condensing tempratures and hence higher C.O.P., and the fan power of the air-cooled condensers/radiators.

The results indicated that the air-cooled schemes used some 30% more electrical energy than that for sea water – equivalent to about 2,600 US barrels of oil/annum.

A cost analysis was then undertaken, (revised frequently to take account of changing circumstances), together with a technical feasibility study. The air-cooled solutions required up to 2,500 m^2 of prime floor area at high level, together with signfiicant vertical riser space throughout the height of the building. Figure 3 shows a cross section of the building. The roof of the centre tier was to accommodate a helipad, the lower two tiers canopies and landscaped garden areas. These were key features of the building, and not available for mechanical plant. Costings were made on the assumption that two of the upper (office) floors of the centre tier would be available with ensuing loss in rentable area.

Whilst the sea water solution did not encroach on office space and required no vertical risers, it did involve major civil engineerng works in constructing a tunnel between the building and harbour (Figure 4). Sea water was in any event required for the flushing of sanitary ware. The existing sea water pipe serving the previous building on the site presented difficulties in refurbishment.

A very high level of reliability was required for the building as a whole and specifically for the large central computer department. All things considered, the sea water proposal was chosen.

The method of heat generation was now studied. The high ratio of cooling to heating load suggested that heat reclaim from the chillers was feasible. Alternatively, the use of sea water provided the opportunity to employ heat pumps. Finally, gas or oil-fired boilers could be employed.

Initial energy and cost studies ruled out the use of boilers for providing base heating load and the heat reclaim/heat pump options were examined in detail. Harbour water in Hong Kong varies throughout the year between 16°C and 28°C.

Realising the great dependence upon the particular plant selected (size, number and performance of machines) manufacturers were invited to submit their proposals for the generation of chilled and hot water using either heat reclaim or separate refrigeration and heat pump equipment, based on employing sea water. They were asked to submit with their selection capital, running and maintenance costs, plus details of space requirements. To this end they were provided with a schedule of hourly cooling and heating loads throughout the year (computer generated) and details of corresponding sea water temperatures.

It should be pointed out that height restrictions in basement plant areas ruled out the use of

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Reliability was one of the key requirements for the system, and at the time of selection direct digital control was discounted as being not sufficiently advanced to meet our criteria. The decision was made to allow all plant to be run independently of the Building Management System if necessary, with the Building Management System capable of providing limited control functions.

Even so, the Building Management System software and hardware has been tailored to carry out an extensive range of functions to reduce energy consumption, generally through its ability to gather information at a central point to assist the energy manager, and to highlight faults and inefficiencies that would not normally be discovered in good time.

The main features of the energy reducing potential of the Building Management System are summarised below:

1. Each air handling module can be independently controlled to suit occupancy times, using optimum start/stop software. This allows any floor to be used without running plant to unoccupied floors. The Building Management System measures outside air and inside air temperature on each floor. The optimum start-up/stop time is calculated using specially written software, for both heating and cooling modes.

   In our experience, indoor air temperature prior to start-up can vary significantly across a large floor, particularly when only one facade may be exposed to the sun. With this in mind, the Building Management System minotirs up to 4 temperature sensors on each floor.

   Proprietary optimum start packages using micro-processors have a limited ability to "learn by experience". By comparison, the BMS system installed in the Bank is able to monitor and log events and conditions which, together with the facility to easily change constants (e.g. time constants) enables the software to fine-tune the performance of the building and its installations.

2. In the event of a particular floor not being occupied, the Building Management System can be used to run the air conditioning if required to maintain reasonable temperatures, but without any fresh air supply.

3. Each air handling module provides constant volume variable temperature supply air to the perimeter to offset conduction gains/losses through the glazing. This temperature is scheduled to outdoor air temperature by a simple linear relationship. This schedule can be changed remotely by the Building Management System for each individual module – again to finely tune the performance.

4. Refrigeration plant is brought on line, ready to run, by the Building Management System by comparing the chilled water requirement to the chilled water output at frequent intervals. (Refrigeration machines of course contain usual hard-wired safety features including time delays). The COP of each machine is also minotired.

5. Lighting and small power consumption is monitored on each floor to provide a basis for departmental or tenancy charging. This will act as an incentive to reduce energy consumption.

6. The Building Management System monitors and totalises all incoming power. Present and predicted power consumption is displayed. Standard software will predict a specified maximum demand being exceeded. In such an event, non-essential plant and equipment can be shut down. These will be restored automatically on sufficient fall in demand.

   All plant and equipment is grouped, each group being given a priority rating. Lowest priority pump is switched off first, from which an optimum selection of plant is made which

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will just suffice to reduce the demand.

Conclusions

The New Hongkong Bank headquarters provided an excellent opportunity for the design team to integrate high standards of environmental control with energy management. This has been achieved to a great extent by a process of optimisation using sophisticated computer programs, and by utilising the latest computer technology to manage the building.

Lessons have been re-instilled in applying these modern techniques, (and no doubt further valuable information will be aquired when the building has been in operation for some time). These are summarised below:

(i) Methods of reducing energy consumption can only be implimented when a full appreciation of other factors is understood. In the absence of regulations, these other factors may prove dominant. This is particularly so in the case of glazing. Present computer technology can only deal with physical quantities which are amenable to mathematical treatment. Subjective values, such as appearance, cannot be handled, yet these may be significant factors in the equation.

(ii) Energy optimisation techniques by digital computer depend upon comprehensive weather data being available and an understanding of how these interact. An excellent example is the relationship between daylight availability and solar radiation intensities. Present theory concentrates on diffuse (and evenly distributed) solar radiation for the purpose of daylighting calculations, whilst the theory of solar cooling loads concentrates on direct solar radiation. Weather data tends not to discriminate between the two, and is frequently not available in any form.

(iii) Analysis of energy consumption involving heat transfer is dependent upon the identification of suitable heat transfer coefficients. Standard values (e.g. CIBSE A.3) may not be applicable, and the designer must ensure the person responsible for carrying out computer calculations is forewarned.

(iv) Detailed analysis of system options involving major and complex items of plant can only be undertaken with the assistance of the manufacturer.

(v) A modern Building Management System can be a powerful tool in ensuring efficient operation of the services installation, by continual monitoring of plant performance.

(vi) The Building Management System may be used to fine tune the building services. At the time of design some aspects of the building behaviour can only be estimated. These can be updated in the light of experience.

(vii) Energy monitoring by a central computer of individual departments/tennants for the purpose of budgeting/charging provides an incentive for those individuals to reduce energy consumption.

(viii) Maximum demand protection requires a fast and flexible response, which can only realistically be provided by a computerised Building Management System.

(ix) If a Building Management System is to succeed in reducing energy consumption, it must be sufficiently flexible and easy to reprogram.

Acknowledgement:

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the developments described and for permission to refer to them in this Paper. Also to their colleagues at J. Roger Preston and Partners and other member of the Design Team who have been involved in a truly multi discipline enterprise.

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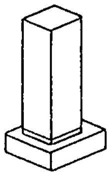
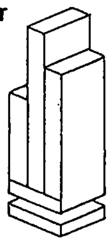
Building format	Ref.	Envelope configuration	Annual energy consumption as % of reference building	Shading Coefficient	Calculated dry resultant temp. 1.5m from glass
PODIUM/TOWER  **Typical Developers format (used as reference)**	A	Podium/Tower configuration giving equivalent gross floor area to final concept development. 40% glazed on all faces with heat absorbing glass.	100%	—	—
HONGKONG BANK CONCEPT DEVELOPMENT  **3-tiered tower with external shading**	B	88% clear single glazing.	91%	1.00	30.0°C
	C	88% heat absorbing single glass.	86%	0.50	26.0°C
	D	88% clear single glazing with reflective internal blinds.	85%	0.38	26.0°C
	E	88% silver reflective single glazing.	81%	0.26	25.5°C
	F	44% heat absorbing glass. 44% translucent insulated panels.	85%	0.34	26.0°C

Figure 1: Comparison of initial glazing options

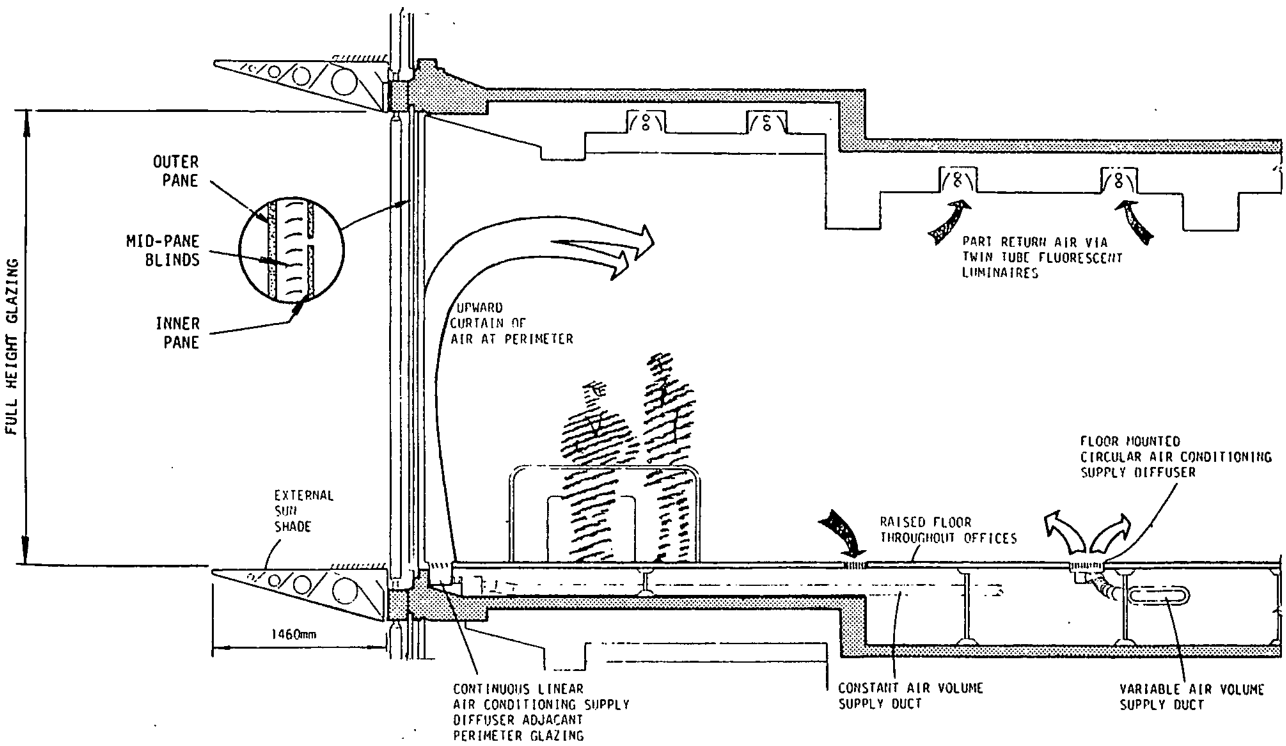


Figure 2: Diagrammatic section through perimeter of typical office floor

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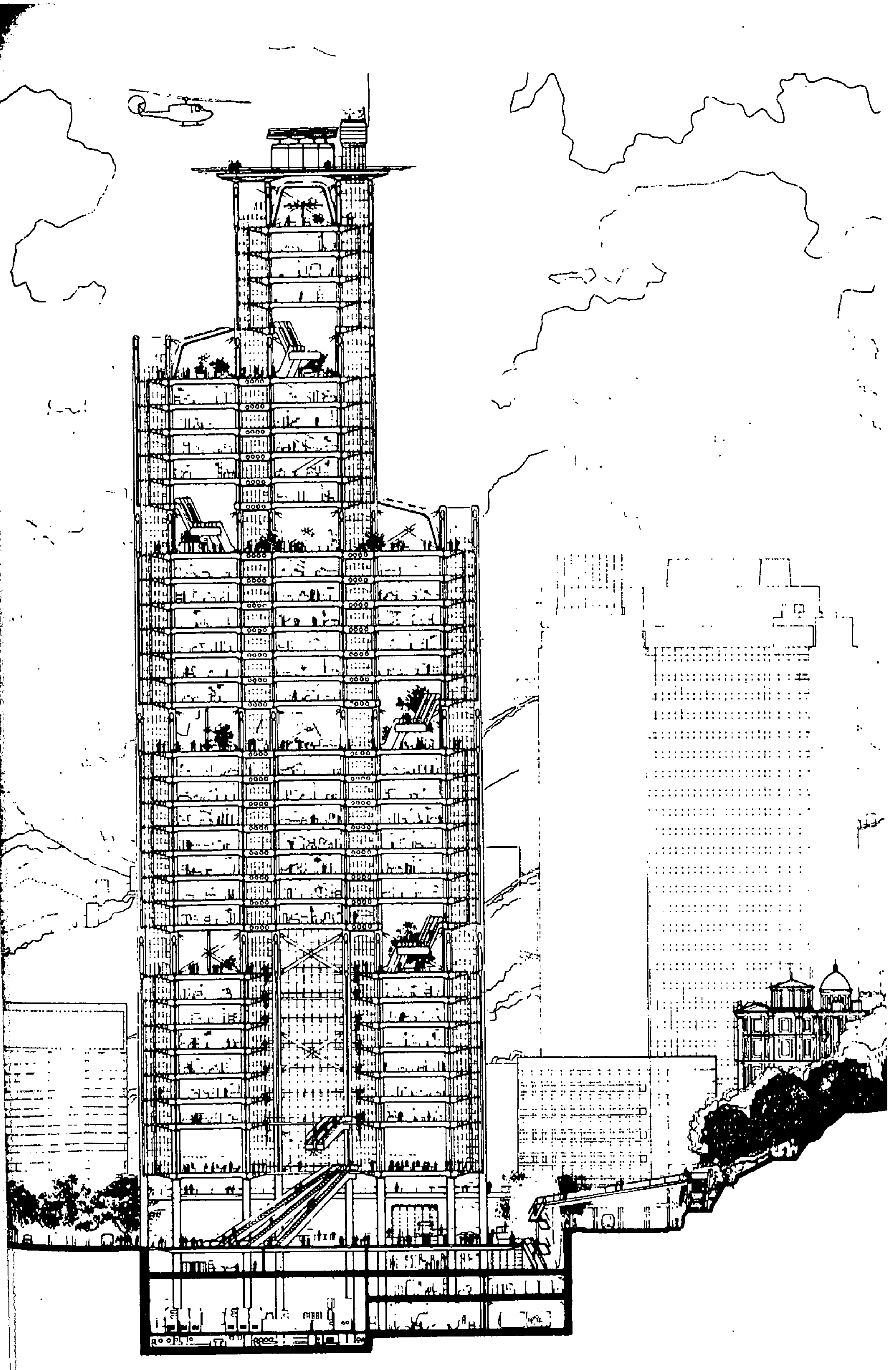

'igure 3: North-South section through building

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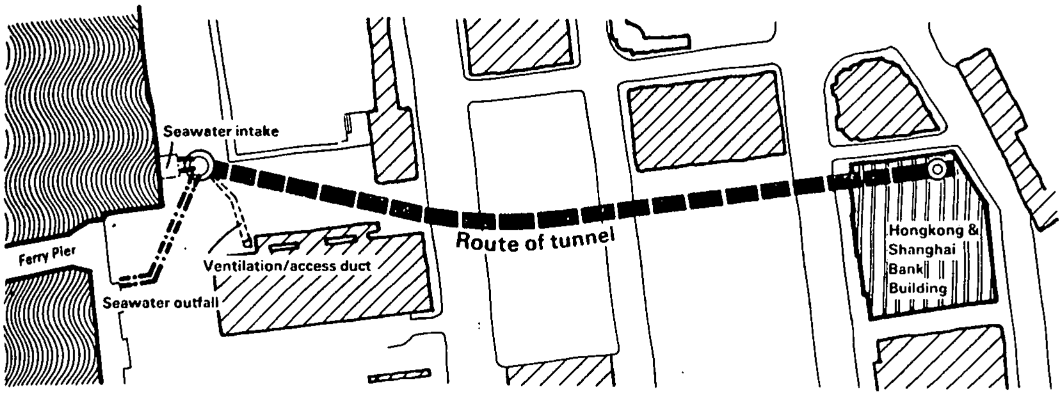
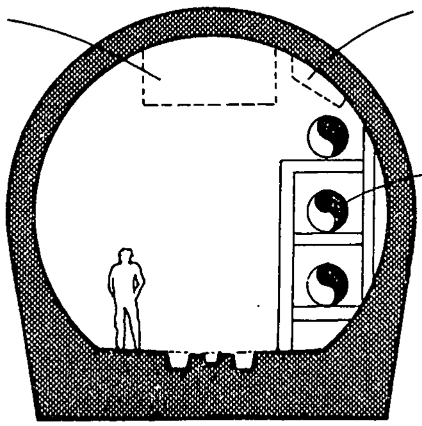


Route of tunnel



Section through tunnel

Figure 4: HongkongBank Seawater tunnel

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— Notes & Questions —

Paper No. 5

Conserving Electrical Energy in Buildings by Computerized Control

Speaker: Mr. Eric L. H. Ho, DipEE, MHKIE, MIEE, CEng, MCIBSE, Manager, Johnson Control Hong Kong.

CONSERVING ELECTRICAL ENERGY IN BUILDINGS BY COMPUTERISED CONTROL

Building owners and managers have long searched for ways to control energy costs – heating, cooling, lighting – costs that keep going up ..... seemingly beyond control. They have tried any number of methods: manual shut-offs, adjustments, time clocks and other simple devices. Some have been successful. Many more have ended in the discovery that complex building problems defy simple control measures.

Today, managers are applying the power of the computer to building energy management -- operating equipment and maintaining comfort while controlling energy consumption. Computerised control is more than data processing. An energy management system (EMS) actively monitors and controls any combination of energy-hungry boilers, chillers, fans, lights and other building equipment. It scans remote corners of the building through active network to detect problems that can escape manual or traditional methods. By automatically and continuously monitoring indoor and outdoor temperatures and humidity, electrical load fluctuations, air flows and building activities, the system optimizes equipment operation, moment-by-moment, to save energy.

The major consumers of electrical energy in buildings, perhaps except factory buildings, are heating, ventilating and air conditioning (HVAC) systems and lighting systems. An EMS is designed to monitor and control energy consumption by reducing equipment operating time, optimizing equipment performance, and monitoring equipment operation of these systems. There are a variety of energy management systems available. Some are more sophisticated systems combining energy management features with security and fire management capabilities. As the complexity and size of the system increases, the initial investment increases, too. But the savings obtained through avoided energy costs also increase.

Sophisticated energy management is accomplished with a centralized computer control system. Field interface devices or field processing units are distributed throughout a large building complex and tied back to a central processing unit. These connections between units may be made with hard wire, telephone lines, fiber optic cable, or microwave communications between buildings.

Direct digital control is another alternative for energy management. Direct digital control is the integration of computer management and HVAC systems control. This control is accomplished by the implementation of an analog-to-digital convertor feeding a computer. This processor replaces the conventional controller and provides a digital output to control the HVAC system.

Direct digital control can provide the capability of energy management and system control simultaneously from the same controller. Direct digital controllers can be integrated into a standard energy management system in place of field processing units to provide centralized control. Or a centralized computer control system may be configured using direct digital controllers, capable of providing stand-alone energy management features.

Computerized energy management systems provide centralised monitoring and control of mechanical and electrical equipment and can include load control, weekly scheduling, demand limiting, duty cycling, optimal run time, supply air temperature reset, enthalpy switchover and chiller control. Some of these energy reduction programmes which are included in most computerised energy management systems available in the market are explained below. Different manufacturers may use different control techniques in achieving the energy savings but concepts will remain the same.

Electrical demand limiting and duty cycling

Utility rates for commercial and industrial customers are based on the maximum power (peak demand) which must be delivered, as well as the total energy consumption. Demand is calculated by the utility as the average power measured over a short period of time, called the demand interval. The peak demand recorded during the monthly billing period becomes a basis for the customer's demand charge.

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The demand calculation may be performed by utilities using either "fixed" or "floating" demand intervals. A fixed interval is one which has predefined start and end times which are established by a pulse transmitted from the demand meter, called the end-of-interval pulse. A demand meter installed to monitor fixed, 30 minute demands, will trigger an end-of-interval pulse every 30 minutes. Knowing that the power company's interval was N minutes long, (where N could be 15, 30 or 60 minutes), demand could be reduced by stopping large loads just prior to the end of an interval and restarting minutes later after the end-of-interval pulse had been received.

Electric utilities are being confronted with a "roller coaster" effect on their distribution systems caused by several customers shedding and restarting loads at the same time during each interval. Due to this "roller coaster" effect, there is a current and growing trend for electrical utility companies to change their means of demand determination to a floating interval method.

When a floating interval is used, demand is still calculated as the average power over a specified period of time such as 30 minutes. However, the demand is calculated for overlapping 30 minute time intervals, not just those which are fixed between end-of-interval pulses. To be compatible with this type of demand monitoring, the Electrical Demand Limiting (EDL) programme uses a modified form of continuous integral demand calculation referred to as "Floating Window" for all applications. Using this method, a new demand calculation is made every minute based upon the total kWh consumption in the last N minutes (where N is once again the length of the demand interval). This past demand is then compared with an operator entered Demand Set Point limit to determine the rate at which the actual demand is approaching this limit and what action is required to keep the demand from exceeding it. The Demand Set Point is determined on the basis of the normal kW demand and the number of loads available for shedding.

. Based upon the demand comparison, the EDL programme provides the present shed or restorable load calculations for further analysis and processing.

Most fans, pumps, and HVAC systems in a building are operated continuously during occupied period to provide the heating, cooling and ventilation for which they were designed. The capacity of this equipment is large enough to maintain occupant comfort during peak load conditions, which generally happen on the hottest and coldest days of the year. On all other days, it is possible to turn off some of this equipment for short periods of time with no loss to occupant comfort. Duty Cycling can offer significant reduction in overall kWh consumption by selectively stopping these loads for predefined amounts of time.

Unlike Demand Limiting, which controls loads to keep the KVA demand below a Demand Set Point, the Duty Cycle programme controls loads to maintain an operator defined reduction in KW. In addition, the cycle times of loads may be automatically adjusted to compensate for external variants such as space or outdoor air temperature.

Demand Limit and Duty Cycle must work in unison to provide both energy and demand savings with minimal disruption to the desired building operating environment. The integration of these programmes is provided through the Load Processor programme.

The Load Processor is used to intellingently select and control equipment to satisfy the calculated Demand Limit and/or Duty Cycle control actions. The Load Processor turns off just enough loads to satisfy the collective requirements of Demand Limit and Duty Cycle, and controls the time each load remains off. It also determines the frequency at which each load may be shed by controlling the minimum amount of time between consectuvie shed actions.

Condenser water temperature reset

The greatest potential for savings due to temperature reset of chillers occurs on the condenser side of the machine. While the increase in efficiency for a degree of temperature reset is approximately the same for both the evaporator and the condenser sides, a greater amount of reset is usually possible on the condenser side. Chilled water reset typically is limited to 1.5 – 3 degree C with an

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unlikely maximum of 5 degree C. However, the condenser water circuit can frequently achieve 5 -- 11 degree C of reset.

Chiller plants are usually sized to reject their rated tonnage through cooling towers sized to operate at design outdoor wet bulb conditions. The leaving tower temperature is primiarily dependant on the outdoor ambient wet bulb temperature. The tower is sized to cool this condenser water down (via evporative cooling) to within a certain number of degrees of ambient wet bulb. This design number of degrees is known as the "tower's design approach" or, how closely the condenser water can approach the outdoor ambient wet bulb. The approach value for most towers is in the 3 – 5 degree C range. As ambient wet bulb drops from the design level, the condenser water will also drop. Usually, there are controls installed to sense this lower temperature and take the necessary actions (tower bypass or shutting off tower stages) to keep the condenser water entering the chillers at its design temperature, normally 30 degree C. This may save some tower fan horsepower, but it will force the chillers to continue rejecting their heat into a needlessly high temperature heat sink (namely 30 degree C entering condenser water). The savings being ignored at the chiller under these conditions will far exceed the gains realized in tower fan horsepower.

Several means can be used to achieve the above control strategy, but the most accurate approach is through the use of a computer. The Condenser Water Reset programme calculates and adjusts the set point of the condenser water temperature to minimize the energy expended at the cooling tower. The set point is dependent upon the outdoor air wet bulb temperature, the instantaneous percent of chiller plant capacity being used and the characteristics of the cooling tower. The following points are required for the condenser water reset programme:

- Outdoor Air Dry Bulb Temperature
- Outdoor Air Dew Point Temperature

A calculation of the outdoor air wet bulb temperature is made using the inputs above. The Condenser Water Reset programme obtains the Chiller plant load data from the Multiple Chiller sequencing programme and the user defines the tower approach temperature.

Multiple chiller sequencing

All centifugal chillers operate most efficiently in the middle to upper portions 40 – 90% of their design capacity range. The lowest input energy to output tonnage ratio usually is between 50% and 60% of maximum tonnage. This mid-load range is also the place where most chiller plants spend most of their time. Consequently, selecting the right chillers to run for any given load is quite important. In theory, it is better to run two equal-size chillers at 50% load each rather than only one at 100% capacity. This, however, ignores the horsepower consumed by any pumps which must be started with the second chiller. This pumping horsepower could consume more energy than the second chiller saves by being in a more efficient part of its part load performance characteristic. The type of plant must be analyzed before a judgement can be made as to which chillers should run to satisfy certain loads. The pumping horsepower required for each additional machine is the primary determining factor. Generally, series piped chillers have good potential because the second machine does not require any additional pumping horsepower. Primary/secondary pumping systems are reasonably good candidates because the primary pumps which are interlocked to the chiller are usually quite small since they only have to move water through the small primary loop within the equipment room. Plants which use the chiller pumps to distribute the chilled water throughout the whole system are less likely to show good possibilities for energy savings via chiller sequencing.

The graphs in Fig. 1 show the composite curves for 1 – 4 chillers running at various loads in an actual plant. It is based on these curves that a Multiple Chiller Sequencing programme is designed. The programme automatically performs a comparison of the current chilled water demand and a chiller sequencing strategy defined by the operator. Based on this comparison, the programme may either automatically start up or shut down equipment, or issue a system output to notify the operator that a switchover condition currently exists which requires his attention.

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Chilled water temperature reset

Chiller efficiency can also be increased by increasing the leaving chilled water temperature. The ratio is approximately 2–3% increase in efficiency for each 1 degree C rise in water temperature. This does not mean the chiller is performing less cooling or that the total temperature drop through the chiller is any less. The chiller simply does not have to work as hard to lower the water temperature from 15 degree C to 9 degree C as it does to lower the water temperature from 12 degrees C to 6 degree C even though both are 6 degree C temperature drop.

Design leaving temperature for the chiller is just as the name implies only meant for design load conditions. Full load conditions do not exist the majority of the time. During these times, there is a good chance that design temperature can be raised. The maximum call for cooling capacity can be obtained by comparing the signals being fed to the cooling coil valves. The coil calling for the greatest amount of cooling can be selected and this cooling requirement can be used to determine the necessary chilled water temperature. Any time this cooling coil is not using full chilled water flow, it implies that supply water of that low temperature is not needed. The chiller temperature controller should then be reset to some higher value. If no cooling coil calls for full chilled water flow at this new temperature setting, the controller should again be reset to a higher temperature. The chilled water temperature should not be readjusted downward until one of the cooling coils cannot produce sufficient cooling to satisfy its load requirements. This condition can be sensed by observing any cooling coil valve which is receiving a control signal beyond what should be required for full chilled water flow to the coil. At this time, the chilled water controller should gradually be reset to a lower temperature until all cooling coil valves are positioned within their control ranges. All of these functions can be accomplished with standard proportional acting temperature controls.

It is based on the above conditions that the Chilled Water Temperature Reset programme is designed, which minimizes the wasted energy by continually adjusting the chilled water supply temperature setpoint based upon the actual requirements of the cooling coils supplied by each chilled water loop. The objective is to readjust the setpoint to the highest possible temperature which will still meet system cooling requirements.

Optimal run time

The Optimal Run Time (ORT) programme controls the start and stop times of HVAC equipment during both the heating and cooling seasons to provide the most efficient operating strategy during potentially energy wasteful periods of the day. The programme determines the morning start time and evening stop time which will maintain occupant comfort requirements and maximize energy savings.

Optimal Start Time control decisions are based primarily upon occupancy schedules, outside air temperature, and interior mass temperature of the building.

The adaptive modeling technique is used in the determination of both the Warm-Up (heating mode) and Cool-Down (cooling mode) Optimal Start Times. Adaptive modeling requires a minimum amount of preliminary engineering work by the user, and will develop a programme which most accurately calculates the minimum amount of time required to bring a building's environment within operator-defined comfort levels by occupancy time.

The following HVAC System points are required to support the Optimal Start Time evaluation:

1. Outside air dry bulb temperature

2. Interior room mass temperature

3. Fan status.

The ORT programme will be activated each day at the operator-entered Normal Start Time

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defined for each fan system. The Normal Start Time may be different for each day of the week and each fan system, but it will always represent the time at which a fan system would be started prior to occupancy, anticipating the worst case seasonal conditions.

The ORT programme performs the analysis required for a particular day by comparing the room mass temperature with four user defined limits:

1. Heating Season Limit

2. Cooling Season Limit

3. Heating Season Desired Mass Temperature

4. Cooling Season Desired Mass Temperature

The Desired Mass Temperature represent the comfort requirements for the respective seasons. If the mass temperature on a particular morning falls between these two limits the programme assumes that the mass temperature of the space is acceptable and that the supportive air handling equipment needs to be started just early enough to bring the space air temperature up to occupancy levels and purge the building. The Purge Interval is the minimum time needed to refresh the air prior to occupancy under the best condition. This Purge Interval is dependent upon the air handling system sizing and is defined by the user.

Two seasonal switchover temperatures are used to more accurately determine the current heating or cooling mode of the ORT operation. As shown in Fig. 2, any morning mass temperature below the Heating Season Limit will request an ORT Heating Season, and any mass temperature above the Cooling Season Limit will request an ORT Cooling Season analysis. If the mass temperature on a particular morning falls between the two limits, the seasonal mode will be the same as the previous day.

The Optimal Stop Time programme calculates the earliest time at which designated equipment may be stopped based upon:

1. ORT Seasonal Mode

2. Earliest Allowable Stop Time

3. Building Vacancy Schedules

4. High & Low Outside Air (OA) Comfort Limits

Occupant comfort is the major determining factor in the early stopping of HVAC equipment. The Earliest Allowable Stop Time is the earliest time the fan can be stopped.

For the heating season the OA temperature corresponding to the Earliest Allowable Stop was a high limit and that coreresponding to a Vacancy Time Stop was a low limit. For the Cooling Season the control philosophy will be the same but the OA temperature corresponding to the Earliest Allowable Stop Time will be a low limit and that requiring a Vacancy Time Stop will be a high limit.

Fig. 3 and 4 show examples of both a Cooling Mode and Heating Mode relationship. Both figures point out the basic principle of Optimal Stop Time: the warmer it is in summer or the colder it is in winter, the later will be the time that air conditioning equipment may be shutdown prior to vacancy time.

Supply air temperature reset

The discharge temperatures of an HVAC system are normally selected to satisfy the building spaces under maximum design conditions when full heating or cooling is required. Since these design

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days occur infrequently throughout the year, the fan system has the capability of tempering the cold or hot supply air through various techniques, such as using reheat coils in the zones or mixing heated and cooled air together to achieve a satisfactory temperature. While these techniques provide good occupant comfort during part-load conditions, they waste energy.

A more energy effective technique is to reset the discharge temperature based on the requirements of the zones which need the most heating and cooling. Not only will this save energy needed to condition the supply air, but it will also save energy needed to temper the air discharged into the space with reheat coils or mixing boxes. The Supply Air Reset (SAR) programme performs this function by monitoring thermostat control signals and return air humidity. Based on these inputs, the programme will calculate:

1. How high cold air discharge temperatures can be reset while still satisfying the greatest cooling load.

2. How low hot air discharge temperature can be reset without causing discomfort in the space requiring the most heating.

The calculated values are output as a new set point for heating or cooling discharge conditions.

The Supply Air Reset programme may be generally applied to two types of HVAC fan systems:

1. Terminal Reheat Systems –
These fan systems have a single source of cold air which is used to satisfy the cooling requirements of all the spaces it serves. Individual reheat units, located near each space, automatically raise the air temperature to satisfy that space's actual cooling requirements. The Supply Air Reset programme adjusts the single source of cold air (i.e., the cooling coil controller) to provide the warmest possible air that will satisfy all spaces. This programme therefore minimizes the mechanical means needed to cool and subsequently rehat the air.

2. Dual Duct Systems –
These fan systems have one source of cold air and another source of hot air which are used to satisfy the cooling or heating requirements of all the spaces it serves. Individual mixing boxes, located near each space, automatically mix the two air sources to satisfy each space's actual cooling or heating requirements.

NOTE:

The SAR programme reduces cooling energy by increasing cooling coil set points as high as possible. If applied to variable air volume (VAV) systems, this will generally increase the amount of air flow used by the system, which will increase the fan horsepower. Depending on the type of VAV configuration, the cooling savings could be more than offset by the increased fan energy. It is recommended that this programme not be applied to VAV systems which use fans with blade-pitch control and volume cut-off boxes in the zones. Application of the programme to VAV systems with terminal reheat is generally acceptable if fan capacity is controlled by inlet vanes, but may not prove energy effective to VAV reheat systems using fan blade-pitch control. Energy trade-off of other VAV configurations should be studied closely before attempting to apply this programme.

The Supply Air Reset programme adjusts the source of the cold air (i.e., the cooling coil controller) and adjusts the source of the hot air (i.e., the heating coil controller) to provide the warmest cold air as well as the coolest hot air it can to satisfy the current cooling/heating needs. This programme therefore minimizes the mechanical means needed to cool and heat the Supply Air to the require temperature.

Enthalpy switchover

The deisgn of many fan systems allows for a mixture of outside air and returned space air to be

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used for heating, cooling, and conditioning the spaces served by the fan. A minimum amount of outside air must be used at all times that the building is occupied to provide ventilation and to make up exhausted waste air from the building. Under certain climatic conditions, it is advantageous to use more than the minimum amount of outside air to provide free cooling in order to reduce the mechanical cooling, thus reducing the cooling energy bill.

The Enthalpy Switchover programme samples analog input data to determine if commands are required to optimize the use of outside air. The programme will calculate outside air (DA) and return air (RA) enthalpies using OA and RA dry bulb temperature and relative humidity or dew point temperature sensors.

When OA by dry bulb temperature is less than RA dry bulb temperature and OA enthalpy is less than RA enthalpy, the programme will cause a fan system's dampers to be placed under control of a supply air temperature controller.

When OA enthalpy is greater than RA enthalpy or OA dry bulb temperature is greater than RA dry bulb temperature, the program will return the fan system's dampers to their minimum OA position. Each fan system will be considered individually.

Energy Profiles

The Energy Profiles provide a valuable management tool with which to evaluate the control and savings obtained through the following programmes:

1. Electrical Demand Limiting and Duty Cycling
   – Peak Measured Demand and its time of occurance
   – Accumulated energy savings due to duty cycling
   – Measured energy usage.

2. Condenser Water Temperature Reset
   – Savings will be calculated by comparing the energy expended at a fixed setpoint with the energy expended at the continually readjusted setpoint.

3. Chilled Water Temperature Reset
   – Savings will be calculated by comparing the energy savings at a fixed chilled water setpoint with the energy expended at the readjusted setpoint.

4. Optimal Run Time
   – Savings are stored and accumulated individually for the start and stop periods.

5. Enthalpy Switchover
   – Cooling coil savings will be calculated dependent upon the enthalpy difference between using 100% OA and using minimum OA, the density of air and the associated fan's air flow rating.

6. Supply Air Temperature Reset
   – Savings will be calculated based upon a comparison of the programme-controlled discharge temperature versus a fixed discharge temperature equal to the specified maximum (heting loop) or minimum (cooling loop) setpoint.

Being part of a sophisticated computerised energy management system, the energy profiles offer a complete set of data summary to complement the basic energy conservation function. With the information provided in the summaries, a user can determine further ways to more efficiently control electrical energy usage.

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Programmable lighting control

Lighting is the second largest single load in many commercial buildings, accounting for as much as 20% to 30% of total electrical energy consumed in a building. While there have been substantial improvements in the efficiency of lighting sources, relatively little has been done until recently to reduce consumption through computerised automation system – using the right amount of light, where needed and when needed.

The computerised automation system focuses directly on the needs of lighting through start/stop control. Multiple levels of lighting could be achieved, say, by using two start/stop points to control "split wired" fixtures, as shown in Fig. 5 for a three lamp fixture. Here selective switching allows OFF, 1/3, 2/3 or FULL ON lighting levels. New lighting installations should always be wired to provide multiple lighting levels.

The following control strategies will result in great energy savings on lighting:

1. Weekly scheduling with holiday skip of lighting levels to match the occupancy requirements.

2. Occupancy override of scheduled lighting levels by zone.

3. Stepped lighting control for day lighting compensation, saving approximately 20 – 30% in the perimeter zone. To avoid nuisance switching, the photo sensors should incorporate a time delay.

4. For open offices, zones of approximately 100 sq. m. are reasonable.

When programming the weekly scheduling, we can take into consideration of the following:

- 1/3 lighting for early arrivals
- Lights turned to 1/3 level for lunch and at the end of the day
- Multiple OFF sweeps at regular intervals insure that lights are turned off
- Provide 1/3 lighting in one quadrant of the floor at a time for the cleaning crews, automatically turning OFF lights in the other quadrants.

The key requirement for effective lighting energy savings is to have proper lighting zoning. To the extent possible, lighting circuits and work zones should correspond. Long strings of fixtures cutting across many work areas limit the ability to selectively control different areas.

Occupancy control

Programmed Start/Stop improves the efficiency of a building's operation by automatically starting and stopping equipment according to occupancy, time of day, and day of the week. This promotes longer equipment life and better utilization of manpower as well as reducing energy consumption.

A Start/Stop programme for a field device consists of a start time, a stop time, and the days of the week to which the programme applies. Each field device can have several unique start times, stop times, and days of the week. This flexibility allows separate programmes to be entered for different days of the week, multiple start and stop times for different days of the week. Holiday schedules will also be taken into account.

The computer confirms each command sent for a correct response and notifies the operator of any discrepancies. If, for some reason, the schedules change, the programme can be updated, added to, or deleted from "on-line" without interfering with normal operations.

In addition to energy savings by interacting the time programmes with the Duty Cycling and Optimal Run Time programmes further savings in occupancy control can be achieved by:

1. Starting fans, pumps, VAV terminals and other equipment based on outside air temperature.

2. Opening outside air dampers for ventilation only when an area is scheduled for occupancy. They stay closed during startup to avoid conditioning outside air.

3. Increasing duty cycle during lunch and breaks.

Maintenance alarms and load monitoring

The computerised system lets you know when maintenance is actually required in the form of maintenance alarms rather than just having it performed on a calender basis. Overdue or prolonged maintenance will require increased system power which consumes a surprisingly high percent (5% to 20%) of an air conditioning system's total energy consumption.

For example, when a supply air fan filter becomes dirty, an alarm is sent back to the computer so that the filter can be cleaned or replaced. The energy required to move air through a dirty filter increases as filter loading increases. It is not uncommon that a filter requires five times as much energy (static pressure drop) during the end of its useful life than at the begging. Multiply this one instance of energy savings by dozens of others and one can appreciate the possibilities.

Other maintenance alarms on selected equipment such as fan differential pressure, space temperature, etc. are possible indications of worn-out fan bearings, slipping motor driving belts and malfunction control valves, all of which are sources of enrgy waste.

Load monitoring include ON/OFF status monitoring, runtime totalization and consumption totalization. While ON/OFF status monitoring will monitor and hence control unnecessary or unauthorised running of equipment, runtime and consumption totalization will help analyse energy usage of equipment, identify and develop future energy conservation opportunities.

Effective energy conservation is far more than simply monitoring a building's energy-consuming equipment. It must involve the reliable, efficient and precise control of that equipment. It must entail a well coordinated, intergrated programme specifically tailored to a building – a programme which optimize the energy usage of the building systems while maintaining acceptable comfort level, health and safety.

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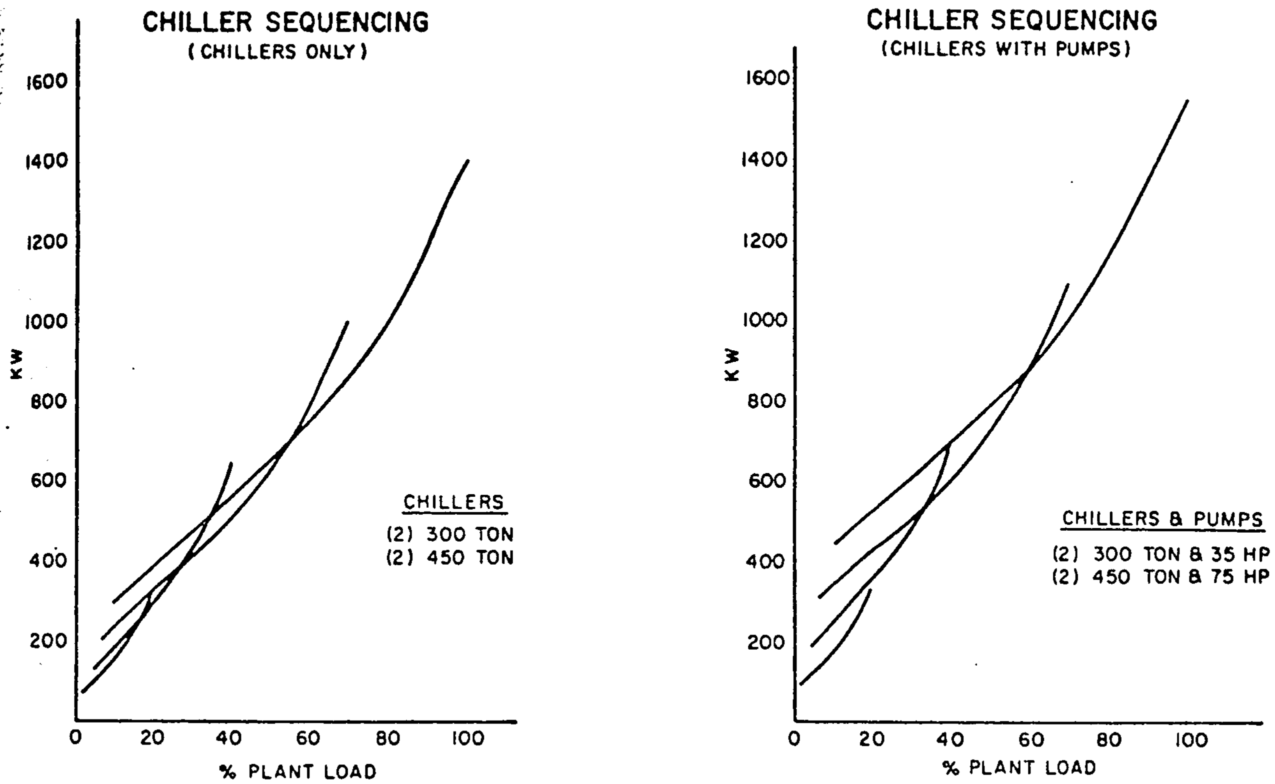

Fig. 1 Multiple Chiller Load Characteristic

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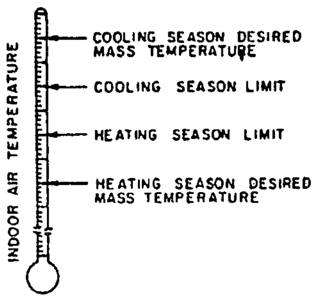

Fig. 2 : Seasonal Mode Determination

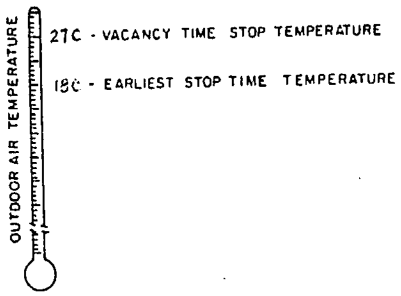

Fig. 3 : Cooling Mode Example

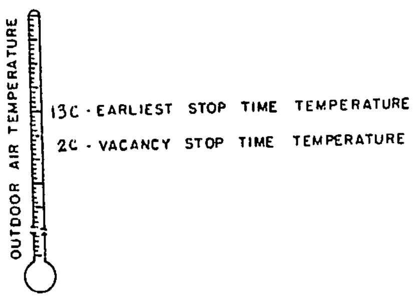

Fig. 4: Heating Mode Example

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Start/Stop Relay States #1	#2	Lighting Level
OFF	OFF	OFF
ON	OFF	1/3
OFF	ON	2/3
ON	ON	FULL ON

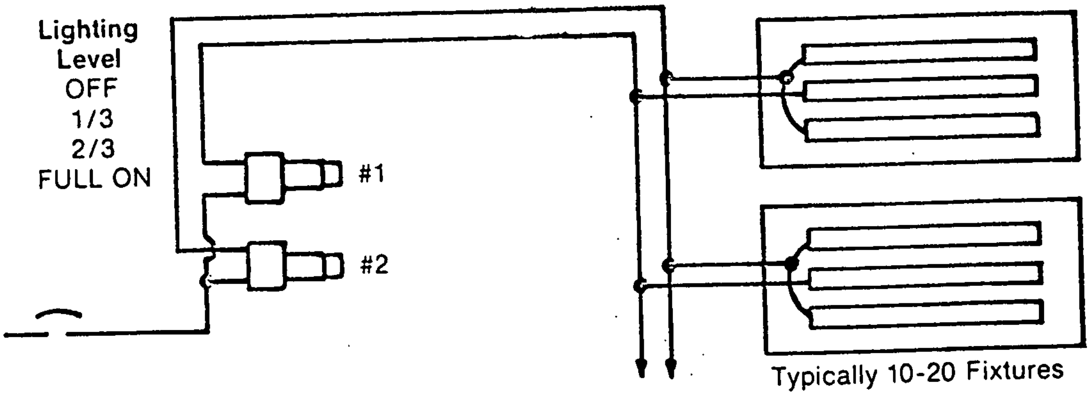

Figure 5. Split-wired Fixtures for Multiple Lighting Levels.

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Paper No. 6

The Application of Microprocessor based Equipment for Energy Saving and Consumption Optimisation in Industrial Installations

Speaker: Mr. M. C. S. Simpson, BSc (Eng), CEng, MIEE, Technical Director, GEC Meters Ltd, UK.

THE APPLICATION OF MICROPROCESSOR BASED EQUIPMENT FOR ENERGY SAVING AND CONSUMPTION OPTIMISATION IN INDUSTRIAL INSTALLATIONS

1. Synopsis

Electricity utilities carefully design tariffs to maximise effectivenss of generation and distribution equipment. A range of electricity metering and Energy Management equipment is described that enables consumers to match tariffs and maximise efficiency whilst maintaining lowest cost.

Described are microcomputer based Energy Management schemes which accept inputs from impulsing electricity meters and process sensors and produce control outputs. Two communication systems for load control utilising existing mains wiring are also covered.

Maximum Demand control equipment and the latest microprocessor based meter recording apparatus is detailed and future trends in metering equipment are predicted.

2. Introduction

Tariffs are introduced in order to encourage customers to move their use of electricity from periods of high demand to periods of low demand. Figure 1 shows the general load characteristic of a power system and it can be seen that the requirement for power is low in the early hours of the day and there is a tendancy for two peak demands, one in the late morning and one in the early evening.

Electricity Supply authorities have to meet the demands of the load characteristic but they also try to alter the shape of their load curve to achieve a better economic balance between demand and generating capacity. This is often achieved by time of use tariffs.

In such an arrangement electricity costs vary depending on the time of day or even the day of the week according to a published tariff designed to match generation costs.

Time of use tariffs alone may not provide the amount of control over electricity usage that some supply authorities require.

Another option is to use a Maximum Demand charge either in isolation or as a supplement to the time of use tariff. Maximum Demand is measured in KW or KVA, is calculated by determining the total number of units consumed in a preset period of time called the integration period (usually 30 minutes in the UK), and scaling this figure to give the equivalent steady state load which would have produced that number of untis in the preset time period.

The Maximum Demand reading is the highest demand reading that occurs over any integration period during the billing period. The billing period is usually one month.

A peak demand incurred in any integration period during the billing period would be used to calculate the Maximum Demand charge for the month and sometimes the year.

In the UK a consumer may be charged for all units consumed according to this Maximum Demand and thus pays a price penalty on all his consumption.

In order to achieve a better balance Maximum Demand charges and tariffs are structured to place the emphasis on the consumer to install equipment capable of accurately monitoring his consumption of electricity and to control his load, spreading his electricity demand more evenly over the working day.

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3. **Acquisition of data**

Before we consider the microprocessor based equipment capable of monitoring the use of electricity, we must address ourselves to the problem of obtaining the electricity consumption data from the single phase or polyphase circuit meter.

Opto-reflective transmitters are now becoming universally adopted, Figure 2. With this method an infra-red emitter directs a beam onto the meter disc and the reflected beam is received by an infra-red detector.

Black marks on the disc which are absorbent to infra-red cause the switching action of the opto-transmitter.

Opto-transmitters provide the following features:

* High pulse rates
* No additional friction
* Wide range of pulse values
* Reliability
* No maintenance

4. **The metering requirement**

We now have electricity meters capable of providing pulse outputs representing the usage of energy by the consumer.

The equipment needed to monitor these pulses will vary according to the particular application, we can specify the common features.

* It must accept digital inputs and be capable of scanning the inputs quickly enough to ensure no metering pulses are lost.

* There should be intelligence to summate these pulses and generate the required demand period information.

* It should be capable of calculating Maximum Demands.

* There should be a customer interface which allows interrogation and logging of the metering information.

If the requirement is for a tariff metering system then it must provide additional facilities for:

* Storing the tariff program and allocating the energy consumption data to the correct tariff store.

* Maintaining a central data base of cumulative consumptions for each meter circuit.

In a situation where we require to dynamically control a consumers load and spread demand more evenly over a period of hours then the equipment must be capable of:

* Predicting trends in consumption

* Switching loads

* Accepting other control inputs, both digital and analogue

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The microprocessor equipment

Having defined the necessary equipment features for the various metering and control applications we shall now consider the consumer. The equipment the consumer requires will vary depending on:

* Size of electrical load
* Operating tariffs
* Flexibility required
* Load control requirement

For a small industrial consumer operating on a restricted time of use tariff, a microprocessor based multi rate time of use register could be used typically offering:

* Four rate registers
* Two maximum demand registers
* Internal clock/calendar
* High security data transfer via optical ports
* Output facilities for load control
* Non-volatile memory

The multi rate register receives pulses from a conventional integrating meter fitted with a transmitting unit. These pulses are recorded and stored in different rate registers according to the tariff period. Switching of the tariff periods can be initiated by an internal clcok or by an external device. Data may be extracted or entered via an optical port and the data then becomes available for further processing on a personal computer.

For the larger industrial consumer, operating on a similar time of day tariff, but with more than one metering circuit, his needs would be satisfied by a more complex multi input device having kVA and summation capabilities. The features offered by this type of equipment can be itemised as follows:

* Eight cumulative units registers. These repeat the readings of each of the meter registers.
* Eight totalising registers. These store the results of additions or subtractions.
* Eight VA registers. These can be used for calcualting the VA from any combination of input registers and totalising registers.
* Eight time controlled registers. These are used for tariff purposes and will only increment between predefined time limits. Each register can be given an on-off time of day, an on-off date and which days of the week the register will be operational.

In total there are 32 main registers. For each of the main registers, the register information in Figure 4 is recorded and stored, also the historical register information detailed in Figure 5 is recorded and stored. All this information gives a total of 288 register values available for billing purposes.

Other features are:

* A real time clock and calendar for tariff control purposes.

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* A real time clock and calendar for tariff control purposes.

* Two retransmit contacts which can be used to output any information including alarms.

* Two auxiliary inputs for communications or external tariff control purposes.

* A serial output port for driving the matching printer.

For the consumer whose needs extend to Maximum Demand Control he will require equipment capable of continuously monitoring electrical demand, recognising imminent peaks and shedding or restoring non-essential loads in a predetermined sequence. Ideally the equipment should offer selective manual override of individual loads.

A typical equiment configuration is illustrated in Figure 6.

However, the aim of Energy Management is not solely to cut total energy use but moreover to reduce waste. With the advent of low cost microprocessor controllers and the rising costs of energy supply, sophisticated Energy Management Systems can now be cost effective even for quite modest users of electricity.

Perhaps the definition of good Energy Management should be, "Efficient control of scarce resources to minimise cost without inconvenience."

In addition to Maximum Demand Control, two areas in which potential savings can be made are:

* Lighting control

* Heating and ventilation

Simply by ensuring that lights are only on when and where they are required can produce significiant savings, especially on a factory or office site where prompt switching at lunch times and outside normal working hours is feasible.

For heating and ventilation, optimum start up times prevent excessive warm-up periods and proper feedback control stops overshoots which cause uncomfortable working conditions and waste energy.

A suitable control system is based on PERM 200, a microprocessor based digital/analogue data acquisition and processing station, for Metering and Energy Management applications. It is a 19 inch rack system using a modular construction. The modular principle leads to a number of advantages:

* Specific equipment demands can be met from the range of available modules.

* No premium is paid for capacity in excess of requirements.

* The easy access afforded by plug-in modules leads to a simpler maintenance and repair resulting in an economic spares policy.

Following the introduction of a 26 part Bulk Supply Tariff in the UK for the supply of electricity from the generating authority to the distribution utilities, this type of equipment has been used to implement the metering of this complicated tariff structure.

In addition to providing logging of the basic kW and kVAr, it calculates kVA and power factors, predicts demand values and sheds or restores selected loads accordingly.

It can provide interfaces for monitoring digital and analogue sensor inputs and perform switching operations based on this information and on a time of day sequence program.

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The equipment also provides various interfaces to the consumer. These enable the user to configure the system operating parameters to obtain optimum performance and maximise energy savings.

A typical display format is shown in Figure 7.

6. The communication problem

Having arrived at the point where we are logging metering information, predicting consumptions and initiating load control sequences, we must now consider the problem of how we can physically achieve the desired switching of loads.

In each case electrical equipment needs to be controlled from a central point where the Energy Management equipment is located.

Unfortunately suitable non-essential loads are seldom grouped together in large convenient blocks. The problem therefore is communication.

An Energy Controller must be able to switch off loads at remote locations and the cost of running pilot wires to such loads may amount to many times the cost of the controller.

The best solution to the problem is probably mains signalling. Two examples of such systems are:

* MAINS LINK –
  a 16 channel frequency shift keyed system operating at 48.6 kHz aimed at small commercial and industrial sites.

* CYCLOCONTROL –
  a higher power 50Hz signalling system aimed at large commercial and industrial sites and for use by Electricity Supply Authorities.

Both devices provide a clean contract interface to the controller and both systems involve a transmitter connected to the supply transformer. See Figures 7 and 8.

The associated receives can be connected around the low voltage network and will switch on detection of the appropriate coded signals. Loads can be controlled directly from the switching contacts of such receivers or from interposing relays.

7 Future trends

With the new generation of flexible microprocessor based devices, utilities are able to implement more complex time of use tariffs, to match their load to the most economic generation. This is likely to spread to domestic consumers with different rates for weekends and holidays. This will leave scope for consumers optimisation equipment to match the consumers load to the tariff.

Many utilities are introducing load management tariffs for large industrial consumers. This has generated a need for more powerful metering system and these systems have now begun to follow the trends in Energy Management, away from standalone units to networked systems and the fully integrated approach. See Figure 9.

Each outstation is capable of operating in a standalone mode in the event of a communications failure, but is linked back to a Central Controller which maintains a main database for the whole system.

This Central Controller can provide a variety of features:

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* Archiving of historical data
* Load analysis and surveys
* Automatic billing
* An interface to mini mainframe computers for further processing and storage.

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DEMAND PROFILE

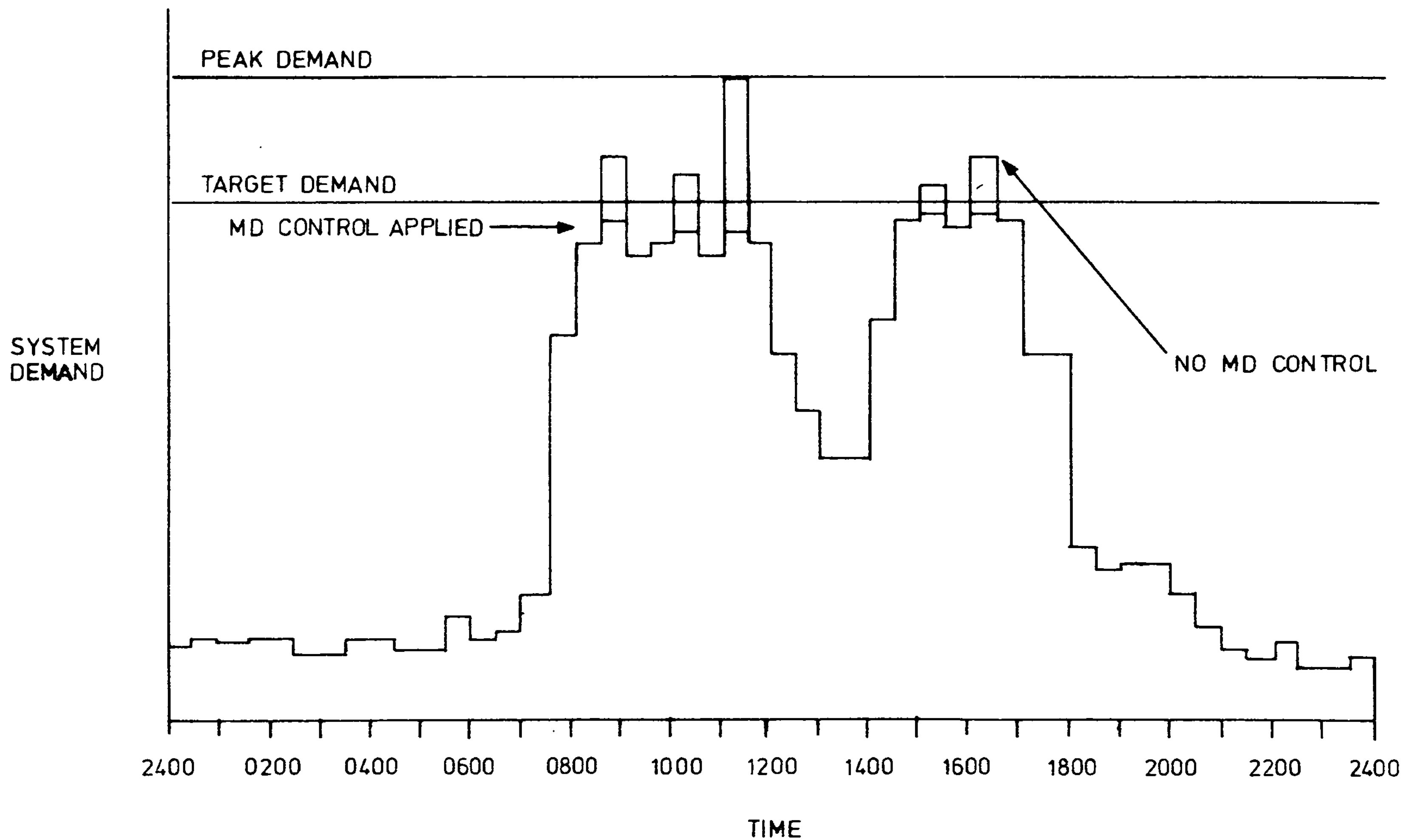

FIG. 1

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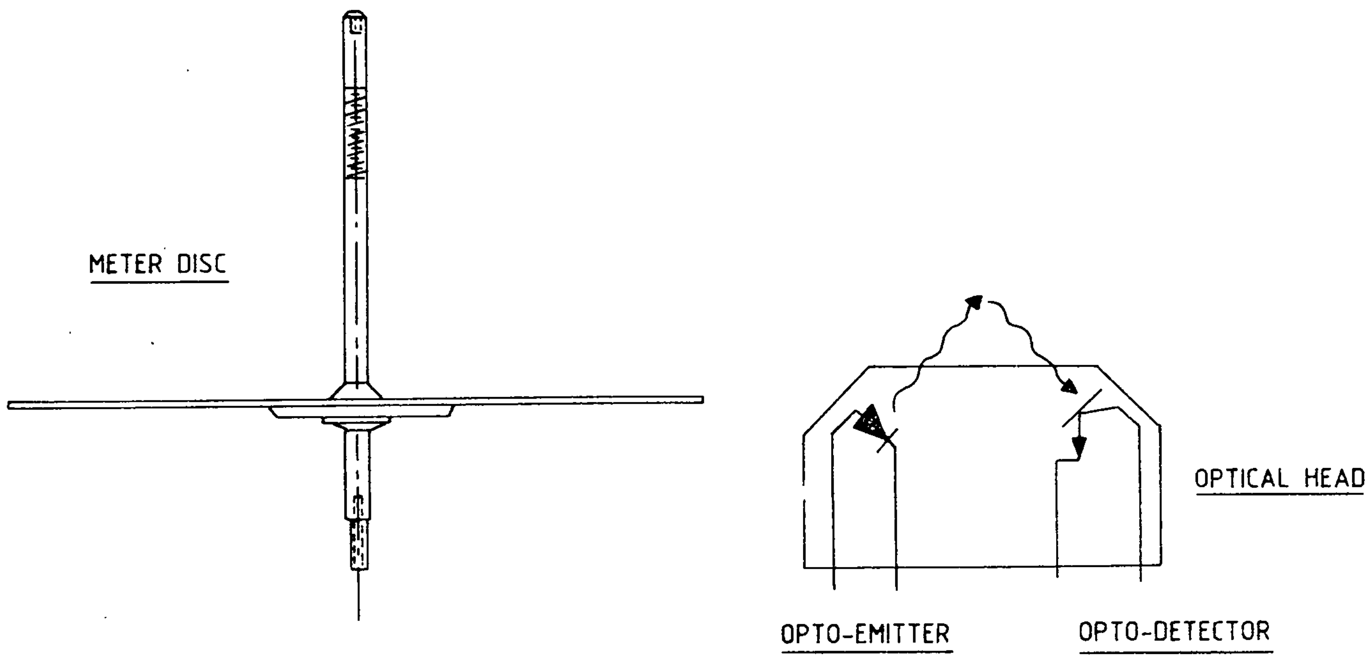

FIG 2 PRINCIPLE OF OPTO-REFLECTIVE TRANSMITTERS

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REGISTER INFORMATION

CURRENT DEMAND

MAXIMUM DEMAND

TIME AND DATE OF M.D.

CUMULATIVE M.D.

DEMAND OF PREVIOUS INTEGRATION PERIOD

FIG 3

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HISTORICAL REGISTER INFORMATION

VALUE OF CUMULATIVE UNITS REGISTERS AT THE

END OF THE LAST BILLING PERIOD

M.D. FOR LAST BILLING PERIOD

TIME AND DATE OF M.D.

FIG 4

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TYPICAL INSTALLATION

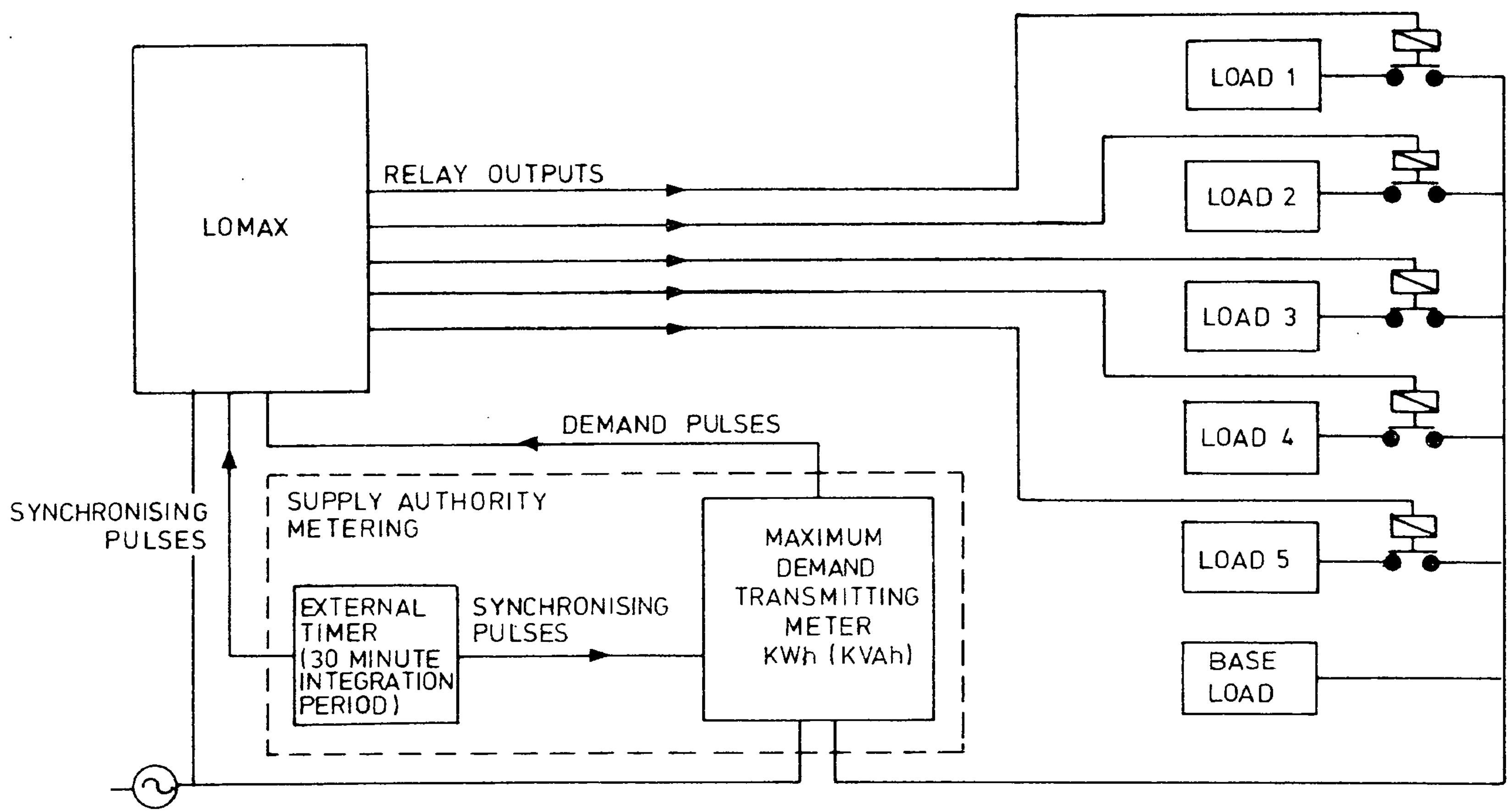

FIG 5

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DEMAND CONTROLLER

```
TIME:-   12:34   DATE:-       29/09/84      TIME REMAINING IN PERIOD:-  25:38

TARGET DEMAND:-               4200.00 kW    LOAD RESTORATION VALUE:-  600.0 kW

UNITS CONSUMED:-               250.0  kWh   CONTROL METHOD:-  CYCLIC

PRESENT LOAD:-                1800.0  kW    CONTROL DELAY:-  10 MINS

PREDICTED TARGET:-            1860.0  kW    DEMAND LAST PERIOD:-  4150.0 kW

MAXIMUM DEMAND:-              4180.0  kW    TIME:-  11:30  DATE:-  24/09/84


LOAD STATUS:-        1  2  3  4  5   6   7  8
                     *  *  *  *  *   *   *  *
                     ON ON ON ON OFF OFF ON OFF

                     DEMAND WARNING


RETURN TO COMMAND MODE BY ENTERING 'ESC' KEY
```

FIG 6

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TYPICAL MAINS LINK INSTALLATION

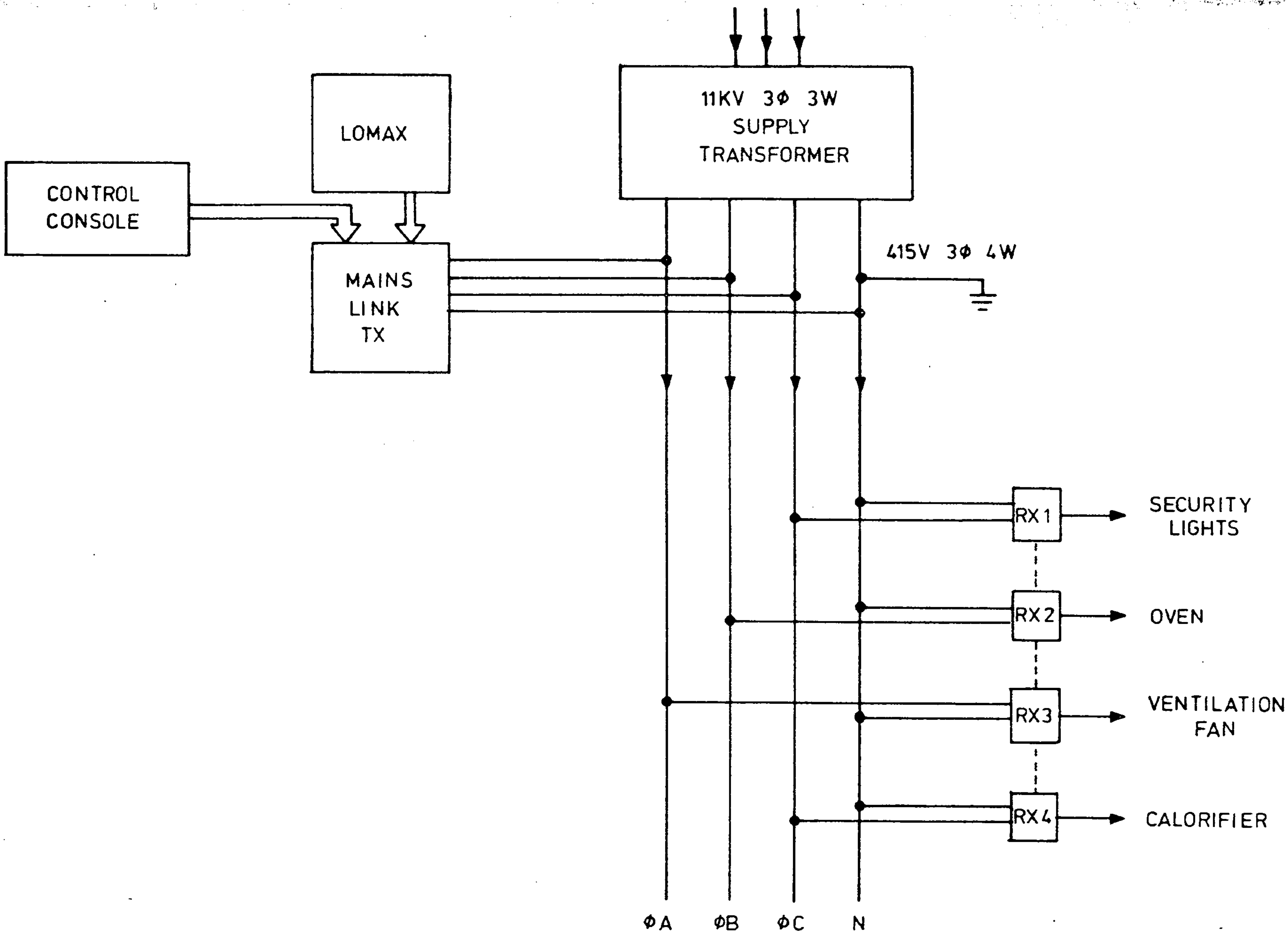

FIG 7

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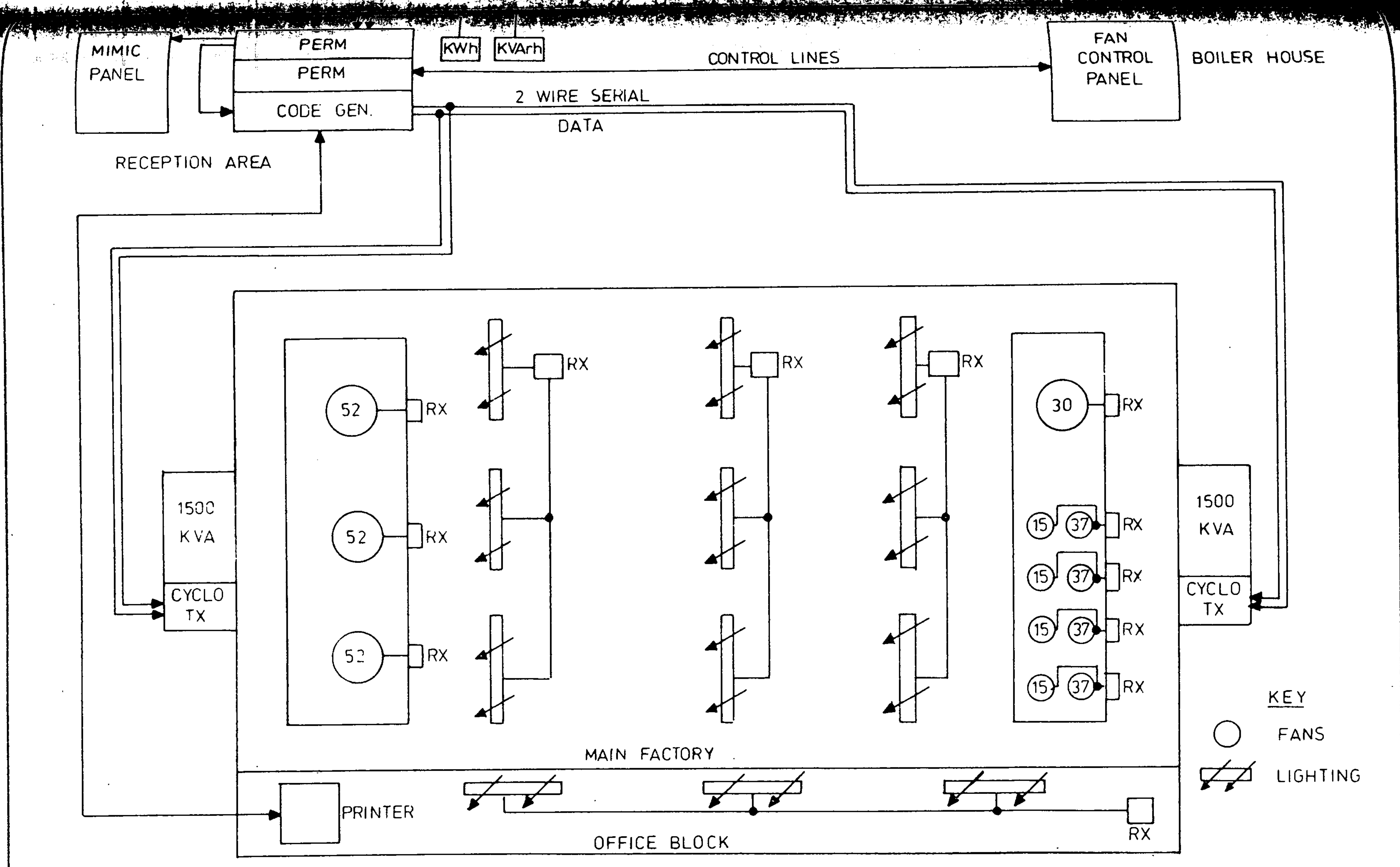

FIG 8

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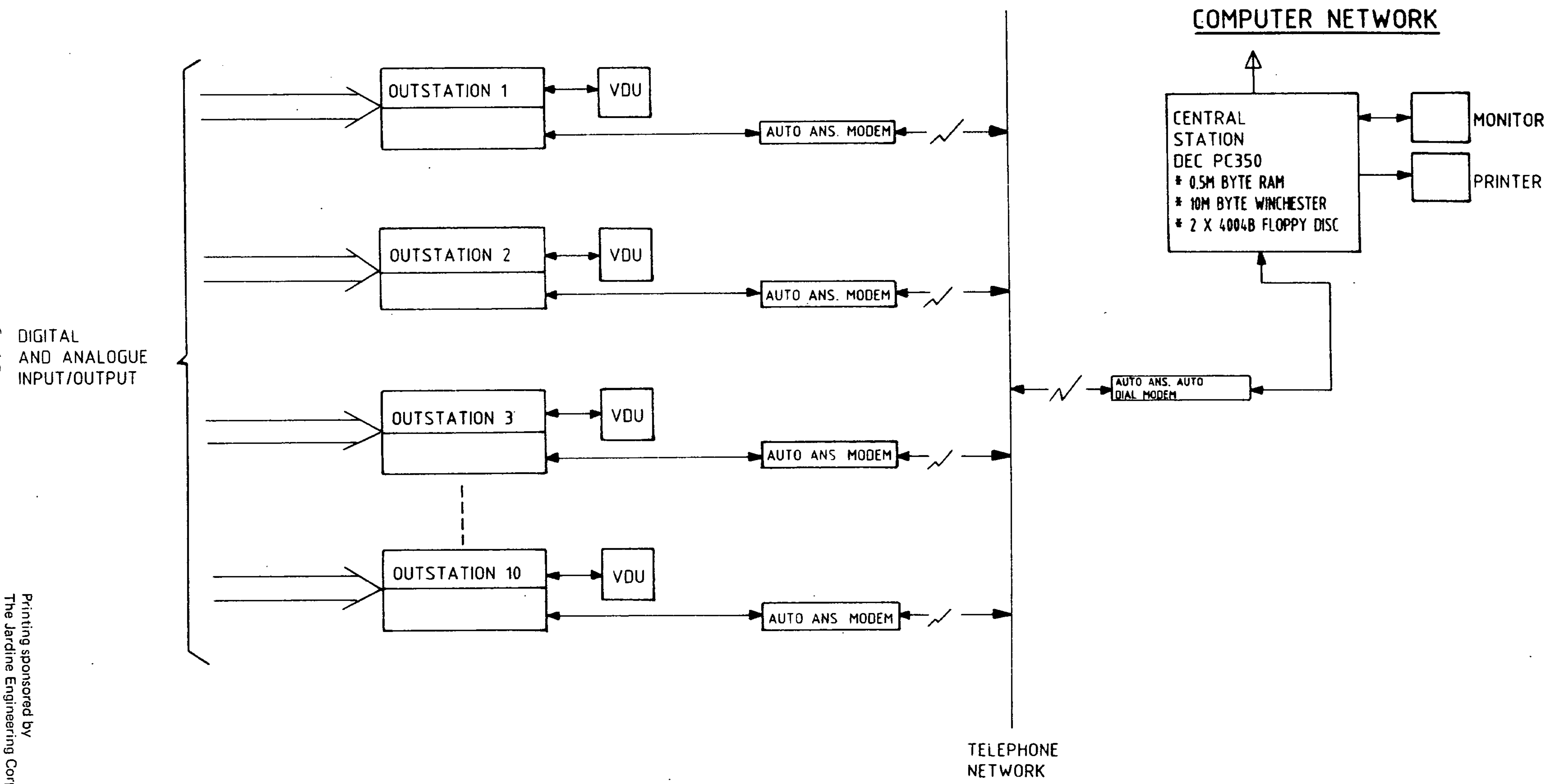

FIG 9

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Paper No. 7

Uplighting & Energy Saving Techniques

Speaker: Mr. L. Bedocs, CEng, MIEE, FCIBSE, Research and Development Manager, Thorn EMI Lighting Ltd, U.K.

UPLIGHTING AND ENERGY SAVING TECHNIQUES

Introduction

Today uplighting of interiors is used widely to provide flexible, diffuse, glare-free and effective illuminance efficiently. Uplights make effective use of electricity in buildings.

However, this lighting technique is not new. In fact it is one of the oldest artificial lighting techniques. Early samples show that man used the flames of burning wood or oil as his light source and a clay dish as his luminaire. This dish only partly shielded the flame from direct view and did little to control the light distribution. More recently suspended uplights fitted with high powered filament lamps were widely used for general lighting. The technique was very successful but with lamps having poor efficacy and short life together with the increasing demand for higher lighting levels (particularly after the war) attention was turned to fluorescent tube lighting. The overhead fluorescent tube luminaires provided a blanket of uniform direct light of efficiently.

The recent revival of uplighting has come about from the desire to harness the output of the newer high intensity discharge (HID) lamps of good colour, long life and high efficacy. The energy crisis has given further encouragement to re-investigate this alternative low energy lighting technique.

What are uplights?

Uplighting is an indirect lighting system where the luminaire emits all its light output upwards onto the ceiling and upper parts of the wall. This output generates large pools of light on the ceiling which are reflected down towards the work plane. Indirect lighting is fundamentally inefficient due to the light absorbed by the reflecting surfaces and the efficiency advantages only accrue by good optical design, high reflectance ceiling (80%), carefully positioned luminaires and high efficacy lamps. In this respect uplighting has come to mean the use of the compact HID lamps. The very bright lamps is totally shielded from direct view by the uplighter reflector (Figure 1) and raised above eye level. With reflector openings being at least 1800 mm above the floor the vast majority of users will not be able to see the lamp and therefore be free of glare.

The upward facing reflectors have to be carefully contoured to produce controlled light distribution. The generation of discomfort glare from concentrated reflections ("hot spots") above the reflector must be avoided. Wide batwing distribution is needed for places where the ceiling height is below 3.0 m but for tall ceiling a much narrower distribution is desirable (figure 2). Such light distributons will avoid the high (hot spot) local ceiling luminance yet remain sufficiently concentrated to create the impression of pools of light on the ceiling. These pools of light will generate a variation of illuminance on the work plane, higher near the unit with a gentle fall away.

The gradient of illuminance is usually subtle with high ceiling but more pronounced when the distance between uplight and ceiling is less than 1 m. This variation permits uplights to be used for both uniform and local or localised lighting systems. Uniform or general lighting with uplights is wasteful and can be uneconomic. But when used as local or localised system they ensure low energy lighting and provide much wanted variety. The local method is best in private or small offices where an uplight is provided to each person to light his task. Localised is when several work stations are grouped together around a single unit to derive the high task illuminance near and a lower level in the less important circulations areas. Uplights can be used almost anywhere. They can be found lighting entrance halls, shopping arcades, swimming pools, sports halls, banking halls, walk ways, offices and even libraries. They are particularly suited for lighting control rooms, drawing offices and offices containing VDUs and keyboards (Figure 3). The omnidirectional (diffuse) nature of the light eliminates sharp shadows from the working surfaces, enhances the volume of the enclosed space, reveals

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interesting features of the human face and lessens the dependance on viewing directions. They avoid VDU screen reflections and the troublesome keyboard reflections that other lighting systems cannot overcome easily.

Uplight optics

Uplights offer great flexibility to the lighting engineer and tremendous scope to the interior designer. To the designer uplighting can produce an interior that is better aesthetically as well as psychologically to live, work and play in. Uplights can be free standing, built into furniture, suspended from the ceiling and attached or set into walls (figure 4). When free standing units are used in offices their appearance becomes very important. They form part of office furnishing and supply a vertical architectural element for the vast open space.

The heart of the uplight is the reflector system. This has to be very efficient to make the technique economically viable. The LOR has to be greater than 80% which imposes a minimum size requirement for the reflector. Typical sizes range from 300 mm square or cylinder to as large as 1000 mm diameter hemispheres. The most effective reflectors produce an axially symmetrical light distribution for use in central areas. But for mounting close to walls or columns an asymmetric distribution is essential in order to avoid "hot spots". In general the uplights come complete with gear and housing except when incorporated in furniture. Apart from the optic the size of free standing uplights is governed by the need to ensure stability. To minimise the disadvantage of taking up valuable floor space often other functions (power outlets, shelves for plants or telephone) are incorporated. Alternatively cantilevered arrangements may be employed where the control gear in the box at floor level can be pushed under desks. Free standing units naturally offer the most flexible solution and simplify future space re-organisations.

Lamps for uplights

The two most useful and efficient types of HID lamps in use are the 250W Metal Halide or the improved colour 250 high pressure sodium lamps (SONDL). However for less critical areas for example shopping arcades low wattage SON lamps are also popular whilst in sports halls (including provisions for colour television filming) 1500 W Metal Halides are a common sight. Both coated or clear lamps may be used but they are not always interchangeable in a reflector. Coated lamps avoid striation problems but clear lamps are more efficient and require more precise optical control. The metal halides are somewhat lower in efficacy but provide cool appearance white light (4000 K) with excellent colour rendering quality (Ra over 80). The SONDL lamps are more efficient and emit a much warmer light (2300 K) with a yellow tinge but have colour rendering index of over 70. The warm-up and restrike characteristics of these two types are also different. The metal halides run up from cold a little quicker (3–4 minutes) but take up to 12 to 15 minutes to relight after extinction; the SONDL will take 5 to 6 minutes to run up from cold but can be relit within a minute of extinction. For some applications these dark periods may not be acceptable. Here an additional source in the uplight reflector (usually 150W Tungsten Halogen lamp) can fill the gap. The lamp can be switched off automatically (photocell or ballast voltage detected) when the HID lamp is run up. Essential to uplighting is a low level of lamp flicker since a substantial part of the bright ceiling and wall are in the periphery of sight where the eye is most sensitive to light fluctuations. The SONDL lamp generates a very low level of flicker and can be burned horizontally or vertically but the metal halide lamp is generally run horizontally to minimise flicker.

Interior considerations

In an uplighter scheme the ceiling is the most important surface. With highly decorative ceilings the elaborate features will be picked out and highlighted by the luminaires. However, in offices or

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stores an essential requirement is a high reflectance matt ceiling. In general white or pastel colour finish with reflectance of over 80% and gloss factor less than 15% are ideal characteristics. In tall rooms the upper part of the walls need similar treatment. In choosing colours for the ceiling one must realise that the whole room will appear tinted by the chosen colour. High chroma finishes should be avoided. The ceiling may be plain, fissured, textured or coffered. One should be aware that louvered ceilings are ineffficient; gloss finish metal panels will reflect an image of the lamp whilst blemishes on the ceiling will be illuminated directly. With large coffered ceilings (1.2 m or 1.5 m modules) often the bright area of the ceiling is concealed or cut off from normal view and the illuminance may be more concentrated. However, textured or coffered ceilings provide the greatest variety and interest.

Scheme planning

The number of uplights required for a scheme depends on several factors such as the lighting effect aimed for, light levels, lamp choice, uplight style, cost etc. For most decorative uplighting the scheme can be planned by using well established floodlighting techniques. For office lighing a quick method may be used for initial design. The table below gives the area served by one symmetrical distribution uplight in typical large offices with ceiling height between 2.4 m and .3.4 m and reflectance over 75%.

Scheme	Lamp 250W MBIF/H	250W SONDL
Uniform	15 m^2	20 m^2
Localised	20 m^2	25 m^2

Alternatively if UF tables (Figure 5) are available the Lumen Method of design can be used to establish the rough number of uplights needed for the installation.

Of course the above two methods do not indicate the variation of illuminance or the ceiling luminance. For these point by point calculations should be made using the intensity distribution and illuminance curves for the chosen uplights.

The value of the ceiling luminance may be estimated by the expression

$$Lc = \frac{I\theta \; Pc \cos^3\theta}{Ho^2 \pi} \; cd/m^2$$

where Lc: ceiling luminance
Pc: reflectance of ceiling
$I\theta$: intensity of the uplight in the direction
Ho: distance from uplight to ceiling (see Figure 6)

For a comfortable scheme the maximum value should not exceed 1500 cd/m^2 with an average of 500 lux and diversity of about 80 : 1.

An example of the illuminance curves is shown in (Figure 6). The curves have been derived for rooms having black wall and floor at a range of ceiling heights. The data have been normalised to 1000 lamp lumens so that it may be applied to lamps with similar characteristics but different outputs. The values may be converted to lux by the factor K.

$$K = \frac{\text{Lamp Lumens}}{1000}$$

Using this curve the initial uplight spacing is estimated to be twice the distance to where the

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illuminance has fallen to a quarter of the design value. Using the distance as the radius, isolux curves may be drawn on the plans (Figure 7). Where the curves overlap the values may be added. These values are the illuminance produced by the first reflection from the ceiling based on black walls and floor. They should be corrected for actual reflectance by adding the contribution from second and subsequent reflections. This indirect component can be calculated with the aid of the utilance table (Figure 8) and using the expression:

$$Ei = \frac{U^1F \times LOR \times F \times MF}{Area} \text{Lux}$$

U^1F is the utilance for the whole room having known ceiling cavity, wall and work plane reflectance.
LOR is the light output ratio of the uplight.
F is the lamp design lumens.
MF is the maintenance factor.
Area is the notional space served by one uplight.

Contrast rendering factor

The common belief that indirect lighting reduces ceiling reflections is broadly correct. An infinite uniformly-lit ceiling would produce a contrast rendering factor of 1.0, which would be considered very satisfactory. A ceiling with a uniformity ratio approaching the proposed lower limit of 0.1 would produce a greater variation in CRF. The extreme case of an isolated uplighter is considered in Figure 9. This empirically-derived chart is based on the performance of well-designed uplighter units, for a limited but useful range of ceiling heights between 1.7 and 2.7 metres above the working plane. It shows that, for the Enfield pencil task at a viewing angle of 20 degrees, the CRF on a given desk depends mainly on the relation between the distribution of the uplighter and the way the occupant faces. If occupants are allowed to sit at random, the diversity of CRFs will rise as the distance H_0 between upligher and ceiling falls. The greatest diversity in CRF, and thus the lowest minimum, will occur when this distance approaches zero. This is also the condition in which ceiling luminance is maximised and ceiling uniformity minimised. Designers should therefore use extra care in designing for ceiling heights less than 3 m.

Economics

In general uplights need power supply from floor level. For maximum flexibility well laid out floor outlets are required. These outlets are already in deemed for offices where the word processors, VDUs, calculators and electric typewriters are also powered from the floor and this feed can be shared with uplights. Most free standing or furniture based uplights can be switched individually, however central switching through dedicated circuits or by lighting energy management methods are gaining popularity. Uplights like any other lighting system can be combined with daylight and occupancy pattern detectors. But one must remember and make allowance for the run-up and restrike time requirements of HID lamps. The capital cost of an uplight scheme is no more expensive than an equivalent overhead fluorescent tube scheme. Comparing supply costs in schemes for every uplight at least two twin 58W reflector type recessed troffers providing similar quality illuminance will be required. Uplights are also cheaper to install particularly the free standing units which are portable and come fitted with a plug ready for connection. Overhead luminaires wil require the installation of separate lighting circuits with twice as many points of connection.

In terms of energy use uplights are again efficient even in uniform schemes. A typical 500 lux uniform lighting scheme can be achieved with a load just under $14w/m^2$ and localised scheme with under $7\ w/m^2$ when using SONDL lamps. Such values are difficult to achieve with the best fluorescent tube luminaire schemes.

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Uplights like any other luminaires require regular maintenance. However this is made easier without the need for ladders. The open reflector units need vacuum cleaning perhaps once a year. Enclosing the tops of reflectors with glass does not reduce the cleaning intervals and can lead to misuse. A typical operating luminaire glass surface can attain temperatures in excess of 200°C. Plastic cups or paper deposited on the top could ignite and the burning paper may fall onto the desks. However with open reflectors the burning paper is trapped in the unit.

Uplights in use

By now there are many hundreds of uplighting schemes in operation. Surveys made in offices showed very favourable user attitude to this lighting technique. Also, the economic arguments have been well aired and indicating that energy efficient lighting can be provided by uplights. To illustrate the application areas a few examples are mentioned very briefly.

EEB control room, Ipswich

This very large control room littered with computer terminals and VDUs is illuminated with 18 white suspended hemisphere uplighters. Each hemisphere contains two sets of reflectors and 150W SONDL lamps to provide an average illuminance of 450 lux. The room is 60 m x 14 m with 4 m ceiling height. Each uplighter has a 150 W tungsten halogen lamp as standby to provide light quickly. The control room is manned 24 hrs a day all year round and the staff judge the lighting system to be "a great improvement on the fluorescent schemes used in previous control rooms".

Institution of chartered accountants, Milton Keynes

The office lighting consists of free standing uplights spaced about 4.5 m apart and provide uniform 500 lux on the task at a loading of 13 w/m^2. The 131 units each containing a 250W MBIF/H lamp also provide power outlets for the VDUs and typewriters as well as home for the plants. The lamp compartment has a downward part through which the plants are illuminated. The units finished in eggshell cream are integrated with the modern furniture system.

Stewarts supermarkets, Connswater

Here special suspended uplights shaped into inverted pyramids provide the illuminance for the store. The pyramids made from glass reinforced gypsum contain the uplight reflector, gear and a 400W SONDL lamp. The high reflectance vaulted ceiling with the 119 suspended uplgiht and 28 – 150W SONDL wall mounted half pyramid uplights generate over 720 lux on the shelfs of the store at a loading of just over 21 w/m^2. Uplights were chosen for their ability to provide nearly equal horizontal and vertical illuminance in the shopping area having numerous shelvings.

Trustee savings bank investments, Andover

In this large office block over 200 free standing uplights are employed. The space is divided into small single man offices using one uplight to larger data processing areas with 30 – 50 people. The illuminance of 500 lux is provided by mixture of SONDL and MBIF lamps at an installed loading of just under 10 w/m^2. Here the uplights are very much used as localised lights with three or four work stations gathered around a unit. An inhouse attitude survey showed that 92% of the staff preferred uplighting compared with the overhead lighting that was used before.

It is clear that uplighting is not only used for its lighting effectiveness but also for its energy efficient operation.

Lighting management

Attention is very much being focussed on the effective use of electricity for lighting particularly when commercial buildings are involved where all too often the lights consume more than half the total electrical load. For these several new techniques have been developed. Energy for lighting can be saved by both management control and by the use of efficient equipment and lighting schemes. These methods can yield high savings without any loss in the standards of lighting quanity or quality.

Presence switching

The management method is by control, to use electric lights only when needed. Even the most effective and energy efficient lighting systems can still provide further cost savings by switching off the lights when not required. Well designed switching systems can provide savings of 20% to 40% depending on the control system. Broadly speaking there are three switching methods. The simplest is an on-off switch detecting the occupancy pattern in the building. In many large offices the occupants are away for more than a third of the working day during which time they do not require electric lights. For this system to work effectively the switches must be segregated and conveniently located near people at their work place. The switch may be a pull cord or the remote hand held infra-red or ultrasonic controls sending signals to selected luminaires. These latter of course also save the installation cost of switch drops and makes office layout changes independent of the lighting circuit. Although convenient this switching still relies on the successful encouragement of staff to switch lights off when leaving the work place. Today we have fully automated solutions too. These "presence detectors" sense human presence either by the amount of noise or heat radiated or by interference caused to standing patterns of energy waves set up by an active sensor.

Daylight switching

The second system is photoelectric switching of lighting adjacent to windows when adequate daylight is available for the task illuminance. The system is particularly effective in interiors where the daylight factor is more than 2%. The photocell control may be open or closed loop. Open loop is when the photocell is outside the building and monitors the sky illuminance. Figure 10. When the illuminance reaches a preset level selected rows of luminaires are switched off. Such a system is in use at Manweb, Chester. A photocell is mounted on the outside of the three wings of the building. When the illuminance on the cells reaches 9000 lux the outer row of luminaires and one lamp in the next inner row are switched off automatically yielding about 20% annual energy savings.

In the closed loop arrangement the photocell is indoors and monitors the task luminance and switches the local lights on or off according to preset conditions. Figure 11. It is very important to carefully set the switching levels to avoid complaints. Field studies indicate that to minimise staff complaints the switch off conditions should be in the ratio of 3:2 whilst switch on may be 1:1. For example in a large accounts office at Enfield the design illuminance is 500 lux. Each perimeter and next inner row of luminaires are fitted with a photocell (Magic eye switch).When the combined electricity and day light reach 1500 lux on the task area then the luminaire above the desk is switched off automatically leaving 1000 lux daylight on desks. When the daylight fades to just below 500 lux the electric light is switched back on again. This scheme has been monitored for the last two years and shows that the energy savings are 45% on the outside row and 20% on the next row of luminaires. The savings on the perimeter luminaires paid for the conversion areas in the first year.

It is of course possible to integrate the "presence detectors" and "daylight detector" systems to

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provide a fully managed on/off switching of the lights.

Central switching

The third method is "load management system" where we make use of a micro-processor for the control. The central control unit distributes the command signals in the form of pulses carried by the mains wiring or by a separate pair of twisted wire or coaxial cable to the individual luminaires. The luminaires are fitted with an addresable receiver and respond according to command. These central controllers are often linked up with the general building management systems. They can be programmed to shed lighting loads at critical times for example to avoid the cost penalties for exceeding the maximum demand or cable ratings when plant is being started or run up.

It is well known that dimmable lighting is subjectively much more acceptable as it avoids any sudden changes in illuminance. It is also true that the finely tuned sensor can save more energy. Unfortunately conventional dimming circuits are expensive and their cost based on today's energy cost is unlikely to give a pay-back period in less than 7 years. However, it is possible that in the near future dimmable electronic control gear built into individual luminaires will give economic closed loop dimming control.

Non-uniform lighting

Management controls can be utilized in old or new lighting installations. But efficient lighting scheme design can best be applied at an early design stage. Here, to encourage further the energy conscious lighting designs, the CIBSE published new design criterias. In the Interior Lighting Code it takes the form of "installed efficacy" (lumens/w) tables which represent the ratio of illuminance in lux delivered to the installed power loading for lighting in w/m^2. But in the CIBSE Energy Codes the criteria is simplified to "target loadings". Target loading in w/m^2 is an upper limit of the electrical load for the lighting system divided by the total floor area and is allocated according to activity area. For example for a typical large office illuminated to 500 lux with high efficacy discharge lamps the target is 21 w/m^2. This limit can be met readily with efficient lighting equipment arranged to provide illuminance to specific task areas. There is no need for the illuminance to be uniform throughout the entire space. In offices for example a lower value of 200–300 lux is adequate for the less demanding tasks such as filing or circulation, while a higher level of 500–750 lux is needed for continuous reading, typing or drawing. This leads to to part lighting of Building and Task illuminance which can be efficient, effective and pleasing provided the ratio between the two is not more than 1:30. Two part lighting can be provided by localised or local lighting systems. Localised is when the luminaires are concentrated in groups around the critical task area to build up the illuminance at the expense of reduced levels elsewhere. Local lighting on the other hand is when the luminaire (desk light) is fixed to the work station or task to provide the high task illuminance with a back-up of a uniform lighting scheme providing the building illuminance. The most energy efficient desk lights use fluorescent tubes. In a typical local lighting scheme single 36W ceiling mounted batwing distribution fluorescent luminaires can provide the building illuinance with an 18W fluorescent desk light raising the task illuminance to 500 lux at a total loading of only 8.2 w/m^2 which is a third of the target loading. Both the 18W an 36W tubes are by now a well established new generation T8 26mm diameter (compared with the old 38mm diameter) fluorescent tubes. These energy saving tubes are filled with krypton gas instead of argon to reduce the lamp power by about 10% and yet when coated with the special selective phosphors (triphosphors) will generate 10% more light of excellent colour rendering quality (Ra 80–90) compared with the performance of conventional T12 tubes. These T8 tubes can be inserted and run on standard glow switch or electronic start control gear circuits.

Electronic control gear

Recently the performance of the control gear had also come under close scrutiny resulting in

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the introduction of limited loss ballasts. For example in a standard 1500mm single tube circuit the standard ballast loss is 13W. This ballast is slender in section and can be readily fitted into any luminaires. Today we can use alternatives which are slightly larger in section. Since they have higher copper and iron content the losses are lower. The low loss version will reduce the losses to 8.5W whilst the very low loss type has losses in the order of 5.5W for a 1500mm tube. There are, of course, penalties to pay in terms of cost and weight. There is no problem with weight when we use electronic ballasts. The losses in a 1500mm tube electronic ballast are below 5.5W and since they run the tube at high frequency over 25kHz, can offer further benefits. These maybe summerised as increased lamp luminous efficacy, unity power factor, no flicker or stroboscopic effects, tolerance of wide voltage fluctuations, instant start, the ability to operate more than one lamp and be adapted to dimm the lamps (figure 12). At the present time electronic ballasts are very much more expensive than the wire wound version but with overall energy savings in the order of 25% the pay back period is 3 to 4 years.

Lights for small areas

In all commercial building there are also small areas such as kitchens, stores and toilets. Some twenty years ago Dr P. Manning, in his study of workers attitude to work place, found that a majority of people judged their working environments by the state of the toilet facilities. However, very few people investigated what the lighting needs are and little if any consideration has been given to the application of energy saving lighting techniques. In toilets the requirements are for a small, simple luminaire fitted with a lamp giving instant light of about 100–150 lux. The simplest light source to date has been the 100W GLS lamp but due to its poor efficacy and short life, bearing in mind the long hours of burning, it has given way to high efficacy miniature fluorescent lamps. These compact fluorescent lamps give instant light for long periods with low power requirements. Today many shapes and sizes are in use. The ratings range from 5W (370 lm) to 28W (2000 lm) in shapes that could only have come from the inventiveness of glass technologists. For example the flat fluorescent lamp (2D) rated at 16W when used with a simple adaptor ballast can effectively replace the 100W GLS bulb (figure 13). This lamp wil provide nearly the same lumens (1050 lm) but for over five time longer (5000 Hrs) and at only just over a fifth of the power (21W) compared with a 100W GLS performance. In most places the increased cost of the lamp and luminaire can be offset by the energy saving costs made in the life of one lamp. This form of lighting makes effective use of electricity and therefore has very wide application in shops, schools and most importantly in our homes. The use of the lamps will not only make real energy savings but also reduce the maintenance costs without loss in the quality or quantity of lighting.

Display lighting

Energy saving techniques are also being applied to display lighting by the use of tungsten halogen technology. The 100 and 150W PAR 38 spot and floodlights can now be replaced by 50W low voltage (12V) miniature tungsten halogen dichroic mirror lamps (figure 14). The high efficiency and long life is afforded by the use of precision faceted dichroic reflectors to control the output of the compact filament and to the halogen cycle. The filament is run at higher temperatures and thus has a higher efficacy and generate cooler white light. The bulb is filled with halides that can repair the filament by reclaiming the evaporated tungsten and at the same time clean the quartz surface giving high lumen maintenance. The dichroic reflector allows half the radiant heat to flow back so that only the visible radiation is reflected, giving, a cool beam. In a typical downlighter application from 3m high ceiling the 150W Par 38 sport will generate a pool of light of an average 350 lux when this lamp is replaced with an adaptor transformer complete with a 50W lamp the average illuminance only falls to 325 lux. This simple conversion resulted in over 60% saving of power (150W down to 57W) and the lamp will last 50% longer than the PAR 38 lamps. Further savings will also result from the reduced heat output leading to smaller air conditioning plant requirements.

Conclusion

It is clear that uplighting and new energy saving lighting techniques are now being introduced in various application areas to make effective use of electricity in and around buildings.

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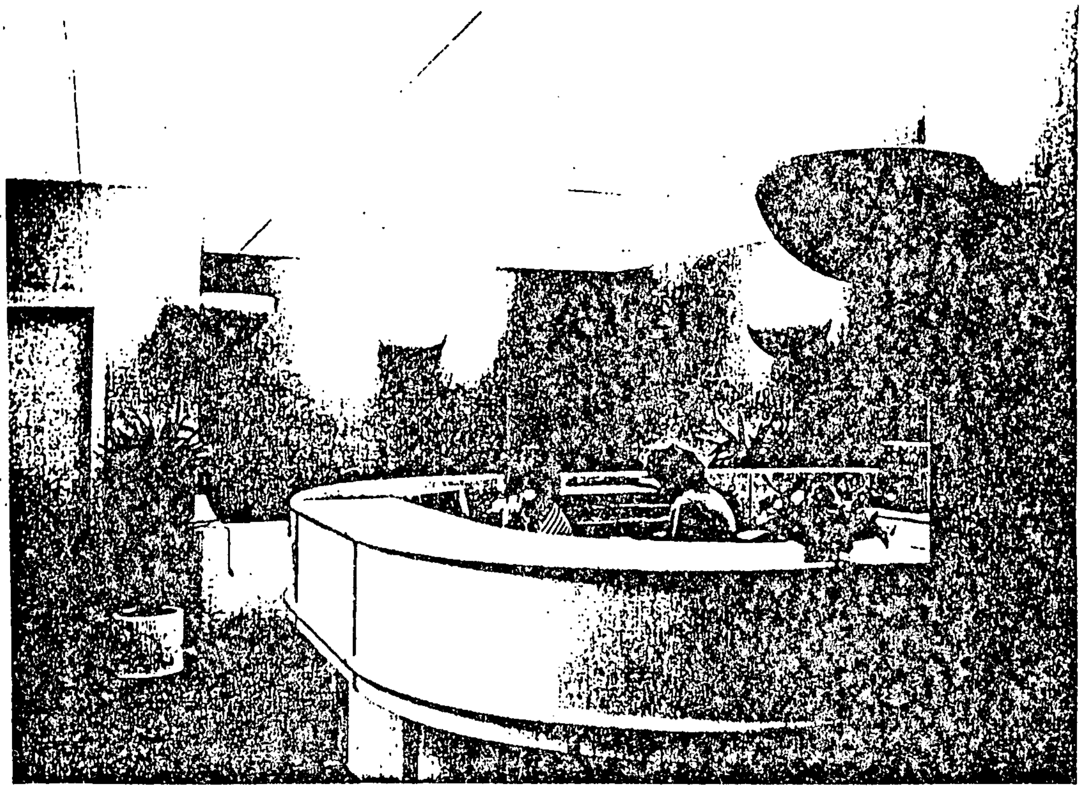

Fig. 1 Wall mounted uplights

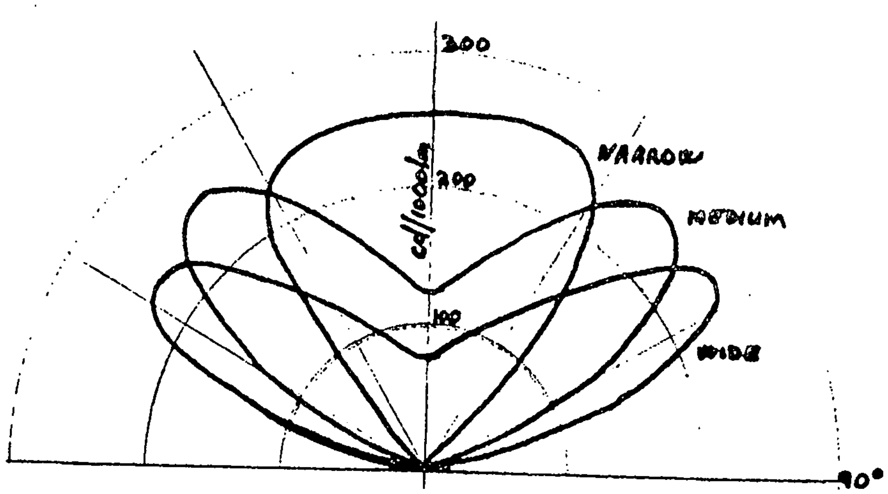

Fig. 2 Uplight Polar Curves

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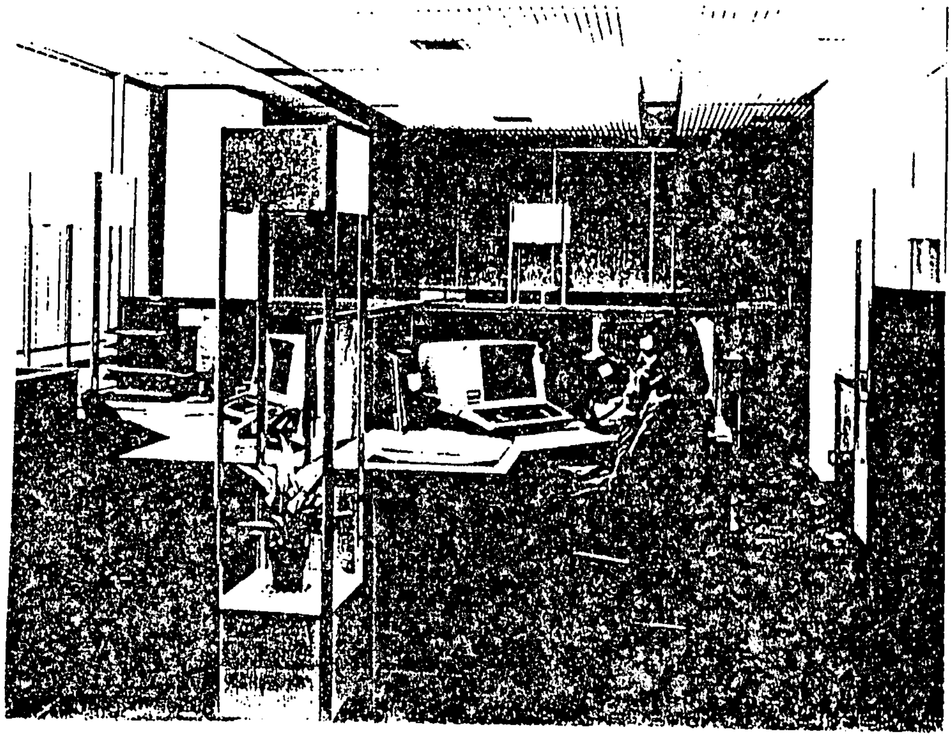

Fig. 3. Uplighting in VDU office at Gatwick Airport

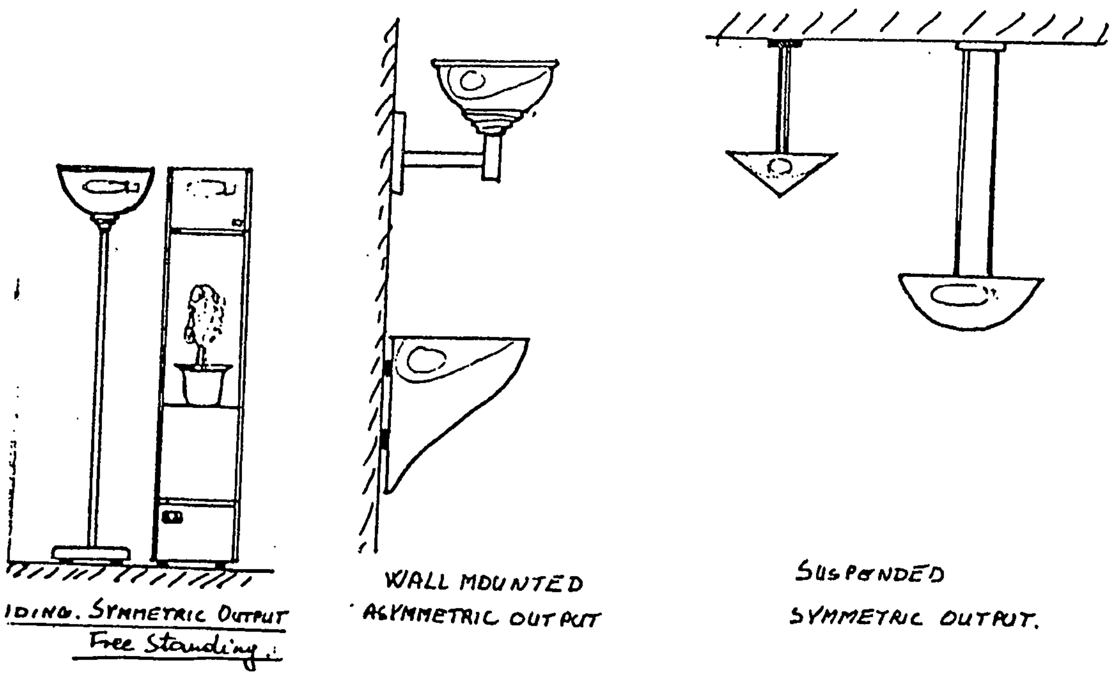

Fig. 4 Examples of Uplights

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Utilisation Factors UF[F]									SHR NOM =3.00		
Room Reflectances			Room Index								
C	W	F	.75	1.00	1.25	1.50	2.00	2.50	3.00	4.00	5.00
.80	.50	.20	.34	.41	.47	.51	.57	.61	.63	.67	.69
	.30		.28	.35	.41	.45	.51	.56	.59	.64	.66
	.10		.24	.31	.36	.41	.47	.52	.55	.60	.64
.75	.50	.20	.32	.38	.43	.47	.53	.56	.59	.62	.64
	.30		.26	.33	.38	.42	.48	.52	.55	.59	.62
	.10		.22	.29	.34	.38	.44	.48	.52	.56	.59
.70	.50	.20	.29	.36	.40	.44	.49	.52	.54	.57	.59
	.30		.24	.30	.35	.39	.44	.48	.51	.55	.57
	.10		.21	.27	.31	.35	.41	.45	.48	.52	.55
.00	.00	.00	0.00	0.00	0.00	0.00	0.00	0.00	.00	.00	.00

Fig. 5 Utilization factors for 350 mm Square Uplight with 250W SONDL Lamp

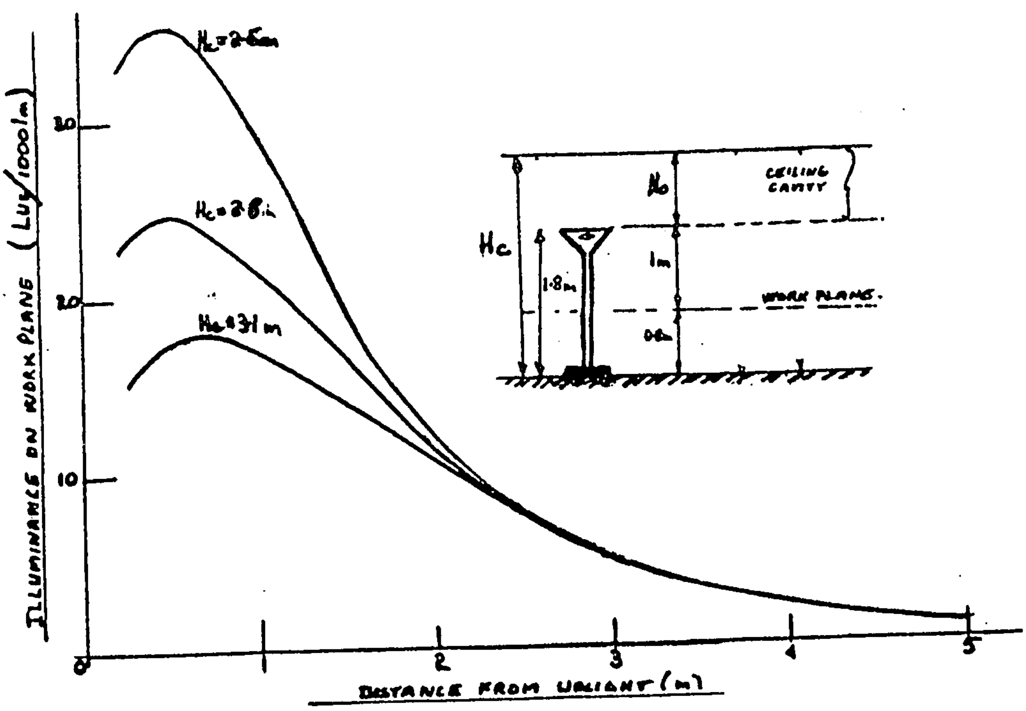

Fig. 6 Illuminance Curve for a 250W SANDL Uplight. Based on ceiling reflectance of 75%

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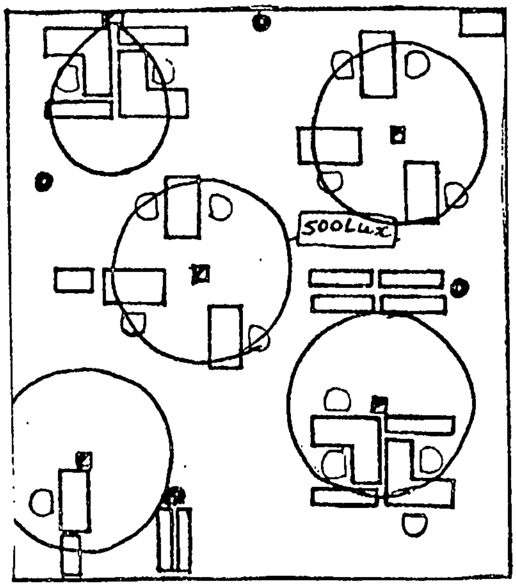

Fig. 7 Use of ISOLUX curves to indicate task illuminance patternsdf 500 LUX uplights.

– Utilance for Second and Subsequent Reflections

Room Reflectances												
C	W	F	.75	1.00	1.25	1.50	2.00	2.50	3.00	4.00	5.00	∞
.80	.50	.20	.150	.160	.165	.167	.168	.169	.168	.166	.164	.152
	.30		.077	.086	.094	.099	.107	.113	.118	.124	.128	.152
	.10		.025	.032	.039	.045	.056	.066	.074	.087	.096	.152
.70	.50	.20	.125	.133	.135	.136	.136	.134	.132	.130	.128	.114
	.30		.064	.072	.077	.080	.086	.090	.092	.096	.099	.114
	.10		.021	.027	.031	.036	.045	.052	.057	.067	.073	.114
.50	.50	.20	.081	.083	.084	.083	.080	.078	.076	.072	.069	.056
	.30		.042	.045	.048	.048	.050	.051	.052	.052	.053	.056
	.10		.013	.016	.019	.020	.024	.028	.031	.035	.037	.056

Note: The effective reflectance of the ceiling cavity, RE (C) is given by the expression

$$RE(C) = \frac{CI \times RA(C)}{CI + 2\,[1 - RA(C)]}$$

where CI = cavity index of ceiling cavity (twice plan area/wall area of space above uplighter).

RA(C) = area-weighted average reflectance of bounding surfaces of ceiling cavity.

Fig. 8 Utilance for Second and Subsequent Reflections

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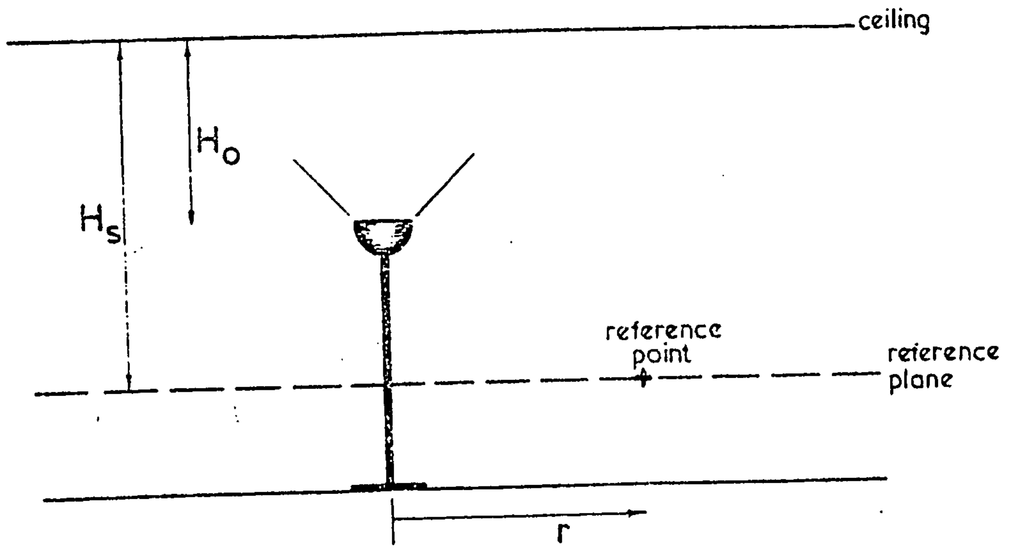

Fig. 9 (a) H_s = height of ceiling above reference plane
H_o = height of ceiling above uplighter
r = radial distance of reference point from uplighter axis

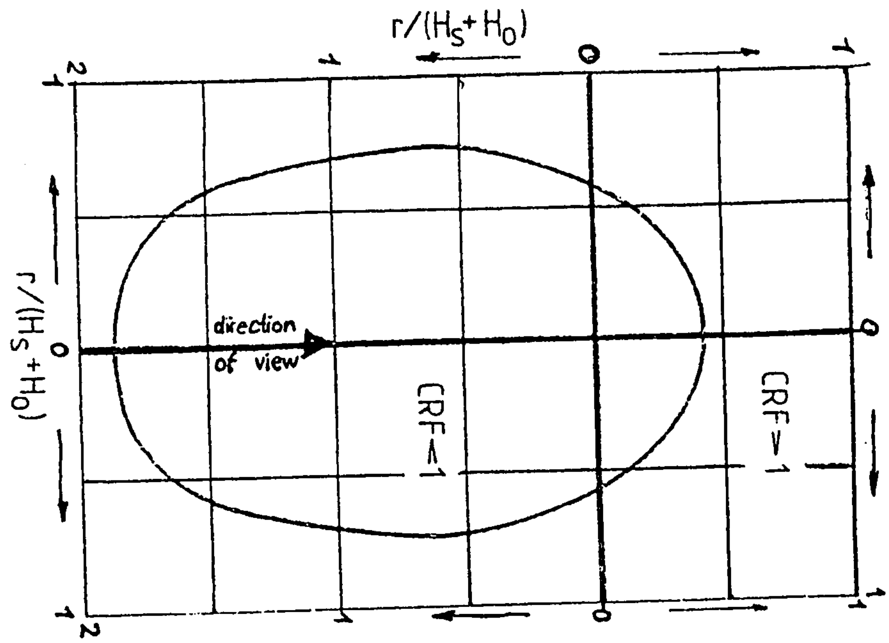

Fig. 9

(b) Outside the egg-shaped contour, the CRF will be greater than unity.

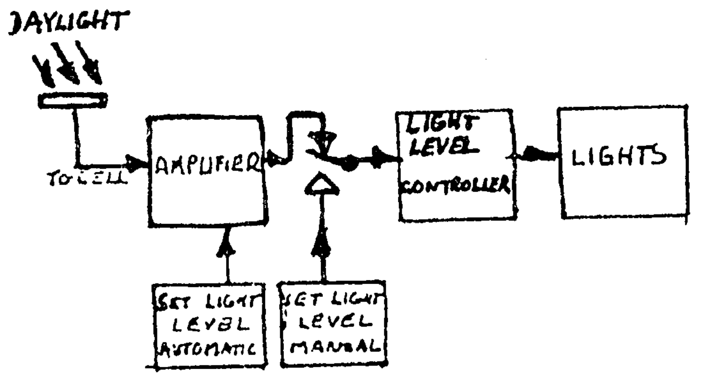

Fig. 10 Open-loop System

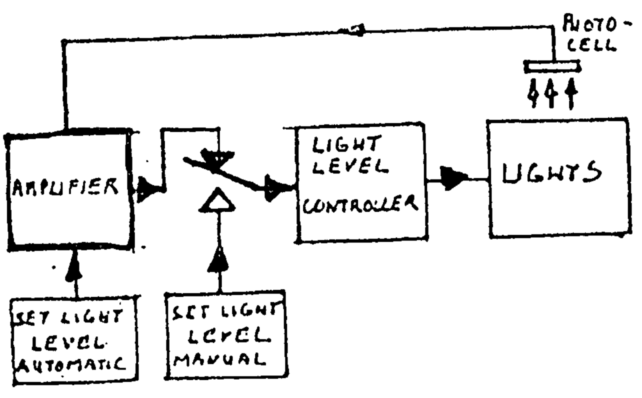

Fig. 11 Closed-loop System

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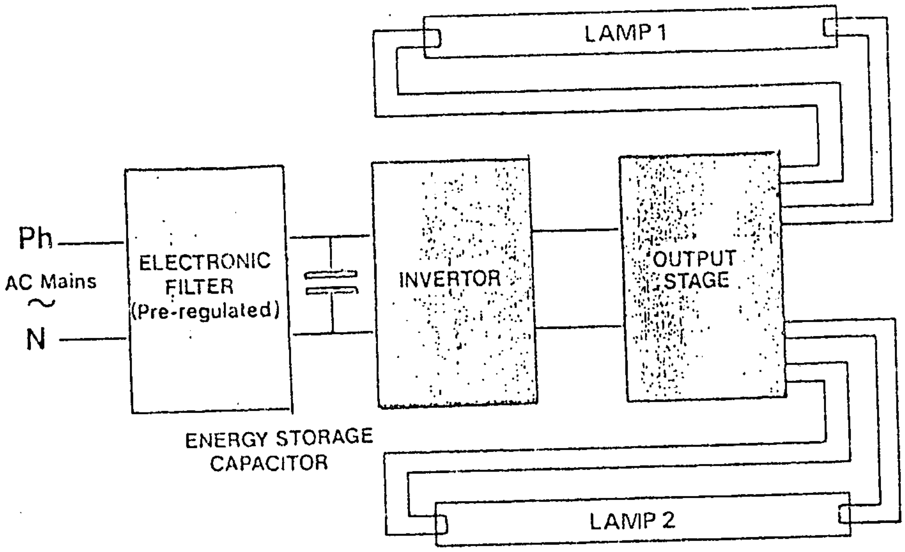

Fig. 12 H.F. Electronic Ballast

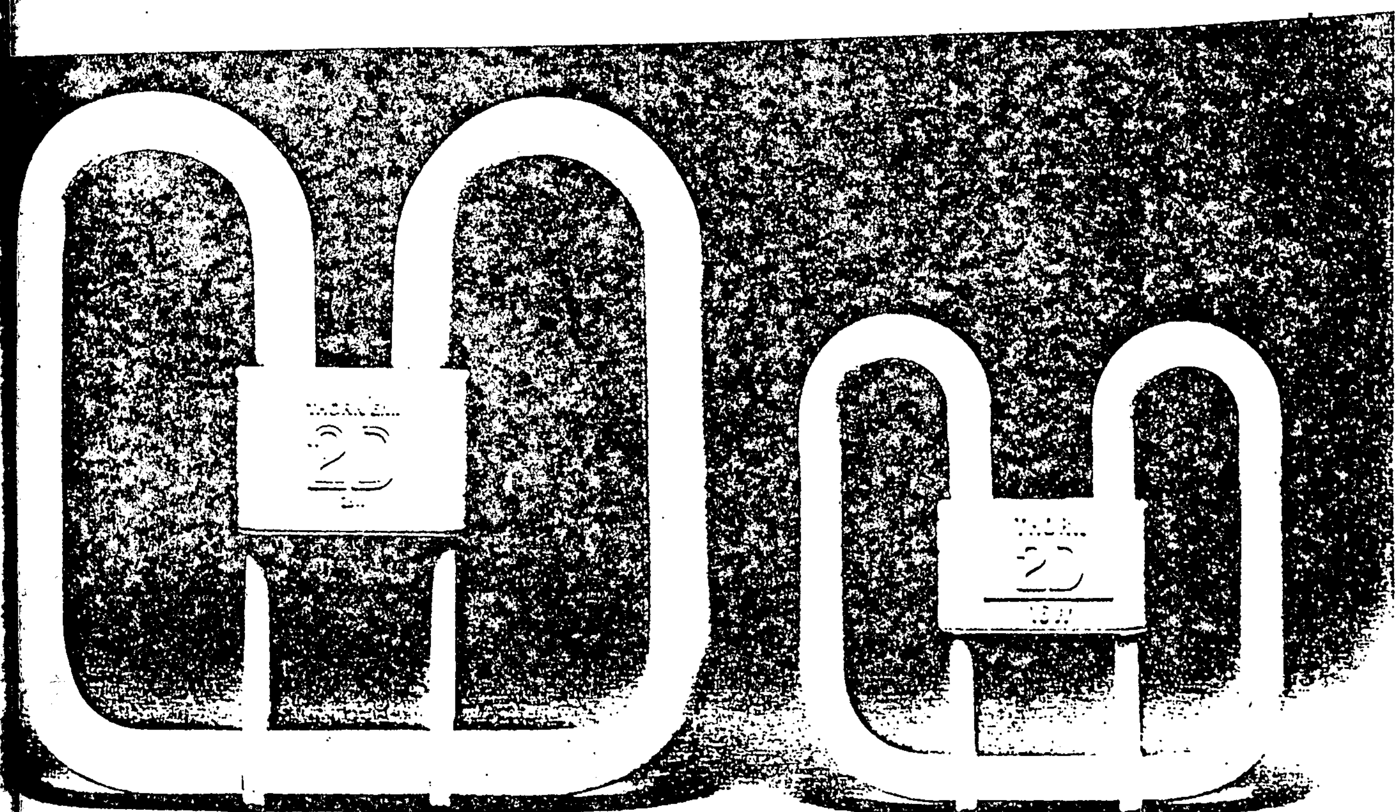

Fig. 13 28W and 16W Flat Lamps (2D)

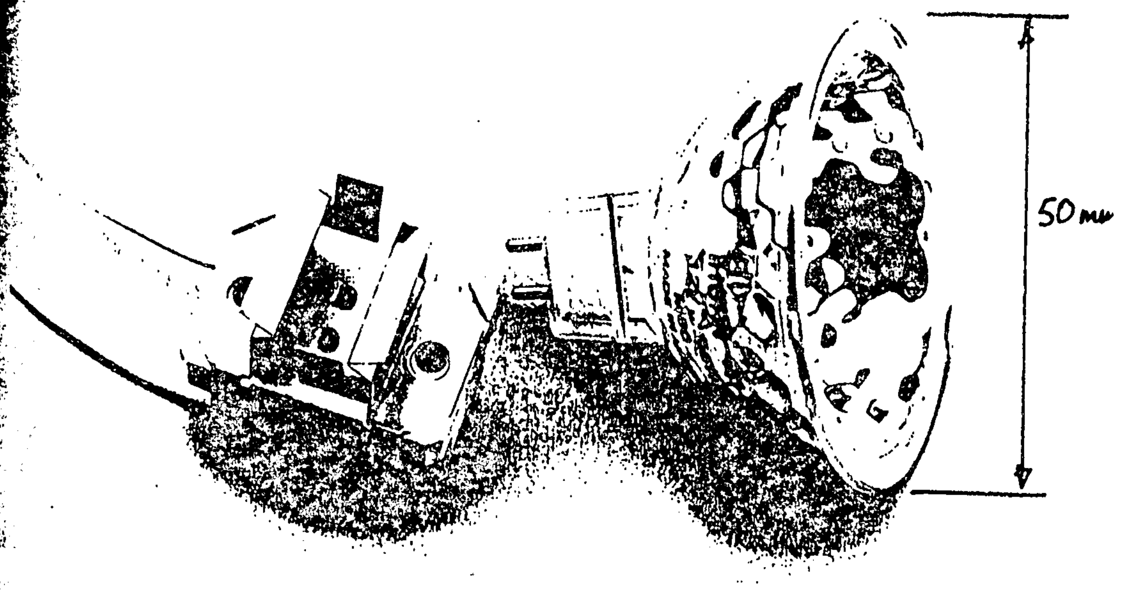

Fig. 14 M50 – 50W Tungsten Halogen Dichroil Mirror Lamp (Lightstream)

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— Notes & Questions —

Paper No. 8

The Control of Lighting-A business Management Service

Speaker: Mr. K. Hughes, Manager, Allenwest P.L.C. Systems Divsion, Simplex Electrical Ltd.

THE CONTROL OF LIGHTING – A BUSINESS MANAGEMENT SERVICE

Last year, Great Britain alone spent £1,600 million on electricity for lighting. Of this, £1,100 million was spent by industry, commerce and the public sector – and this does not include the cost of street lighting.

As a business management service lighting control has always been in the shadow of potential environmental savings. With these figures – and the knowledge that efficient lighting controls will reduce it by 40% – then the control of lighting is an important aspect of any BM service.

The problem is how to efficiently reduce unnecessary lighting.

For the majority of people it is natural to leave all the lights on at work, expecting somebody else to switch them off. These sentiments are universal and can be seen in the evening skyline of every major city from Hong Kong to London.

Making sure that lighting is switched off is not the complete answer however. Lighting must be adequate to allow for people working outside normal hours, and to accomodate cleaning staff. Obviously, some form of lighting control is necessary.

The first requirement of a lighting control system is to provide the right amount of light where it is needed, when it is needed.

An inexpensive time clock may fulfil these requirements where a few individuals work regular routines, but as the numbers increase, the problem of control becomes more complex.

The selection of an efficient control system can only be justified by the potential savings it can realistically achieve together with the degree of control it offers. Such a lighting control system must provide flexibility with occupant overrides at a low cost per control point.

Flexibility implies that the system can be altered by existing staff to adapt to changes in the building, it also implies the system can provide unique lighting functions such as daylight time control and the integration of lighting with the B.M. system for security, fire etc.

Occupant overrides allow the individual to make exceptions for his own area. The system has to adapt to the needs of the individual and not the other way round. By allowing the individual to override his area for after hours operation you enhance productivity and, more importantly, gain user co-operation.

The real difficulty is providing this control at a low cost per control point.

Historically, lighting is a highly distributed base load of only 1,000 – 2,000 watts per circuit, with local switches providing the occupant with the means to override at anytime.

Let us examine in detail how we can convert this generalised technology into a practical lighting control system – with no apologies for selecting the Simplex PLC system for the example.

The system in its simplest form consists of a central controller or microprocessor, a data or communication line and field stations called transceivers or modules, each containing sixteen relays to control individual lighting circuits. The central controller acts as the brain for the system, with every command to turn a relay on or off originating in the controller.

The operating programme for the building is entered over the keyboard, prompted by simple

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English commands which allows a non-technical operator to be trained in approximately half a day.

The programme for the building is protected against power outages by both an internal battery back-up and by storing the program on a disc.

The data line is a low voltage, low cost twisted pair connecting the controller to the transceiver. Here a plug-in board provides the local intelligence to decode the commands coming in over the data line and activate the appropriate relays.

To control more than 16 relays we simply add more transceivers to the same data line. This modular build up allows us to control up to eight thousand independent loads or lighting circuits and to install the transceiver close to the circuits controlled so minimizing wiring costs.

For existing installations, the relay is simply wired in series with the lighting breaker allowing on or off control for each individual lighting circuit.

For new installations, it is an advantage to have fittings that can be split wired. For example, in a three tube fitting one ballast controls one tube while the second ballast controls two tubes. So we can programme from the Controller for the area to have light levels of one third, two thirds or full. These are evenly distributed light levels from only two relays. With this simple configuration we could schedule the lights to come on low at 7.00 am, full at 8.00 am and drop back to low at 5.30 pm. An improvement, but still not good enough.

To be more effective, the system has to provide more convenient overrides. It does this in two ways:

Firstly, by the use of standard switches connected directly to a switch input board at the nearest transceiver. The way it works is that when an individual operates a switch, his input message is immediately transmitted back to the controller which then sends out the appropriate command to operate the circuits programmed to respond to that switch. This switch input system is unique in that it provides fast response while allowing the input to control any number of relays anywhere in the system.

This approach opens up a number of application advantages. For example, the switch in a perimeter office may be programmed to provide for automatic daylighting compensation. When we turn on the switch, the lighting in the room tracks a photo-cell sensor. All of the rooms on the perimeter of the building could track this sensor, but only areas which have been turned on would be affected.

Switches may be programmed to accomodate cleaning staff. Each switch activates the lights in its own area and turns all others off. The cleaning staff can now work at any time with only their working area lit.

The universal nature of this intelligent switching function allows the control of lighting to be effectively integrated with all building management services, fire alarms, security etc.

The second override technique is to use a standard multi-frequency telephone. A telephone interface device is added to the controller and plugged into an extension jack giving the controller an extension number. To override the scheduled programme, an individual simply has to call the controller extension number, wait for the signal then enter his access number pressing the hash button to activate the command.

Since the overrides from a telephone or a switch are centrally processed, it is practical to protect an occupant from unwanted nuisance switching. For example, at the end of a normal working day the controller can be programmed to warn the occupants of impeding scheduled light reductions by switching off all the lights for one second.

Occupants calling for their override inform the controller not to change the state of their lights until the next but one sweep.

When first introduced, this concept of automated lighting coupled with simple occupant overrides met with a lot of enthusiasm. At the same time, some building owners and managers expressed concern that their building could actually end up using more energy than before because occupants would override the automation.

Our experience told us that this simply wasn't the case, what was needed was a positive means of knowing that overrides were being effectively managed.

This was accomplished by adding printout capability to the controller. Since all overrides are initiated through the controller it can provide a positive record of when and where an override occured. This feature closes the management loop and allows us to more fairly allocate energy costs.

But there are problems: Who is going to read through all the overrides at the end of the month? What happens if the printer runs out of paper?

The interest in this function justified the development and introduction of the auditor. This unit simply connects to the data line and acts as a system accountant, collecting historical data and arranging it into a useful format, for tenant billing, load utilizing and runtimes, for example. It can also be used to provide the building owner with load status and alarm processing information.

Here we have an extremely flexible, binary-based, lighting control system with the ability to meet the demands and needs of the occupants by allowing simple overrides by switches or telephone.

Now let us examine, and learn from a case history what impact the system had on lighting energy consumption.

In time, our example could well be the prestigious Hong Kong and Shanghai Bank headquarters building in Queens Street, but for now we will take New York's World Trade Centre.

The necessary information has been well documented, funded by the Department of Energy and administered by the Lawrence Berkley Laboratories. Figure 1 shows the profile of lighting energy consumed before and after the system was installed. The before profile illustrates how four contactors, each covering a quarter of the floor area, were controlled by the building computer with override switches positioned at the core on every floor.

The concept looked good on paper and simplified the installation, but in practice it ran into a number of problems. The normal work day was 8.00 am to 5.30 pm but the people who arrived early put all the floor lights on.

Similarly, the people working late had all the lights on. There were also problems with the cleaners, so it was left to security staff to switch off the lights after their final occupancy check.

For this project every single ballast on the fifty eighth floor of the World Trade Centre was retrofitted through a system relay to provide complete flexibility.

This was an expensive approach which would not be recommended for normal applications, but it allowed total flexibility for the project. Each fitting could be operated at one third, two thirds or full lighting levels.

Individuals were allowed to override their area using their telephone, and by tracking the state of each relay it was possible to provide a profile of both the energy consumption and the source of each change; schedule, override or photo-cell.

The series of tests focused on progresively tightening the lighting schedule. The floor was divided into zones of approximately one thousand square feet and anyone within a zone who came in early or stayed late could operate his lights by using his telephone.

This first loose scheduling produced savings of thirty two per cent, mainly by reducing lighting levels to one third after 5.30 pm, as can be seen in Fig. 1.

Progressively tightening the schedule increased the savings, the small steps before and after a scheduled change indicated the presence of overrides. This shows the energy manager that his squeeze is effective, if the overrides were not available, it is logical to assume that the occupants would complain to the management.

The final profile in Fig. 1. shows the combined savings achieved with a tight schedule and daylighting control by photo-cells controlling the periphery zones. During working hours savings in these zones of up to thirty per cent were achieved, but total savings per floor was only three per cent due to the limited distance of ten to fifteen feet the zone effectively extends in from the window.

These profiles show visually the effect a good lighting control system can have on an existing installation. The savings of fifty two per cent shown by this independently monitored project are higher than we normally forecast because we would not expect the pre-system profile to be so wasteful of lighting energy.

However the profiles clearly show why the strategies reducing lighting levels outside normal working hours and the occupant based overrides are essential.

In new installations the scope and application of a lighting control system is even more rewarding. The control philosophies required to provide environmental conditions are complex and different from those required for lighting control which has to react instantaneously to the demands of the occupant.

We are always surprised at Management's assumptions that a full building management system automatically provides the degree of lighting control so necessary to an acceptable efficient lighting service. In the World Trade Centre, for example, originally the lighting contactors were connected to the building computer but the means of override and control were missing.

The practical solution is to link a stand alone lighting control system with the building management system and get the best of both worlds. This has been accomplished in the Hong Kong Shanghai Bank Building.

Estimating lighting savings can be accomplished in two ways:

First: a simple calculation of the lighting reduction in KW multipled by the total yearly hours reduction achieved. The connected lighting load is calculated by totalling the lamp and ballast loss wattages for an area. For simple applications, or a quick estimate, you could use the following:

$$\text{Total savings/year} = \frac{\text{total area x watts/ft}^2 \text{ x hrs eliminated per day x days/year x £/KWH}}{1000}$$

Second: a better approach is outlined in the sample. For a particular area, such as the offices

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described, list the strategy elements chronologically (including the percentage of the zone affected) the percentage reduction achieved and hours in effect for each strategy. Tracking each change in operation as it occurs on a typical weekday and weakend helps to eliminate errors and provide the control stategy necessary to program the system once installed.

There are many aspects of lighting control that time has not allowed me to include in this paper, but I trust from the information presented you will agree with us when me say that lighting control is an important management service.

With the advent of new control technology, we will achieve the right amount of light when it is needed where it is needed. Only by these means will we achieve our end objective of attaining maximum usage for minimum wastage.

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GEZ 7231

LIGHTING ENERGY SAVINGS

Zone: Offices Size: 29,000 Ft² Connected Lighting Load: 72.5 KW

Typical or Present Control Operation:

Four contactors control floor lighting by quadrants - overrides by four switches at core entrance. First arrivals switch all lights on - security switch all lights off during security checks at 12 am and 3 pm on Saturday (250 days at 17 hrs and 50 days at 8 hrs). Open office area 65%. Individual offices 15%. Access area 20%.

Resultant KWH/Yr. 337.125

Proposed Operation: Programme control- by zone - by function to one third, two thirds and full lighting levels with telephone overrides and daylight control of periphery circuits during normal working hours with off sweeps every hour from 5 pm - low level for individual offices - access - corridors toilets etc. and cleaning. Work level for open office areas.

Estimated Reduction in KWH/Yr. (Calculate Below)

Strategy Element	% of Zone Affected	x	Reduction in Light Level	x	Hrs in Effect	x	Days/Yr.	=	Equivalent Operating Hrs Reduced
Access	.8		.66		1.0		300		158.4
Morning Daylighting	.15		.33		2.0		300		29.7
Lunch Break	.8		.66		1.0		300		158.4
Afternoon Daylighting	.15		.33		2.0		250		24.75
5 pm Sweep	.8		.65		1.0		250		130
6 pm Sweep	.8		.75		1.0		250		150
7 pm Sweep	.8		.85		1.0		250		170
8 pm Sweep	.8		.9		1.0		250		180
9 pm Sweep	.8		1.0		1.0		250		200
10 pm Sweep	.97		1.0		2.0		250		485

Total Operating Hrs Reduced/Yr. (ΔH) = 1686.25

Total Decrease in KWH/Yr. = (Lighting KW) x (ΔH) = 122253 KWH/Yr

Estimated lighting energy savings of 36.26%/year

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SAVINGS

	RELAY Hrs.	REDUCTION %
CONTACTOR ON/OFF	25,000	BASE
LOOSE SCHEDULE	16,900	32%
'SUPERTIGHT' SCHEDULE	12,800	49%

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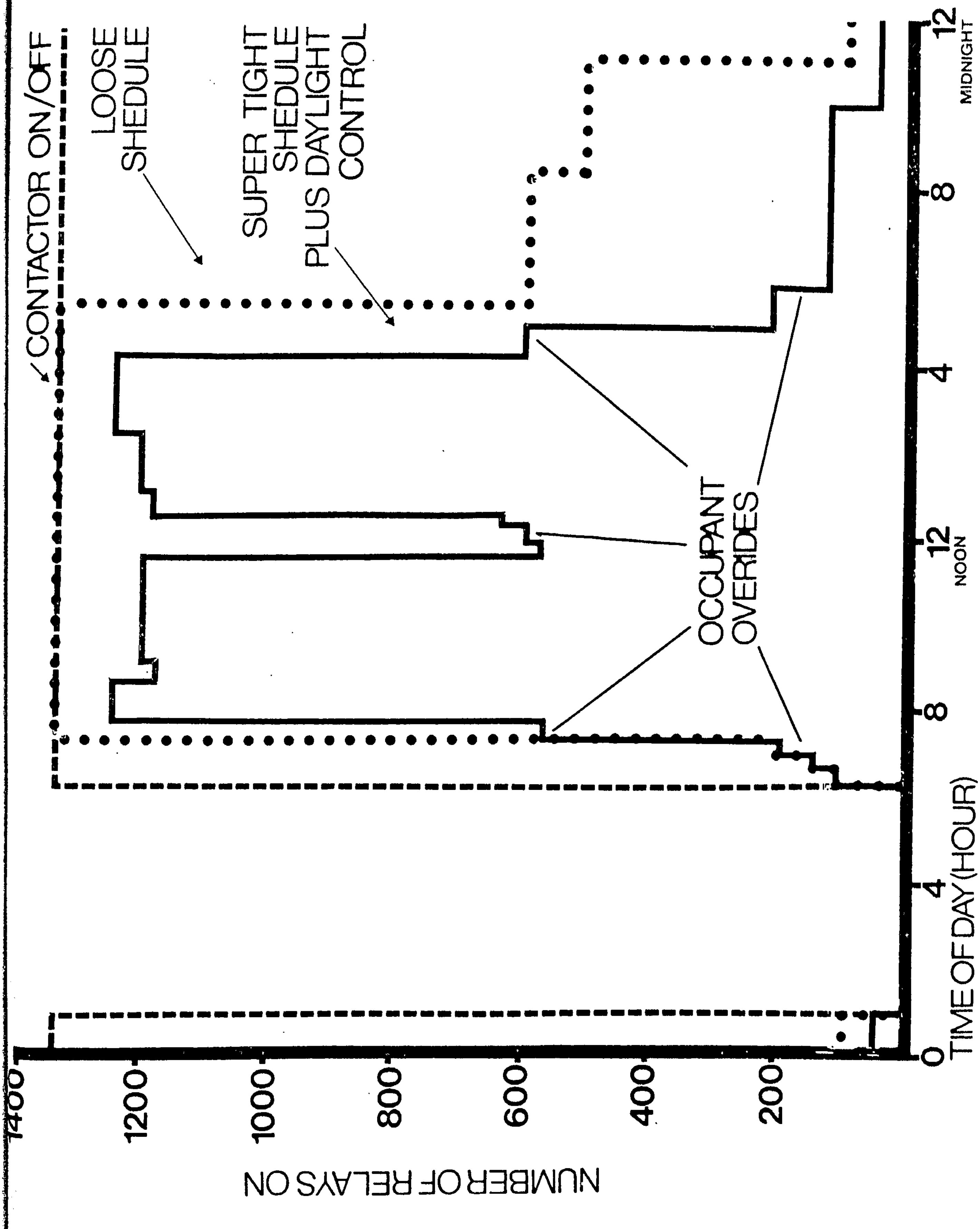

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— Notes & Questions —

3. Means for Effectivness

Paper No. 9
Energy Conservation – The role of Electrical Accessories and related equipment

Speaker: Mr. C. J. Stares, Senior Product
Manager, MK Electric, London.

ENERGY CONSERVATION – THE ROLE OF ELECTRICAL ACCESSORIES AND RELATED EQUIPMENT

Energy management means a variety of things to any person you ask. Its turning off lights when not required, or it can mean specialised, complex computer systems which provide the complete control of commercial buildings.

Today I have specifically been asked to talk to you about the role of accessories, related equipment, the data management and conservation of manpower energy in these and other electrical installations.

Just before we got into detail, I think it is important to reflect on some of the information and statistics which are available from experience gained in the U.K. and European market. Needless to say, in differing parts of the world, climates, operating procedures, and, operating priorities change the emphasis thus systems have to be tailored to the particular needs of the local environment. I would however suggest that the principles and needs whilst varying in magnitude and emphasis, are very similar and that experience gained in other parts of the world would certainly have a great benefit to anybody embarking on consideration of energy management implementation in any proposed building.

In 1981, 317 million tons of coal equivalent was consumed in England. Estimates show that between 10 and 20% of this could have been saved. Whilst this covers the building heating by gas and oil, lighting, air conditioning and all other necessary energy inpute; never the less between 30 and 50% of all business energy is consumed solely for the lighting of buildings. In 1981, to which these figures particularly refer, only 1% of commercial buildings were undergoing any form of energy review and the uptake of energy management systems was extremely small indeed. With the ever increasing cost of fuel, the awareness is now happily prompting accountants to motivate building engineering and design staff into attacking this enormous problem, but even today with the market worth over £100 million in 1983 in the U.K. alone, this is only scratching the surface of this largely untapped market.

The 30 to 50% of building energy consumed for lighting is also the area where the single largest savings can be made. It is estimated between 30 and 70% of all the energy consumed by lighting equipment is wasted and most of this waste can be contributed to three particular areas:–

– lighting unnecessarily lit outside working hours.
– lighting in use whilst staff are away from their work place.
– lighting energised when daylight lighting levels would be satisfactory.

You've heard from my colleagues today about sophisticated lighting control systems, but some 80% of costs can be saved by relatively simple systems. It is the last 20% that requires the sophisticated and somewhat expensive approach.

A simple approach requires no software or additional maintenance expertise and should be given full consideration as a viable alternative to complex systems.

So lets look at some of these simple controls.

Probably the most well known is the photocell control. The product here has been devised for dawn/dusk control with adjustable light level which can bring on external lighting at the desired preset level. It may, however, also be used in the application of peripheral lighting of an office area by carefully adjusting it within a reasonably fine limit. But it is important to offer not just the basic facility, but to have some peripheral advantages. This particular one incorporates a remote override device which may be connected to a push-button for local user override, providing a switch-off facility

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at the end of an evening when lighting is no longer required, or indeed to switch on lighting in the morning following a manual switching into the off position the previous night. Appiications include car park lighting, security exterior lighting, or peripheral office lights and coupled to an external relay will operate almost any lighting load.

The device which we have ourselves found very useful and potentially very interesting from a cost saving point of view, is the ultrasonic presence detector. This works principally on the doppler effect, being sensitive to movements or changing movements within the area served by the device. It provides a facility for operating lighting, vantilating or heating only during the occupation of the area involved. The unit comprises a sensor head which is mounted in the most optimum position to give approximately a 9MTR by 8MTR control area, or can be adjusted to react to movements within a very much smaller area by reducing the sensitivity.

The transformer and relay unit incorporates two switching circuits to enable two independently wired circuits to be switched by the product, which, in a rectrofit situation, considerably cases the connection to existing circuits.

It has been estimated that energy savings of up to 50% in any single area are quite possible using such devices and applicatioans are numerous. In the office lights can set to automatically switch off after a set period of inactivity. In a conference room, bith lighting and fan assisted heating or air conditioning can be successfully controlled by such a device. In toilet areas not only the lights can be switched on directly somebody enters the room, but the device can also be wired to water supply solonoid valves, providing water for flushing only when occupation demands.

For safety and convenience, the ultrasonic detector is a useful way of providing lighting in store areas, by activating lights directly someone enters it, negating the need for hunting for switches. To prevent vandalism and for other security operations, the arrival of a person in an area of a building can trigger local lighting, and indicating the presence by an alarm signal if required. And there are numerous other uses for product of this nature which provide both convenience and energy saving.

Another interesting product is the infra-red passive detector. This device senses body heat and is suitable for internal and external use since it senses movement by heat presence and changing patterns of heat such as bodies moving through an area. It is ideal for corridor areas, hall ways and entrances where other disturbances may negate the possibility of using ultrasonic detection. The product can be used outdoors to turn lights on in yards, delivery areas, car parking, driveways etc., The finger like pattern of the detection circuit provide multiple protection and detection paths to ensure that the presence of one body or vehicle within the range of one finger does not inhibit the operation as a second body moves into one of the other finger patterns.

The next logical step is the use of a simple programmable multiple control system such as that pictured here. There are a number of products of this nature available on the world market which purport to provide the answer to simple switching of local and remote sources of a centralised control. However, there are two key areas which we firmly believe are extremely important when considering the adoption of any programmable control system.

Firstly, does it provide direct feedback of the status of the equipment being controlled, and secondly, can you reliably expect any system to operate over an electrical mains supply system by overlaying control pulses or should the data for such switching operations be transmitted over a separate low voltage data base. I'm sure you can see that the first requirement i.e. the feedback of information to tell the controller that the junction box operating relay has indeed operated is an essential requirement for any system which is going to reliably monitor and control the management of energy in any building.

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Equally important, can anybody guarantee that the operation of data communications via the mains wiring will be reliable in the future after the instllation of computer equipment, word processors and other products which will almost certainly attenuate signals being transmitted by adding filter components, comprising simple suppression networks or any other passive components thus inhibiting the use of the mains wiring systems for reliable transmission.

We have spent a number of years researching both the design and application of the MK Response system. Initially we did announce a system communicating over existing mains wiring. However sophisticated the system and hower much power is available to transmit information around that electrical wiring system, the problems and interferences from spurious responses from secondary equipment completely unconnected with the control system make it almost impossible to operate a reliable energy management system over the mains wiring of the building. Indeed from practical experience gained over the last year with this system which utilises separate low voltage bus wiring, has proved to be a significant benefit, many problems are simplified.

You see here a typical control layout. The controller comprises a box containing a digital clock and all the main programming functions for the system. This is plugged into a convenient power supply and the data wiring connected via a socket in the side of the product. Similarly, fused junction boxes are connected in the supply feed to the equipment to be controlled and the data connections are terminated to independent terminals. The data is transferred by a simple two wire bus from one equipment to another, and each junction box returns a signal on the same bus cable. The programmer can control up to 32 junction boxes and can be programmed with 160 individual instructions to on and off any junction box within that system at any time of the day or night. It also incorporates a calendar to pinpoint precise days for operations to be performed; for example an operation may only be required on particular days of each week or on specific dates set by the operator.

A zone controller may also be programmed from the main controller to provide local control for particular functions required in that area, maybe the local heating, or lighting, or any other functions required by that particular area.

A zone controller contains four operating buttons and an LED indicator above each to indicate that switching has taken place according to the functional of the button. Because the zone controller, like the junction boxes feeds back to the controller, the switching operation is duplicated on the controller showing that the device has operated. In a similar way, individual buttons on the controller may be programmed to do particular functions. So all 32 junction boxes maybe pre-programmed by the building operator for that particular set of conditions. And in addition the security officer or manager of the building may have simple manual control by programming local buttons of a controller to switch particular functions such as warehousing, a main button to switch all lights off, a button to illuminate the yard areas, to reactivate heating or lighting in conference facilities used after hours, or any operation may be required.

Response is very easy to program, after very little training any one capable of operating a calculator or video recorder will find no difficultyin programming.

The junction boxes are addressed by a code set by the two code wheels under the cover of the junction boxes and on the rear of the zone controller. These control wheels ensure that only the particular junction box being addressed operates with its own pre-programme instructions and that the returning signals are identified and reported on the controllers display.

As I mentioned earlier, 80% of all savings can be saved by simple control systems. Response is simply installed in almost any commercial or industrial building. It may, of course, also be installed in the larger domestic premises, although the cost is higher than some other simple domestic control systems.

I think it would be useful for you to have an appreciation of four Response systems currently in use.

Here is an installation at the British Sugar Corporation. Particular problems on this site were that

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external lighting was left on at the end of shifts, mainly due to the large area controlled by the lighting and lighting being out of reach without the security officer leaving his security post. Some 22 junction boxes were installed in the base of lamp standards and two systems were installed in the gatehouse to cater for future expansion to a possible 64 locations. It was possible to use existing redundant wiring for the control circuits and already there have been substantial cost savings, and the systems are expected to pay for themselves within 1 year.

This leisure centre at Milton Keynes in the centre of England had particular problems in that a number of special functions took place at varying times throughout the year outside normal hours. With conventional time clocks it was a laborious operation to circuit the area and reset time clocks to the needs of these functions and reset them for the following sessions. One controller and a total of 17 junction boxes has been installed to operate space heating, ventilation and lighting. The air conditioning is set to drop back to a pre-set level and comparing January 1985 with January 1984 prior to the installation being operational, it's remarkable to note that in January 1985, even though the weather was much colder for very much longer than in 1984, the energy usage of the building was very much lower.

Another interesting application is the use of this sort of control system within a retailing operation. An area that you may say is pre-determined in terms of requirement, lighting, energy management, but which still needs control of an economic source and can potentially give large savings.

This company, installed Response to control its heating, ventilating and lighting in their new store, incidently a not particular energy efficient building. The manager has the control system on his desk for all key functions within the building. There are a total of eight junction boxes and one controller sat for opening times, closing times and also for cleaning and security operation. This system is already saving several thousand pounds per year.

The last application that I'd like to mention is an application for Trumans Brewery office lighting. The system incorporates 100A contactors controlling lighting on each floor. Since wach lighting fitting incorporates heat recovery fittings there is a dual problem since not only is lighting energy being wasted, but air conditioning is having to cope with the heat gain from fittings in addition to solar gain from buildings during the summer period. So reducing the lighting load not only has a direct effect from lighting alone, but also effects the work to be carried out by the air conditioning system.

In the winter heat from the tubes and body heat building provides 80 to 90% of the winter heating requirements i.e. approximately 400 kilowatts of lighting. We installed some 24 junction boxes and one controller to operate over 5 floors. The cost of the installation was in the region of £1,500 in hardware, plus some £600 in installation. The payback period is expected to be 1 year.

Whatever form of the pre-programmed system takes, whether it be a fully integrated microprocessor system or a more simplified system such as Response, there is one common problem, namely the distribution of the data.

A complex system is outlined here where a central interface feeds out-stations which in turn provide control and monitoring of the various devices which are connected to the central microprocessor. If the energy management system is integrated with the company's computer system, then available cables frequently have spare capacity to handle the additional data, there are however, various other options.

it is quite conceivable that the interconnection of all the company's requirements involves transmission of data both to and from remote stations on different sites. In Europa digital telephone exchanges both in the form of the public switch telephone network and local in-house PBX system are now allowing, for the first time, interconnection of data directly into, the network without the need for modems or other sophisticated interconnection devices. And, more importantly, transmission speed is improving almost daily as the telephone communication companies commissioning more and

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more high speed data lines.

In the U.K. for instance, British Telecom have already installed full field trial data networks in a number of the major city centres and are planning to offer a minimum of 72,000 digital exchange lines over the next two years allowing high speed data to be directly transmitted.

Within large commercial complexes, universities and even some university towns, local area networks (or LANS for short) providing independent data networks either on a single or multi client basis, are not just the subject of technical papers.

A number of systems are in operation, some have so called intelligent interfaces requiring retrieval, collection and onward transmission of data. Some operate on the simpler bus arrangements and are already available at relatively moderate cost.

The speed of many simple LAN installations is limited by the sophistication of the cabling equipment and the conversion from one users equipment interface to a common transmission medium which inevitably slows down transmission speed. But, it will not be very long before common problems and allow a VDU word processor or micro computer to be directly coupled to a local area network in the same way that today we plug our telephone in where required. Sending memos by cable between offices will, I'm sure, be commonplace in a few years time. Exit the internal postman.

Typically, the Americans, in the form particularly of IBM, have introduced a new transmission system aimed at high speed data transmission and the standardisation of interfaces to one particular connector. At the same time, an international standardisation committee is considering the merits of various alternative connectors for use as Standardised Data Network connectors.

Both of these proposals include hardware and software interfaces and will hopefully soon start to unscramble the multitude of interfaces currently in use. But, whatever software or hardware interface is used, how often do we find the wiring within buildings installed in an unplanned way.

Cables are often loosely laid under floors, within trunking or simply clipped to the wall; and with the expansion rate of data networks being in the region of some 72% increase per year, there is a need now to ensure that all telephone and data networks are installed in an equally professional manner which our industries have shown towards the interconnection of power accessories. The easy availability of data interconnection accessories, we feel, is the key to encouraging the contractor, specifier and architect alike to tidy up and formalise management of data cables.

The TV CO-AX connector has a useful but limited role in providing a convenient relatively low speed connector interface and is the first step in providing an integrated data system, with the ability to install cables at stategic points and provide an interface where VDU's and micro-processors can be plugged in when required. More commonly, BNC or 23 way 'D' connectors mounted as part of a wall accessory can be used not only to interconnect the main VDU or micro-processor to the main frame computer, but, are useful for interconnecting printers and other peripherals and hence aid cable management, particularly in a crowded and already over-calbed office.

A very useful new interconnection gaining popularity in the UK is the 6 way data version of the British Telecom telephone plug. It's coded by a unique key-way and the plugs incorporate the quickly terminated installation displacement connectors providing a very cost effective method for interconnecting up to 6 circuits. When combined with a face plate matching the electrical accessories this provides a very useful interface, particularly for use with bus wired twisted pair or parallel wire systems.

We intend that the electrical industry should be given the means to provide all the connections required in data and telephone interconnection and to work with you to develop these new business opportunities. Likewise the introduction of telephone outlets sockets in both the British Telecom and

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Western Electric versions in ranges matching the electrical accessories provides the contractor with the means to make connections to privately owned telephone systems, where the national telephone monopoly arrangements allow.

I think you will agree that the high tech office now has three needs, power, telephone and data. Integration of all of these three services is a key part of the direction in which we see the industry moving, and the anything that we can do to provide total flexibility of installation, I'm sure will be welcomed by your sales. Our investigation has shown that from the power point of view, it is not a question of just providing lots of sockets or a dedicated grid within the floor on 3 or 6 metre centres, its important to provide the method to place sockets, connection units switches and other electrical interfaces precisely where the customer requires them and if tomorrow the customer changes his needs then we should offer him the ability to move them to new positions.

However carefully a customer plans his requirements, with offices changing their requirements statistically at 18 month intervals, it is almost impossible for the specifier to provide for all future requirements.

There are also increasing pressures to manage our energy in the form of labour too. Even in areas of the world where labour is cheap, there is a need for a system that will reduce the total labour content of any building specification. To be able to be in and out of a building, whether it be new or refurbished in quicker and quicker times is an absolute necessity since business cannot afford these days to be out of action for one hour longer than necessary.

Now you may rightly argue that its difficult to find a way to bring all these important factors together, but we believe that we have found a solution which offers many benefits and addresses these very problems.

Powerlink was introduced in February 1985 in the U.K. and is gradually penetrating many areas of the globe, and its being received very enthusiastically by users, specifiers, architects and installation engineers alike. Powerlink is the culumination of several years of intensive research into the requirements of the market place and we believe it really does address the requirements of the modern electronic office.

Powerlink is a fully integrated, adaptable wiring system which will meet the needs of the office of today and as far as we can see in the future. It provides power outlets sockets where the user needs them, telephone sockets in any required position, and provides for computer sockets where the VDU or micro-processors are situated and the ability to house all the required cabling in one housing. It also provides unique adaptability of all services to allow any socket, power, data or telephone to be placed exactly where it's required today and moved to a new position tomorrow if the need arises.

The heart of the system is the busbars which run along in the central compartment. Above these busbars is an open trough capable of housing additional mains wiring for specific purposes which we will discuse shortly. Both above and below the central compartment are two additional compartments which can be utilised for extra low voltage wiring such as telephone and computer cables. So let's look closer at the system construction.

Two of the principle accessories are a switched 13 amp socket outlet and a 13 amp switched socket outlet with pilot lights. These simply plug-on to the busbars in any position and secured using two screws.

Two connection units are available, one with a flex outlet to feed locally positioned fixed equipment and a second for feeding remote equipment with fixed wiring.

Fixed cables feeding particular equipment may exit the trunking using mini-trunking adaptors which simply snap into a slot cut by the contractor in either the upper or lower side wall.

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The single phase busbars are rated at 63 amps. Powerlink may be wired as a ring or as a radial. We believe that in many cases a radial supply fed at the end or centre of the system from a supply rated up to 63 amps may provide the greatest flexibility, particularly where a larger installation is involved.

A 32 amp switch disconnector provides a convenient means of isolating a particular sector or circuit. The neon indicator can be connected to either the cable or the busbar side of the switch, thus giving increased adaptability in the use and positioning of this switch.

One further electrical accessory is a 20 amp switch. This is primarily intended to be wired to independent lighting drops for the control of room or local task lighting. Integrating this facility into the Powerlink system, really does give it completeness.

All electrical accessories can be fitted anywhere the user requires them. Indeed, during installation of the basic trunking, it may be practical not to install any accessories at that time, thus when occupation of the building takes place, the socket outlets can be placed exactly where they are required – in Powerlink's case, a very simple operation.

Now lets take a look at the extra low voltage accessories.

Firstly we have telephone socket. This comes complete with a rear isolation box which is mounted in the central compartment to segregate it from the live busbars. The isolation box is dropped into place, secured with 2 screws and the telephone socket front plate fitted with 2 additional screws. If the electrical contractor is wiring the telephone installation, the wiring for the telephones may be carried out at this stage. The cables can enter directly into the upper or lower compartments and are wired to the accessory using insulation displacement connectors identical to those already used on our other Telecom products.

Similarly, an ELV blank plate can be fitted with a computer socket or any other low or extra low voltage product and wired via the other upper or lower compartment as appropriate. After installation of the accessories, the central cover is simply cut to length and snapped in-between products and screwed, into place to meet the Health and Safety requirements.

Once the central covers are in place, the system is completely safe and the extra low voltage or other wiring in the outer two compartments can be installed without any access to live busbars.

Cable terminations clip directly onto the busbars and provide easy connection for the feed cables. Cable can access via a special cable entry box which is available in a flush or surface version accepting 2 sizes of mini-trunking adaptors.

Naturally a complete compliment of track accessories are available for Powerlink, comprising inside and outside corners, couplers and end caps.

Because of our concern for adaptability in the design of the Powerlink system, we have gone yet one step further.

An extension trunking provides a fourth compartment for other bulky cables such as main wiring feeds for the power supply, telephone, computers or other services.

This product is particularly useful for converting Powerlink into a skirting trunking. It provides a recess for the carpet to easily butt into it and rasses the level of the sockets to an acceptable height whilst providing a great deal of additional wiring space.

Where this extension trunking is used for extra low voltage cables, an extra low voltage blank

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plate may be pierced and fitted with any extra low voltage product such as computer sockets.

Naturally internal and external corners, and plates and couplers are available for use with extension and main trunking when fitted together.

I am sure that you will already agree that Powerlink isn't just another new product – it's a system designed to meet the users needs and to give maximum flexibility.

It comes in 3 metre lengths complete with busbars and all the outer covers.

Powerlink trunking and accessories are available in three colours, white, brown and charcoal and accessories may be installed exactly where they are required.

This system really does provide economy of energy in installation. Typically total installation costs are similar to those of conventional wiring system, but the actual time spent in installation for all these services is far less than you would normally expect. When it comes to modification, the time taken to move or to install additional sockets within Powerlink is some 12 minutes compared with at least 45 minutes for a standard modification of a conventionally wired system, a tremendous benefit in today's modern commercial world.

Well I'm sure you have heard quite enough from me for today. I hope that my presentation here today has given you fresh insight into the way that energy management system products and accessories are being developed to meet your needs for today and very many tomorrows. I'm sure that you are only too well aware that MK is investing heavily in our joint future and will continue to do so whilst there are so many new avenues to be explored.

It remains for me to thank you for inviting me to speak here today and I trust that although we are obviously addressing a market formed on some different principles here in Hong Kong, that the principles and accessories I have spoken about will encourage you in the same way that it has encouraged our home industry in England and Europe.

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— Notes & Questions —

Paper No. 10

Power Capacitors for Financial Saving

Speaker: Mr. G. Martin, MISE, Regional Sales Manager, London, Johnson & Phillips (Capacitors) Ltd.

POWER CAPACITORS FOR FINANCIAL SAVING

1. Introduction

To obtain the best possible economic advantage from electrical power, both the generating and consumers's plants should be operated at high efficiency. To achieve this it is essential to have a good power factor throughout the system.

Most a.c. electrical machines draw from the supply apparent power in terms of kilovolt amperes (KVA) which is in excess of the useful power, measured in kilowatts (kW). The ratios of these quantities:–

$$\frac{\text{Useful Power}}{\text{Apparent Power}} \text{ or } \frac{\text{KW}}{\text{KVA}}$$

is known as the power factor (Cos ϕ) of the load and is dependent upon the type of machine in use. A large proportion of the electrical machinery used in industry has an inherently low power factor, which means that the supply authorities have to generate more current than is theoretically required.

In addition transformers and cables have to carry this extra current. When the overall power factor of a generating station's load is low, the system is inefficient and the cost of electricity correspondingly high. To overcome this, the supply authorities often offer reduced terms to consumers whose power factor is high, or impose penalties for low power factor.

Any installation including the following types of machine or equipment is likely to have a low power factor which can be corrected, with a consequent saving in charges.

(a) Induction Motors of all types
(b) Power Transformers and Voltage Regulators
(c) Welding Machines
(d) Electric Arc Furnaces
(e) Choke coils and Magnetic Systems
(f) Neon Signs and Discharge Tubes

If there is no tariff penalty, the factory cabling and supply equipment can be relieved of a condierable wattless or reactive load. This will enable additional machinery to be connected to the supply without enlarging these services, and the voltage drop in the system will be reduced.

The method which can be employed to achieve these improvements is by introducing reactive KVA (KVAr) into the system in opposition to the wattless or reactive current mentioned above and cancels its effect in the system. This is achieved either with rotary machines (synchronous condensers) or static capacitors.

2. Power factor correction by shunt capacitors

The apparent power (kVA) in an a.c. circuit can be resolved into two components, the in-phase component which supplies in useful power (KW) and the wattless component (KvAr) which does no useful work. The vector sum of the two is the KVA drawn from the supply and the cosine of the phase angle between this and the KW represents the power factor of the load.

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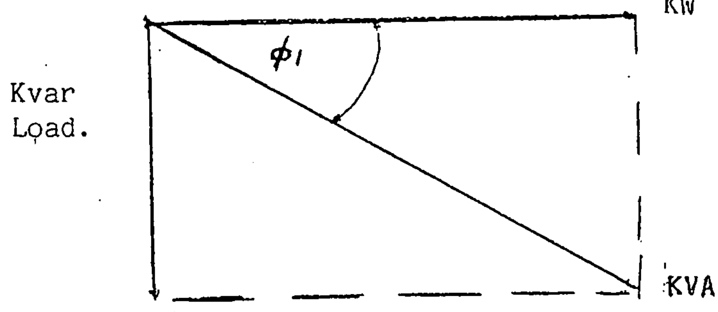
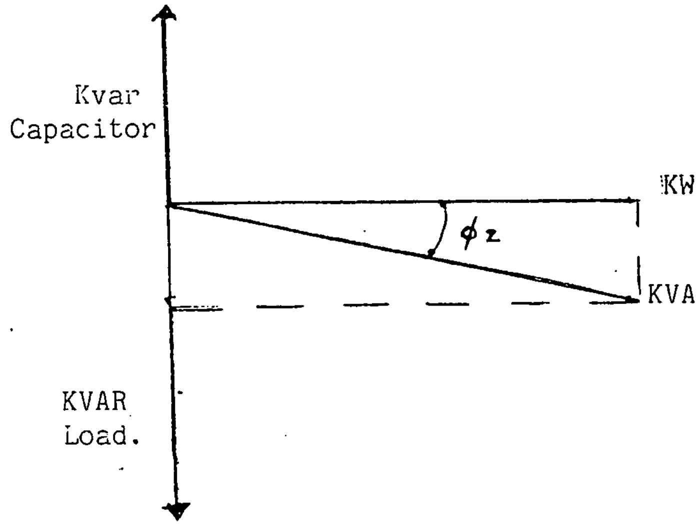
This is shown vectorially.

FIG 1.



When equipment drawing KVAr of approximately the same magnitude as the load KVAr, but in phase opposition (leading) is connected in shunt with the load, Power Factor is improved. The resultant KVAr is smaller and the new power factor (Cos ϕ_2) is correspondingly increased. Obviously Power Factor is controlled by the magnitude of the KVAr added, so that any desired power factor can be obtained by varying the leading KVAr, see Fig 2.

FIG 2.



Careful consideration should be given to the various methods of correction possible in order that the most satisfactory results may be obtained.

(a) By rotary phase advancers, synchronous condensers or synchronous motors.

(b) By static cpacitors.

The points to be considered in any installation are:–

1. Reliability of the equipment.
2. Probable life.
3. Capital Cost.
4. Maintenance cost.
5. Running costs.
6. Space required and ease of installation.

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Generally, it will be found that for normal industrial installations the capital cost of rotating machinery, both synchronous and phase advancing, are uneconomic and the wear and tear inherent in all rotary machines involves increased maintenance costs.

Capacitors have none of these disadvantages. The initial Capital cost is low, Maintenance costs are minimal and they can be used with the same high efficiency on all sizes of installations. Capacitors are compact, reliable, highly efficient, convenient to install and are suitable for individual, bulk or atuomatic methods of correction. The installation of capacitors is the most efficient and economical method of Power Factor Improvement.

With little exception, capacitor installations are undertaken with the sole objective of reducing Energy Costs, consequently the tariff under which the consumer is charged must be examined closely.

3. The China Light & Power Co. Tariff

Industrial & Commercial consumers of electricity with a monthly unit consumption greater than 20,000 KW hours will be charged on a KVA Maximum Demand Tariff, assuming a load factor of 28%, it is evident that consumers with a Maximum Demand greater than 100KVA will be subjected to this tariff.

In order to highlight the case for power factor correction capacitors we detail the following examples.

3.1 Small Engineering Works

Maximum Demand.

KVA	KW	P. F.	KVAR.
125	81	0.65	95

Recommended capacitor. 70 Kvar.

<u>Improved Maximum Demand</u>

KVA	KW	P.F.	KVAR.
85	81	0.955	25

Reduction in Maximum Demand 40 KVA.

Financial saving H.K. $9600 Per Annum

Cost of Equipment:– H.K. $15,000 approx.

Note:– This consumer would also contravene the supply agreement as the Power Factor is worse than 0.85 lag.

3.2 Air Conditioned Hotel

Maximum Demand.

KVA	KW	P.F.	KVAR.
500	400	0.8	300

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Recommended Capacitor	200 KVAR

Improved Maximum Demand

KVA	KW	P. F.	KVAR.
412	400	0.97	100

Reduction in Maximum Demand		88KVA
Financial Saving	H.K.	$21120 Per Annum
Cost of Equipment.	H.K.	$30,000 approx

Note:– This consumer would also contravene the supply agreement as the power factor is worse than 0.85 lag.

The examples show that the installation of power factor correction equipment an economic proposition in Hong Kong. The Rate of pay back on Capital Cost is relative to the basic power factor of the installation.

We detail below various installations together with typical power factor and the pay backs which may be expected.

Fig. 3 Illustrates Typical Premises which would benefit from the installation of Capactiors.

FIG. 3

INDUSTRIAL OR COMMERCIAL PREMISES	TYPICAL P. F.
Air Conditioned Hotel.	0.8 Lag.
Engineering Factory.	0.65 Lag.
Textile Works.	0.72 Lag.
Bottling Factory.	0.77 Lag.
Office Block.	0.88 Lag.
Department Store.	0.85 Lag.

4. Methods of correction

Each power factor correction scheme requires individual consideration, and as the successful operation depends largely on the positioning of the capacitors in the system, the importance of all relevant factors should be emphasised.

1. Tariff
2. Metering point
3. Details of light, average and full load, KVA, KW and power factor.

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4. Position of motors, welders, transformers, etc.
5. Supply system ratings, harmonics etc.

Large Motors which are constantly in operation or only in circuit during Maximum Demand are suitable for individual Power Factor Correction. This method reduces the current loading on the distribution system with consequent improvement in voltage regulation and, generally speaking, is more economic. No additional switchgear is required as the capacitor is connected directly across the motor terminals and switched with the load by the motor starter. The balance of the correction required, can then be connected to the main busbars of the supply system controlled manually by a fuse switch or automatically. Some Supply Authorities stipulate the maximum amount of KVAr which may be switched manually.

Automatic switching of capacitors is recognised as an ideal method of obtaining Maximum benefits from a capacitor installation. Optimum power factor is thus achieved under all conditions and there is no possibility of the equipment being inadvertently left out of commission. A bank of capactiors with the required total capactior KVAr controlled in equal stages by a multi-stage relay and air break contactors connected to the main busbars, is used in many applications.

Large industrial sites involving different kinds of manufacturing processes often require a combination of bulk and individual correction to provide the most economic means of power factor correction.

When considering power factor correction it should be remembered that distribution boards and circuits can carry a greater useful load if the capactior are installed as near as possible to the source of low power factor. For this reason either bulk or individual correction rather than correction at the intake point, can almost invariably be justified.

5. Individual correction of motors

The practice of connecting a capacitor across the starter of an induction motor and switching the motor and capacitor as one unit is now universally established, and it is to be recommended where there are no objections on technical and economic grounds. One size of capacitor will give an almost constant value of power factor over the normal load range since variations in motor KVAr are comparatively small.

Connecting a capacitor direct to a motor results in a lower load current for any particular operation and therefore the overload setting on the starter should be reduced in order to obtain the same degree of protection.

Individual Power Factory Improvement should not be applied where the motors are used for haulage, cranes, colliery winders or where "inching" or "plugging" and direct reversal takes place. Individual correction of tandem (or two speed) motors should be avoided. Where capacitors are connected to motors it is unusual to provide the capacitor with any individual protection or isolation.

Where star-delta starting is used, a standard three terminal delta connected capacitor should be used giving, maximum power factor correction at the start when the power factor of the motor is low.

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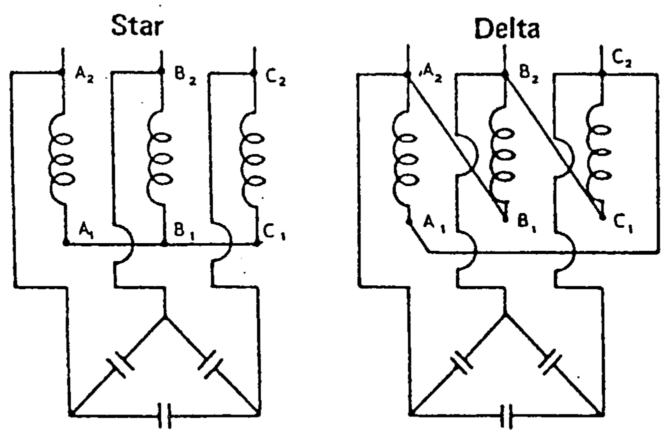
Fig 4



Capacitor ratings for individual correction of motors may be obtained from data supplied by the Motor manufacturer.

6. Individual correction of welders

Welding equipment generally has an inherent power factor of approximately 0.35 lagging, but as welding loads are intermittent, the degree of correction, based on its continuous KVA ratings, is usually to a value of 0.6 to 0.8.

7. Bulk power factor correction

As it may not be economic or desireable due to adverse conditions to individually correct each piece of electrical equipment, Bulk Power Factory Correction should be considered.
Where capacitors are connected to busbars they must be provided with protection and isolating equipment.

METHOD OF CONNECTION	ADVANTAGES	DISADVANTAGES
Manually connected via suitable rated fuse switch	Cheap method of control Mechanical Failure of Switchgear unlikely.	Electricity Authorities only allow small amounts of capacitors. Manually connected normally Max 50Kvar.
Individual Power Factor improvement of motors.	Cheap Method of control. Reduces current to actual source of Kvar.	Several small capacitors cost more than one single capacitor. Loss of Capacitor effect due to Motor Diversity. Maintenance of Capacitors tends to be overlooked.
Automatic Power Factor Improvement using Kvar sensing relay and contactors.	Power Factor Correction. Housed at one point. Ease of maintainance better utilization of capactiors.	Higher Capital Costs. sensing relay

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8. **Installation of power factor correction capacitors**

Installation and maintenance should be carried out generally as specified in the "Relevant Standard Code of Practice." Due to the fact that the permissible temperature rise and the maximum permissible temperature of capacitor is low, it is essential that they should be installed in a well ventilated position. Any variation in the ambient temperature or ventilation conditions will have a materially greater effect on capacitors than or other electrical apparatus.

The table shown below, taken from BS 1650 gives the ambient temperature range for capacitors.

9. **Ambient temperature categories**

Temperature Category	Maximum permissible ambient temperatures. Mean over 1 hour	Mean over 24 hours	Mean over 1 year
Temperature	40°C	30°C	20°C
Tropical	45°C	40°C	30°C
Super Tropical	50°C	45°C	35°C

10. **Installation of manual and automatic equipment**

The cable supplying either an automatic capactior bank, or a permanently connected capactior should be protected by means of a suitably rated H.R.C. fuse and switch. The only exception to this would be where the cable connecting an automatic bank and the main switchboard is less than 2M in length and has a rating:

1. not less than half the rating of the protection device fitted at the origin of the circuit, and
2. not less than the rating of the protective device in switchgear controlling the capacitors.

11. **Switchgear and fuse gear for capactior control**

The duty imposed on switchgear and fuse gear associated with capacitors is subject to more onerous conditions of use than similar apparatus carrying alternating current loads of equivalent KVA.

1. At the instant of switching a large transient current will flow.

2. High overvoltage transients can occur when capacitors are disconnected by switching devices which allow restriking of the arc.

3. The switchgear has to carry continuously the full rated current of the capacitor at all times when the capacitor is in circuit.

4. At light loads when the voltage may be higher than normal the capacitor current will be increased accordingly.

5. If harmonics are present in the supply voltage the capacitor current will be increased.

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In Europe capacitors are normally manufactured in compliance with BS 1650 and/or I.E.C. 70/70A, which specifies the following conditions.

1. The output of a capacitor can be between – 0% and + 10% of its rated output.

2. The capacitor shall be suitable for operation under abnormal conditions where the applied voltage rises for prolonged periods to a value not exceeding 1.1 times the rated voltage, excluding transients but including the effect of harmonics.

3. The capacitor shall be suitable for operation under conditions in which the maximum r.m.s. current through the capacitor does not exceed the current which would flow through it at the rated (sinusoidal) voltage and rated frequency by more than 30% (B.S. 1650 states 15% I.E.C. 70 states 30%).

In view of these onerous operating conditions it is normal practice to de-rate switchgear and fuses used for controlling capacitors.

12. Maintenance of power factor correction capacitors

Capacitors, being static apparatus are not usually given the same care as rotary machinery, but nevertheless, require regular maintenance. Normally, a power factor correction capactior should be inspected every 12 months. The time interval between inspection is, however, governed mainly by the conditions, on site. Where capacitors are installed in humid atmosphere or subjected to chemical fumes or exposed to dirt and dust, more frequent maintenance is recommended.

Before examination always ensure that the apparatus is switched off, allowing time (1 minute LV, 5 minutes HV) for the capacitor to discharge completely, as stated on the rating plate.

The following points are to be observed for maintenance of a power factor correction capaciotr:–

1. Condition of exterior finish, protective paint should be maintained in good condition.

2. Remove the terminal box cover and note any abnormality, special care being taken of the following points:–

   a) Conditions of cables.
   b) Conditions of interior paint work.
   c) Tightness of nuts and bolts particularly earth connections.
   d) Removal of dust and other foreign matter.
   e) Clean any surface that needs attention. Particularly insulators and terminals.
   f) All auxillary gear should be inspected and regularly maintained in accordance with the instructions provided by the supplier.

13. Automatic power factor correction

In larger installations, automatic power factor control is being increasingly recognised as the ideal method of obtaining, the full electrical and financial benefits from a capactior installation. Optimum power factor is achieved under all conditions and there is no possibility of the equipment being inadvertantly left out of commission.

The equipment will consist of a capacitor bank sub-divided into two or more equal steps, each

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step or capacitor being controlled by a contactor.

In turn, the contactors are controlled by a reactive relay. Consisting of a potential coil connected across two phases of the supply and the current coil, rated at 5 amps is taken from a current transformer on the third phase of the system, so as to obtain a 90 degree phase displacement at unity power factor.

The number of stages installed is usually a compromise between the technical requirement and cost. The requirement of an automatic system is to have each contactor switching its maximum rated capacitance and, at the same time, have the capacitor bank divided into the most economic subsections, so that all variations in laod can be corrected.

14. Special Conditions

Capacitors are generally suitable for use on most installations. There are however special conditions, where the type of capacitor equipment has to be carefully considered to ensure that problems are not experienced elsewhere within the plant.

14.1 Capacitors and Main Frame Computers

When a capacitor is switched into circuit there is a large transient current associated with the switching. This is accompanied by a transient peak, or dip in voltage. The effect of this on a computer load creates serious problems with computer operating and computer storage systems.

The magnitude of the transient condition is governed both by the size of capacitor and by the short circuit capacity of the system. Usually the smaller the capacitor the smaller the transient effect. In the past it has been suggested that capacitors connected to a computer loads, is therefore not recommended.

There are, however, two exceptions to this rule. Capacitors can be automatically switched in large or small steps provided:–

a) that the computer is supplied from a motor generator and the capacitor is connected to the mains side of the motor,

b) that the computer is fed from its own transformer and the capacitor installation is connected to the medium voltage side of a second transformer installed to supply the air conditioning plant.

In these two cases there is an effective "buffer" between the computer load and the capacitors are not reflected into the computer load.

Apart from these two exceptions, in every other case where a computer forms the main load the capacitors must be permanently connected in one of the following ways:–

1. Permanently Connected Capacitor using a Fuse Switch

   The capacitor is connected to the system by means of a suitably rated fuse switch and switched into circuit initially at a time when the computer is not in use. Thereafter the capacitor is left permanently in circuit.

   The advantages of this method of capacitor connection are low cost and simplicity.

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The disadvantage arise should there be a system power failure, as when power is restored the capacitor will be switched into circuit at the same instant. If the computer is switched into circuit at the same time it will be subjected to the transient conditions associated with switching the capacitor.

2. Permanently Connected Capacitor using a Contactor

The capacitor is connected to the system using a contactor unit fitted with a "no volt reset" feature.

This method is costly but has the advantage that in the event of a power failure the capacitor will be disconnected from the system. The capacitor will remain disconnected, even though power is restored, until "reset" by hand at a convenient time, to suit computer operating conditions.

Computer Input Terminal

Care must be taken in deciding whether a customer has a computer or merely an input terminal. The notes contained in this paper apply to computers only. Capacitors will have no detrimental effects on computer input terminals, or desk top computers.

14.2 Harmonic

Modern DC equipment using thyristors rectifiers etc can introduce harmonics in the waveform of the network voltage. As the system is generally inductive a capactior in parallel with the load may create resonance. If the resonant frequency is close to one of the harmonic frequences present there will be a significant increase in both voltage and current at the same time. Which will cause premature failure of capacitors.

The most common way of overcoming the harmonic problem is to introduce inductance in series with the capacitor.

It must be realised however, that the series inductance will only protect the capacitor from the overvoltages caused by harmonics. The harmonics will still be present on the system.

15. Polychlorinated Biphenyl Impregnated Capactior's (PCB)

Power Factor Correction Capacitors were first manufactured in the early 1930's using mineral oil impregnated and immersed cylindrical paper/foil elements housed in tanks.

This type of capacitor dominated the market until the late 1950's when the excellent electrical properties of Polychlorinated Biphenyl were discovered which enabled manufacturers to reduce physical size and material content of capacitors in addition to making them virtually fire proof.

In 1976 the toxi hazards of PCB were recognised and alleged to cause kidney disease, bronchitis and various cancers. This dictated a complete re-design by the capacitor industry in the Western World and the totally dry metallised polypropylene element was born.

All European countries are now actively indentifying existing PCB impregnated capacitors within industry and replacing them with environmentally acceptable equipment.

Ainc metallised polyropylene windings, individually encapsulated in resin are the main concept of modern design, with low loss, self healing elements, dry, nonflammable, completely no toxic and biodegradable.

Metallised capacitors are currently saving World industry millions of pounds in reduced energy costs each year.

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— Notes & Questions —

Paper No. 11

Practicable, Practical & Practised

Speaker: Mr. S. T. Tam, MHKIE, CEng, MIEE, Vice President, Hong Kong & Kowloon Electrical Contractors Association Ltd.

PRACTICABLE, PRACTICAL AND PRACTISED

Introduction

The ultimate goal of using electrical energy is to relieve the burden of work for human beings, and to improve the quality of their lives. How this goal can be achieved effectively depends upon a number of factors. These include the systems of generation, transmission and distribution; the method of conversion from electrical energy to other forms of energy; the pattern in which the converted forms of energy is put to use. These factors, in turn, are limited by the developments in science and technology; the application of these developments to the manufacturing of equipment and material; the incorporation of these manufactured equipment and material into the designs; the installation of the system in accordance with the design; and the education of the operator or user of the system provided.

Based on these factors and limitations, we have to work out not just a practicable solution but indeed a practical solution, and make sure that it is practised to what constitutes the effective use of electricity. Basically, an effective electrical system should be economical both from the initial cost and running cost points of view. It should have security for its application. Also, it must be safe for the operator, end user and the public in general.

Economical considerations

The percentage of power loss in transmission and distribution vary from system to system but it is an unavoidable part in carrying electrical energy from the generator to the point of application. The transmission line losses, the transformation loss and the distribution losses are in the hands of the Power Supply Companies when the systems are deisnged. However, these do ultimately affect the rates that are charged for the electrical energy consummed. Well, it is practicable to install one's own generators to provide for one's own needs. There are a full range different types of generators manufactured by various companies to meet most of the needs for individual consumers. This may or may not be cost effective depending upon the location where the electrical energy is to be used; the availability of the energy source for electricity generation; the availability of suitable technical manpower to service, and maintain the installation in relation to the security of the power system required.

For example, an isolated farm where a nearby steady stream could generate enough hydro electric power for the household needs may well find that this may be the ideal solution rather than transmitting electricity over great distances from established power grids. On the other hand, it would not be practical to install a diesel generating set as a constant source of electricity supply for a domestic unit in a building complex where the normal electricity supply system is well established. Not only will there be the initial cost of the generator set itself, but also the space required for the installation, the fuel supply requirements, the problems of enviromental protection, the cost of servicing and maintenance will all have to be considered. To meet these requirements could be very expensive if not prohibitive.

In order to minimise the transmission and distribution losses, reduction in conductor loss and improvements in transformer efficiency could be considered. It is well known that the specific resistance of different conductor materials are different. The specific resistance at 0°C per centimeter cube for annealed silver, copper, aluminium, iron and steel are 1.468, 1.561, 2.665, 9.065 and 15 to 50 microhms respectively. Then, would it not be better to use silver conductors or large cross-sectional area iron conductors for transmission? Here again, economic considerations, to a very large extent, dictates the use of suitable conductor materials. Silver is too expensive for use as normal transmission line conductors. Large cross-sectional area iron conductors would be too bulky and too heavy for most purposes. Super cooling of the conductors could also greatly reduce the resistance of conductors.

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However, the high cost of running enormorous cooling plants necessary would greatly out-weigh the savings in conductor losses.

The other major elment in transmission loss is transformer efficiency. It may account for about 5 per cent of the total generation. The use of amorphous steel cores for transformers can reduce the iron losses by up to 75 per cent. Amorphous metals have a non-crystalline liquid-like molecular structue, and have been shown to exhibit excellent soft magnetic properties with alloy compositions of 80 per cent and 20 per cent metalloids, such as boron and silicon. At equivalent inductance, losses for electrical-grade amorphous metals are 25–35 per cent of those for the best conventional electrical steel. However, there are still some practical problems in the design and manufacturing to use amorphous metals widely for transformer construction. These problems are mainly due to their inherent properties as their thinness, hardness low stacking factor and difficult annealing process. Despite these problems, they are still practicable propositions and some twenty-five preprototype pad-mounted transformers with amorphous steel cores have been made, and are being operated and monitored. Another thousand hand-made 25 KVA pole-mounted units are being manufactured on a prototype production line to determine their production cost.

System security considerations

From economical considerations, the supply of electrical energy to a group of loads may be best done by a single connection. Taking into consideration diversity factor of energy usage, the capacity of the installation could be smaller than the sum of the individual connections for each of the loads. Thus, the initial cost for the installation would be lower if the loads were supplied collectively. The running losses would also most probably be lower owing to the over-capacity of the system provided for a particular laod at the point in time when the other loads may not be in use. However, if a fault should develop in one of the loads, it may affect the electricity supply to all the loads connected by the common feeder. This is obviously not satisfactory for some of the essential loads.

For consideration of supply to major loads, we may have to provide more than one route of transmission. The one and a half switch configuration is a typical example where fault developed or maintenance required on a single circuit breaker would only affect the supply to the load within the switching time of the changeover of the circuit breakers. This arrangement would satisfy the requirements of security for most major loads.

However, for circuits requiring even greater security, a backup source for the essential load may be provided usually in the form of a standby diesel or gas turbine generating set or a storage battery system. It is normal to consider using the storage battery system as a backup source for small loads and minimum interruption time. This could be supplied in the form of direct current to the load or it could be transformed by an invertor to the required operting frequency of the system. For larger loads and where a longer interruption time is permissible, a standby diesel generating set as a backup source could well be considered. Sets of rating ranging from 50KVA to 1MVA are commonly used in Hong Kong for such purpose. For even larger loads sets running in parallel may be required but under these circumstances, it may take a longer time for the sets to synchronise before taking up the load. With recent developments in metallurgy and increasing use of industrial gas turbines, there is the trend of using smaller rating, higher speed gas turbine generating sets for standby duty. Quite a number of 750KVA and higher rating sets have been installed in Hong Kong in recent years. The gas turbine running at about 10,000 RPM is of smaller physical size, and lighter in weight than that of equivalent rating diesel generating sets. Since it is easier to attenuate higher frequency noise than those of lower frequency, it is easier to treat the noise pollution problems generated from the gas turbine generator sets.

There are still more critical cases where any disruption in the power supply even for a short period of time would have serious consequences. These would not be adequately protected by the

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backup generating set arrangements described above. Under such circumstances, it is usual to install no-break supplies provided by either rotary motor-generator arrangement or battery-invertor arrangement. In the former case, the normal power supply is connected to the motor which drives a large fly wheel and an alternator. Should the normal pwoer supply fail, the kinetic energy of the flywheel keeps the alternator rotating, and at the same time, starts up a diesel engine. When the diesel engine is run up to speed, it provides the driving energy for the flywheel as well as the alternator. The no-break power supply is always derived from this alternator and, thus, is maintained even when the normal power fails. In the latter case, the normal power supply is rectified to charge a bank of storage batteries as well as feeding a bus common with batteries. The supply on the bus is then converted to the alternating current of the required frequency to supply the ciritical load. Thus, even if the normal power supply fails, the bus power supply is still maintained by the storage batteries and the power to the critical load is maintained. Very often the normal power supply is itself backed-up by a standby generating set in order to limit the requirement of extremely large capacity for the storage.

Although these are some of the common provisions to enhance the system security, we should not loose sight of the facts which make them practicable. We should look out for the types of load and their characteristics which may affect the proper operation of the generating sets. In particular, the starting currents in the case of large motor drives and the harmonic currents in the case of thristor controlled equipment would adversely affect the operation of the generator sets if these loads form a high percentage of the total load, and are closed to the generator rating. On the other hand, to maintain the system in a reliable state, regular and sensible servicing and maintenance should be carried out. It is just not practical to install a backup system and forget about it, and hope that it will perform its function when required. At the other extreme, too frequent misguided serviicng and maintenance could also be detrimental to the reliability of the system. A typical example is the frequent start up of the diesel generator set and running it for short periods on no load. This would result in accumulation of carbon deposits in the diesel engine which affects the starting reliability. It is important that the diesel engine be run on full load from time to time for it to reach its design temperature for a length of time in order to burn off the carbon deposits. Thus, proper servicing and maintenance is an extremely important factor for unkeeping practical systems security.

Safety considerations

When considering the safe use of electricity, the first measure would be the use of 'Safety Extra Low Voltage' which limits the highest voltage to 50V A.C. and 120V D.C. However, the use of a voltage within this ranges alone is not sufficient to classify the system as SELV. Special safeguards are required to ensure that even in the case of a first fault, no danger exists. There are stringent requirements regarding the insulation between SELV circuits and other circuits, particularly the source of the safety extra low voltage, e.g. the isolating transformer. The motor-generator arrangement is a good source of isolation but for electronic devices, care must be taken to ensure that even in the case of an internal fault, the voltage at the outoging terminals must not exceed the specified values. Exposed conductive parts of such circuits should not be connected directly or indirectly to earth. If all final sub-circuits are rated at SELV, then there would be extremely good prtection against electric shock both in normal service and in case of fault. Unfortuantely, this type of protective measure is not practical except in particularly critical situations.

Another method of protection against electric shock is by the use of residual current breakers. In theory, a single RCCB installed say at the incoming terminals of a distribution board, and rated for operation at a leakage current of 30mA would offer sufficient protection against shock for most systems. However, there are practical difficulties with such an arrangement. Dependent upon the types of loads connected to the installation, the RCCB may trip off inadvertantly affecting the entire installation supplied from the distribution board, and create a great nuisance to all the users. Even the current practice in Hong Kong of protecting all the circuits supplying to the socket outlets by a single residual current device at the distribution board often causes nuisance tripping if some of the sockets outlets supply to window type air-conditioning units. It has been found that some consumers simply by-pass the RCD, while others get round the requirement by using connector units for supplying to these air-conditioning units, and group these circuits as supplying to fixed appliances. This would be perfectly in order if the earth loop impedance is low enough to trip off the supply within the required time to prevent dangerous shcok should a fault develop in the circuit. A point to be noted in this connection for hand-held equipment is the maximum disconnecting time of 0.04 secs applying to a prospective touch voltage of 240V A.C. The maximum disconnecting time should be about 0.06 secs for a prospective touch voltage of 200V A.C. in accordance with I.E.C. Publication 364–4–41. Rather than having to by-pass the RCD which gives a false sense of protection, it is more practical to condiser a window type air-conditioning unit as a fixed appliance.

Conclusion

The effective use of electricity is never at an absolute state. Having briefly cited some examples on current practices and possible alternatives, it can be demonstrated that it is up to engineers to develop and manufacture equipment based on up-to-date development in science and technology; to design and install systems by using these new products to their best advantage; to educate the operators and users of the system with due consideration to the economic, security and safety aspects of the system. At any stage in time what is practicable, may not necessarily be practical. However, what is practical should be encouraged and be practised. This should be our philosophy in the effective use of electricity.

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