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ABSTRACT

Presented are 13 lecture outlines with accompanying handouts and reference lists for teaching school administrators and maintenance personnel the use of electrical load management as an energy conservation tool. To aid course participants in making cost effective use of electrical power, methods of load management in a variety of situations are discussed. Topics covered range from how electricity is generated and transmitted to rate schedules, principles of load management, and computerized building automation systems. (Author/WB)

ELECTRICAL LOAD AND ENERGY MANAGEMENT

by

Paul Wang

Summer, 1979

for

Energy Conservation Curriculum and Short Course Project #8208 Program Development Section, North Carolina Dept. of Community Colleges

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FOREWORD

This instructional manual was prepared by the Department of Community Colleges as a part of its plan to provide courses on energy conservation which reflect the current energy concerns and the application of available technology to statewide needs. The manual provides instructional material to teach school administrators and maintenance personnel the use of electrical load management as a valuable tool in energy conservation. The presentation of appropriate methods of load management in diverse situations should aid users to apply cost-effective approaches to the use of electrical power.

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CONTENTS

LECTURE I: THE NATIONAL ENERGY PROBLEM

The nation faces a serious and continuing energy problem characterized by limited energy choices and increasing dependence on diminishing oil and gas resources. This problem is currently exemplified by an undue reliance upon imported fuels.

To provide alternatives to undesirable dependence on oil and gas, the nation must undertake a program of technological development which will be difficult and costly and will require time.

The United States is a nation rich in domestic energy resources, yet depends on the importation of large quantities of fossil fuels. This is the essential paradox of the nation's energy problem.

Solving the energy problem requires broadening the base of domestic energy resources and adapting to the new resource base more quickly than ever before. An aggressive national program of technological development can expedite this process because broadening the domestic energy resource base requires rapidly expanded utilization of existing and new technology.

According to the National Plan For Energy Research, Development and Demonstration: Creating Energy Choices For The Future 1976, published by United States Energy Research and Development Agency, priority ranking of conservation has now significantly increased.

This major change from ERDA-48 reflects observation of only moderate progress to date on supply technologies, public comment on ERDA-48, and further analysis of conservation opportunities. Specific reasons for assigning higher priority to energy efficient technologies are identified below. Many of the technologies to improve energy efficiency currently appear to have one or more of the following characteristics: (1) A barrel of oil saved can result in reduced imports. Conservation combined with fuel substitution efforts reduces dependence on foreign oil. The focus is on available cost-effective approaches. (2) It typically <u>costs less to save a barrel of oil than to produce one</u> through the development of new technology. (3) Energy conservation generally has a more beneficial effect on the environment than does energy produced and used. (4) Capital requirements to increase energy-use efficiency are generally lower than capital needs to produce an equivalent amount of energy from new sources since most new supply technologies are highly capital-intensive. (5) Conservation technologies can generally be implemented at a faster rate and with less government involvement in the near-term than can supply technologies. (6) Energy efficient actions can reduce the pressure for accelerated introduction of new supply technologies. Since the actions persist over time, the benefits are continuing in nature.

These reasons for assigning higher priority to energy efficient technologies deal generally with conservation technologies. The rate of application and introduction of conservation technologies in specific instances will be determined by the comparative economics and social acceptability of the available alternatives. There shouldn't be any doubt in our mind that electrical load management, as one method to conserve our limited energy resources, ought to be pursued with rigor.

The conservation programs of the federal government include: (1) Programs whose purpose is to speed the introduction of equipment, such as appliances, automobiles, industrial processes, which use less energy. (2) Programs aimed at stimulating efficient energy use through such means as incentives, regulations and loans.

Energy conservation may be grouped approximately into the following systems and end-use areas:

(1) Electrical Energy Systems
(2) Energy Storage Systems
(3) Industry Conservation
(4) Building Conservation
(5) Transportation Energy Conservation

One of the items listed in (1) is "improved load management," which is closely related to the subject matter under discussion here. Clearly, the system (4) Building Conservation is our primary concern. <u>Building Conservation</u> is directed at encouraging private sector activity in the development of energy-saving technologies for more efficient energy use in buildings, community systems and consumer products. The activity includes development of retrofit equipment for existing structures, as well as new equipment for new structures. It consists of waste systems and utilization activities dedicated to the recovery of fuels, recyclable materials, and energy from urban and industrial waste.

References and Suggestions For Further Reading

(1) U. S. Central Intelligence Agency. The International Energy Situation: Outlook to 1985, April, 1977. U. S. Government Printing Office, Stock Number 041-015-00084-5.

(2) U. S. Energy Research and Development Agency. A National Plan for Energy Research, Development and Demonstration: Creating Energy Choices for the Future: The Plan, Volume 1, ERDA-76-1, 1976. Stock Number 052-010-00478-6.

(3) Same as above, Program Implementation, Volume 2, ERDA 76-1, 1976. Stock Number 052-010-00492-1.

LECTURE II: ELECTRICAL POWER GENERATION

A. Characteristics of Electrical Energy

There are three main characteristics of electrical supply which are summarized as follows:

(1) Electricity, unlike gas and water, cannot be stored and the supplier has little control over the load at any time.

(2) There is a continuous increase in the demand for power which is roughly equivalent to a doubling in demand every ten years.

(3) The location of fuel supplies creates distribution problems because it does not coincide with load centers. This aspect is of great interest as coal is mined in areas that are not necessarily the main load centers; hydroelectric power is usually remote from the large load centers.

B. Energy Conversion Using Water

Perhaps the oldest form of energy conversion is by the use of water power. In the hydroelectric station, the energy is obtained at a very low cost. This attractive feature has always been somewhat offset by the very high capital cost of construction, especially of the civil engineering works. In the 1970 United States energy flow diagram, hydroelectric power accounted for only 0.4 percent of total power supply.

The general modes of operation of hydroelectric stations are as follows: The vertical difference between the upper reservoir and the level of the turbines is known as the head. The water falling through this head gains kinetic energy which it then imparts to the turbine blades. Hydroelectric plants have the ability to start up quickly and the advantage that no losses are incurred when at a standstill. They have great advantages for generation to meet peak loads at minimum cost, working in conjunction with other electric generating plant stations.

A recent method of obtaining the advantages of a hydro plant where suitable water supplies are not available is by the use of pumped storage. This consists of an upper and a lower reservoir and turbine-generators which can be used as motor-pumps. In this method, the upper reservoir can be used during peak periods for power generation. During low demand periods, electricity can be used to drive generators which will pump water from the lower reservoir to the upper so that it may again be used during peak load periods.

C. Energy Conversion Employing Steam

The combustion of coal or oil in boilers produces steam at high temperatures and pressure which is passed to steam turbines. Oil has economic advantages when it can be pumped from the refinery through pipelines directly to the boilers of the generating station. Another source of energy which is progressively being used in the production of steam for turbines is nuclear fission.

The steam power-station operates on the Rankine cycle modified to include superheating, feed-water heating and steam reheating. Increased thermal efficiency results from the use of steam at the highest possible pressure and temperature. Also, for turbines to be economically constructed, the larger the size the less the capital cost. As a result, turbogenerator sets of 500 MW and over are being used. With steam turbines of 100 MW capacity and over, the efficiency is increased by reheating the steam after it has been partially expanded by an external heater.

Despite continual advances in the design of boilers and in the development of improved materials, the nature of the steam cycle is such that efficiencies are comparatively low and vast quantities of heat are lost in the condensate; however, great advances in design and materials have increased the thermal efficiencies of steam stations to over 40 percent. These low steam cycle efficiencies have resulted in much research effort into other means of producing electricity notably by fuel cells and magnetohydrodynamical methods.

D. Gas Turbines

The use of the gas turbine as a prime mover has certain advantages over the steam plant, although with normal running i is less economical to operate. The main advantage lies in its ability to start and take up load quickly. Hence, the gas turbine is coming into use as a method for dealing with the peaks of the system load. A further use for this type of machine is as a synchronous compensator to assist with maintaining voltage levels. Even on economic grounds it is probably advantageous to meet peak load needs by starting up a gas turbine from cold in two minutes time rather than running a spare steam plant continuously.

The installation consists of a turbine, combustion chamber and a compressor driven by the turbine. The compressed air is delivered to the combustion chamber where continuous combustion of the injected fuel oil is maintained. The resulting hot gases then drive the turbine.

E. Magnetohydrodynamic (M.H.D.) Generation

Whether the fuel used is coal, oil or nuclear, the result is the production of steam which then drives the turbine. Attempts are being made to generate electricity without the prime mover or rotating generator. In the M.H.D. method, gases at 2500° are passed through a chamber in which a strong magnetic field has been created. If the gas is hot enough, it is slightly electrically conducting and constitutes a conductor moving in the magnetic field. An e.m.f. is thus induced which can be collected at suitable electrodes.

F. Nuclear Power

Nuclear fission takes place when a free neutron strikes the nucleus of a fissile material such as Uranium-235. On impact, the nucleus splits into two particles, releasing energy which is manifested as heat. In this process, some of the new neutrons released collide with other fissile nuclei which also split and a chain reaction is set up. The plant containing the fissile material is called a reactor or pile. The reactor produces heat which must be converted into electrical energy via a heat exchanger, turbine and generator.

There are a number of versions of the reactor in use with different coolants and types of fissile fuel.

G. Solar Power

Solar power undoubtedly will become a viable technology of the future. The basic idea of a solar power plant is to collect solar radiation and use it to convert water to steam which will be used as the working fluid. These plants can be used to produce great amounts of electricity or could be used to produce power for areas such as isolated small towns, industries and military installations. This is one technical area which has received serious attention and support by ERDA.

H. Other Energy Sources

There are some other sources for energy to make power which are not included in this lecture. They are as follows:

(1) Ocean Tides and Waves
(2) Winds
(3) Solar Rays
(4) Terrestrial Heat (Geothermal)

References and Suggestions for Further Reading

(1) Kramer, A. W. A Power Plant Primer. Barrington, Illinois: Technical Publishing Company, 1954. ($1.00, Zip 60010)
(2) Weedy, B. M. Electric Power Systems. 2nd ed. John Wiley & Sons, 1972.
(3) Wolfe, R. "Techniques for Solar Power Production." Unpublished term paper for E. E. 155.2, 1977. (Instructor: Paul Wang)

LECTURE III: ELECTRICAL POWER TRANSMISSION, DISTRIBUTION AND VARIABLE LOAD PROBLEM

A. Nature of Transmission and Distribution Systems

Transmission is the bulk transfer of power by high voltage links between main load centers. Distribution, on the other hand, is mainly concerned with the conveyance of this power to consumers by means of lower voltage networks.

Generally, a power system is a complex interconnection of generating plants through a network of transmission lines and distribution systems. The synchronous generators and prime movers normally have to be controlled through voltage regulators and speed governors in the plants and the network of transmission lines with connected loads. There are large amounts of switching equipment, protective devices, and communication and instrumentation systems.

B. Industrial Production, Large Office Buildings and Power Generation

Most of the perplexities and complexities of modern power plant operation arise from the inherent variability of the load demanded by the users. The industrial managers and large office building executives have to realize that their power plant is an important branch of their production process. <u>The power plant is not completed until the instant it</u>

is needed, and then only in quantities exactly equal to the instantaneous demand. There is no simple way to warehouse an extra supply of kilowatt hours against some future period of extraordinary demand, yet it is certain that such a period will occur, for it is rare indeed that a power demand is uniform.

C. Ideal and Realized Load Curves

The ideal load from the standpoint of equipment needed and operating routine, would be one of constant magnitude and steady duration. Such an ideal load is shown in Figure III-1. The cost to produce an elementary area of this load curve (i.e., one kilowatt hour) could be from 1/2 to 3/4 of that to produce the same unit under the more frequently realized condition illustrated in Figure III-2. The actual load curve departs far from this ideal.

Industrial processes and domestic uses impose highly variable demands upon the capacity of the plant. For example, Figure III-3 might represent the domestic demands of two adjacent residences. There is no great similarity between them. However, as the number of connected customers increases, the effect of individual differences is submerged to the general use conditions of the community. (see Figure III-3A)

Figures III-4 and III-5 show the Carolina Power and Light Company daily profiles for their peak summer day and peak winter day. Of course, these are system loads which represent the composite curves of many different kinds of loads. It can be readily realized that a tremendous amount of waste exists in keeping power available during wide perturbations of loads.

Unusual conditions of service reflected in load curves are as follows:

(1) Sudden thundershowers which darken the skies (Heavy lighting demand.)

(2) Daylight saving creates an abnormal offset of one hour in the time at which the peak occurs.

(3) Holiday crowds

(Definition 1) - Load Curve: The operating data of demanded load plotted against time sequence. (KW versus time) The sequence being the 24 hours beginning with midnight.

(Definition 2) - Load Duration Curve: (Very useful in financial studies.) Is obtained from the same data as the daily load curves. The number of hours during which 1000 KW, 2000 KW, 3000 KW, etc., is demanded is recorded from the daily load curves, then totaled for the year (8760 hours).

The energy output of a single power plant is subdivided and sent to thousands of individual customers and is diagrammed as follows:

Power Plant

Substation A		Substation B	
Feeder A	Feeder B	Feeder A	Feeder B
...	...	...	...
Customers	Domestic	Industrial	Business etc.

References and Suggestions for Further Reading

(1) Morse, Frederick T. Power Plant Engineering. 3rd ed. D. Van Nostrand Company, Inc., 1953.

(2) Weedy, B. M. Electric Power Systems. 2nd ed. John Wiley & Sons, 1972.

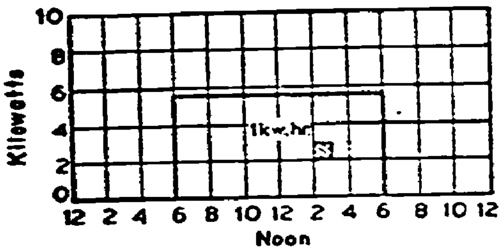

Fig. III-1 (a) Ideal Load

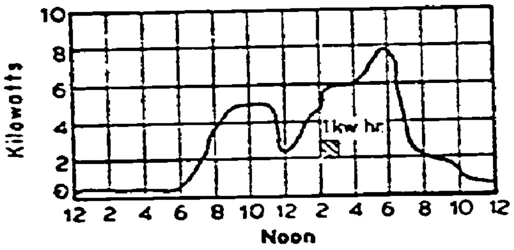

Fig. III-2 (b) Realized Load

Ideal and realized load curves compared. Note: Each represents the same quantity of energy.

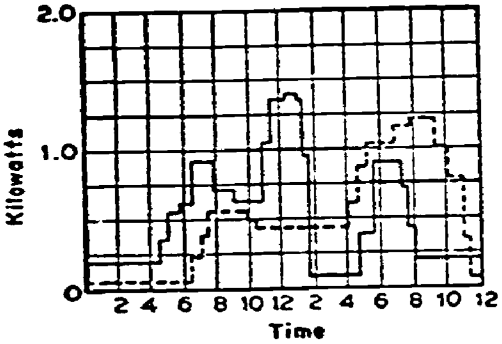

Fig. III-3 Individual customers' load curves.

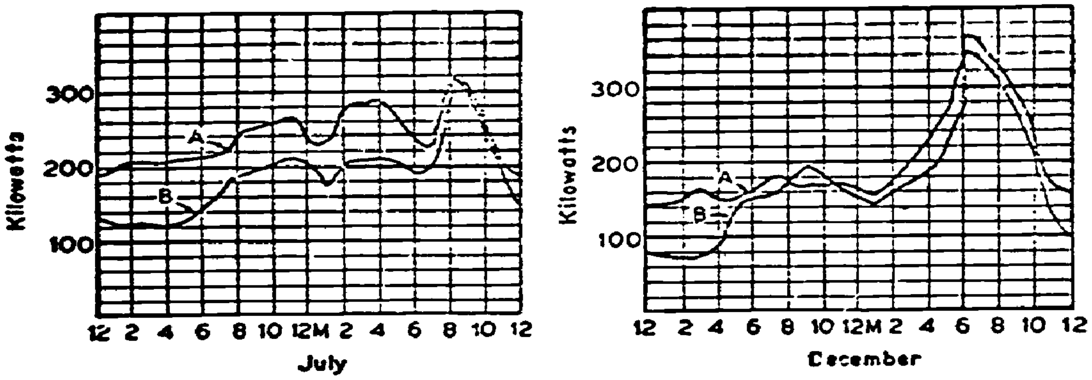

Fig. III-3A A comparison of the actual average load curves of two towns A and B of about 4000 population each, situated 45 miles apart, and having similar community life. Both are served by municipally owned and operated Diesel plants.

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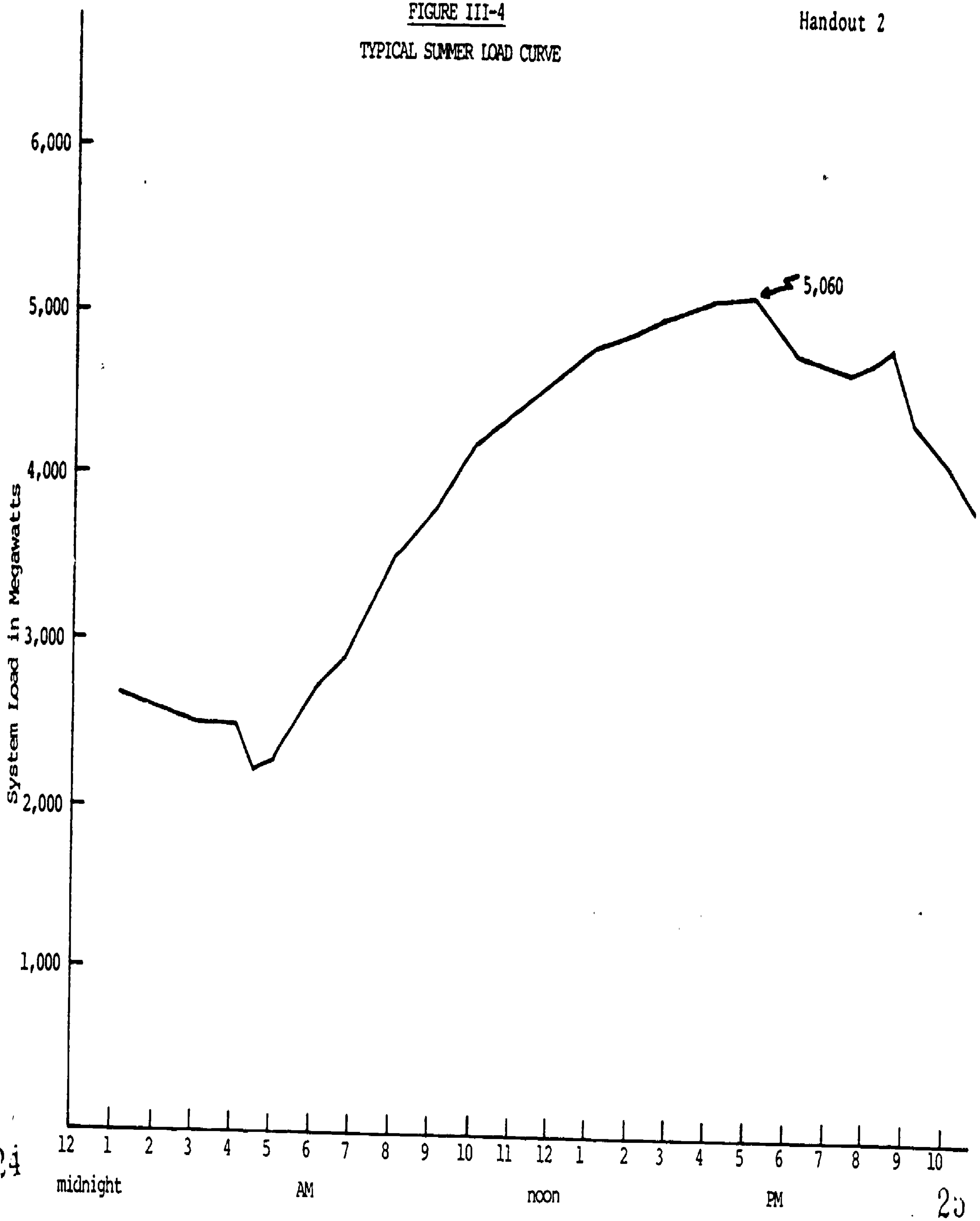
Handout 2

FIGURE III-4

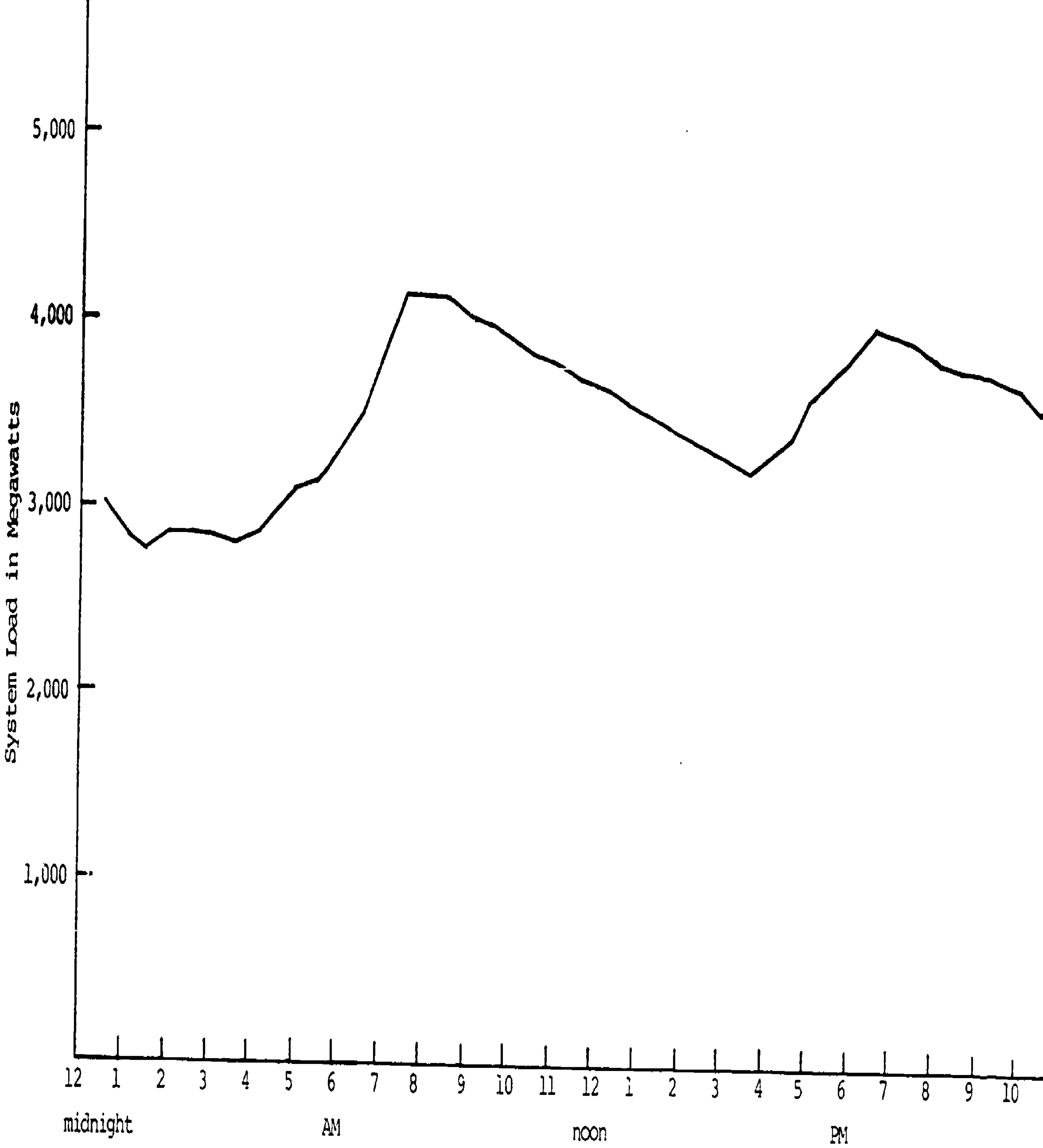
TYPICAL SUMMER LOAD CURVE



Handout 3

FIGURE III-5

TYPICAL WINTER LOAD CURVE



A. A Brief Profile of the Energy Situation

Energy use in the United States

in 1970: 29.7 million barrels per day

in 1975: 40 million barrels per day

in 1980: 80 million barrels per day (including conservation measures; estimated by AEC)

Energy uses may be classified into three categories:

(1) Industrial ——· drives, steam, process heat, productions, etc., 39.44%

(2) Residential and Commercial 29.88%

(3) Transportation 30.67%

(Computed from 1970 U. S. Energy Flow data of ERDA.)

It is clear that a 10% reduction in residential and commercial use of scarce energy would result in a savings of 2.4 million barrels per day in 1980, which certainly is an attainable goal.

B. The Nature of the Electrical Utility Industry

An electrical utility industry is a capital intensive industry, which means that a larger portion of the revenue dollar goes toward cost and depreciation of capital than toward wages and benefits.

Sales of electricity to ultimate consumers are divided as follows, according to 1950 data:

(1)	Industrial	48.2%
(2)	Residential	26.2%
(3)	Commercial	17.6%
(4)	Others	8%

Included in the customer's bill must be an element of charge which will pay for the plant and system investment, one which will pay for the labor and raw materials used, and one which will reimburse the investors with the profit which applied capital is expected to produce. From a business viewpoint, the supply of electric energy is public service, and the industry is possessed of those characteristics which mark the so-called "public utility." The electric energy industry is characterized by elaborate and expensive distribution systems, and by a comparatively large ratio of capital outlay to labor cost.

Many utilities are publicly owned and operated, but the majority are private businesses. The electric service industry operates under monopoly conditions by reason of the long-term franchises granted to the individual companies. In nearly all the states, government authority, acting through public service (or corporation) commissions, has assumed a degree of control over privately owned public service corporations in the public interest, so that excessive profits will not be made by companies which are free from the restraint of normal competitive business conditions. (State Commission Jurisdiction and Regulation of Electric and Gas Utilities, and Federal Power Commission). These commissions do not have final authority and sometimes have to argue their decisions before higher courts.

C. Rates

The variable load problems, presented in Lecture III, serve to show that the cost of producing a KWH is not the same for all users but increases with increasing departure of the customer's load conditions from the ideal. These facts make the establishment of suitable rates a task of some magnitude.

The rate of charge for electrical energy should satisfy the following conditions: fairness - taking full account of the variable conditions of the customer's demand; simplicity - easy to compute; and cost - the following elements enter into the cost of electrical energy to the consumer: fixed element, energy element, customer element and investors' profit.

In 1974, typical disbursement of utility company revenues were spent in this manner: fuel costs, 41%; cost and depreciation on capital, 28%; taxes, 15%; wages and benefits, 8%; material, purchased power, etc., 8%. (See p.26)

D. The Fixed Element

(1) Capital cost of the power plant
  (a) Real estate
  (b) Building and equipment
  (c) Cost of installation
  (d) Engineering fees
(2) Capital cost of primary distribution system
  (a) Cost of right of way
  (b) Cost of line
  (c) Cost of substations
(3) Interest, taxation and insurance rates
(4) The rate at which capital cost is written off to depreciation and obsolescence. Salvage values.
(5) Management cost
(6) General maintenance

E. The Energy Element

The components of the energy cost are:

(1) Cost of fuel
(2) Cost of labor
(3) Cost of water for boiler feed, condensers, cooling and house service
(4) Oil, waste and supplies
(5) Maintenance

Labor is a small part of the cost of a KWH.

Factors that have to do with <u>variable load</u> element.

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(1) Extent of reserve capacity carried
(2) The operating status of the plant considered as a member of a power system
(3) Being in "readiness to serve."
(4) Amount of starting, stopping, and banking of power units that is necessary

F. The Customer Element

Cost of the secondary distribution system:

(1) Depreciation, interest, taxes and insurance
(2) Line and transformer maintenance and inspection
(3) Labor cost of collecting revenue
(4) Cost of franchise
(5) Publicity

G. The Investor's Profit

The public service plant is expected by those who have invested funds in its development to produce a profit.

The relatively safe investments in public utility companies are restricted to 8% or less by state regulation. An examination of state commission regulation practices discloses that the approximate rate of return prescribed in most cases is between 5% and 6 1/2%.

H. Major Factors Affecting the Overall Cost of Electricity Today

(1) Fuel costs

(2) Prime interest rate

(3) Inflation

(4) Safety and environmental standards

(5) Labor costs

Most widely used in generation of electrical power are fossil fuels.

The price of coal increased from an average of $12.56 per ton in 1973 to an astounding $27.64 per ton in 1974. Government safety and environmental regulations represented the major portion of this cost increase. Almost 60% of the fossil fuel generators still use coal.

The price of No. 6 fuel oil (2nd most popular fossil fuel in electrical generation) also took similar price jumps between 1973 and 1975. These increases were mainly influenced by OPEC pricing policies which cannot be predicted nor controlled by the U. S. Government.

Large amounts of capital are needed to design and construct new generating plants and new distribution facilities. Interest rates affect their costs enormously. Inflation rates of 9% to 14% per year have caused steady increases in electric utility rates.

Most electric utility companies have been spending from 10 to 80 million dollars per year for environmental and safety needs to satisfy federal standards.

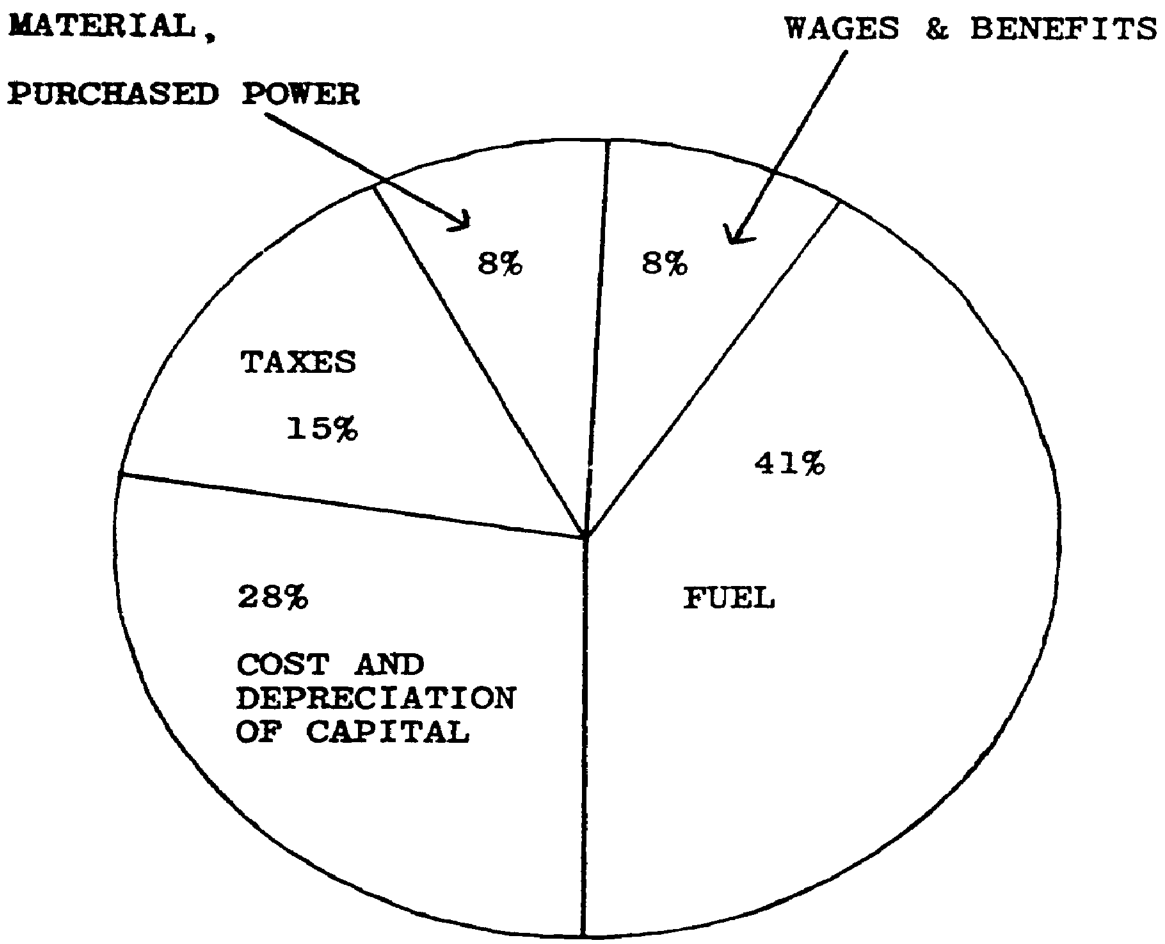
Union activity is expected to give rise to further labor cost increases over the next few years. Electrical energy costs are predicted to double or triple over the next five years.

References and Suggestions for Further Reading

(1) Eaton, W. W. *Solar Energy.* U. S. Energy Research and Development Agency.

(2) *Electrical Energy Management.* Charlotte, N. C. Process Systems Incorporated.

(3) Morse, F. T. *Power Plant Engineering: The Theory and Practice of Stationary Electric Generating Plants.* 3rd ed. D. Van Nostrand Company, Inc., 1953.



TYPICAL DISBURSEMENT

OF UTILITY COMPANY

REVENUES IN 1974

LECTURE V: METERS FOR DEMAND & CONSUMPTION MEASUREMENTS

A. Quality of the Electric Power

The quality of electric power is described by:

(1) The frequency and the limits between which it is constant,

(2) The voltage and the limits between which it is constant, and

(3) The continuity of service.

The standard system used for power transmission is a three-phase (3-Ø) system. In this system, three separate sinusoidal voltages are generated with equal magnitudes but displaced in time from one another by 120°. This 3-Ø arrangement has to be dealt with throughout the system.

B. Three-Phase Systems

Large 3-Ø electrical machines are more efficient, draw less current, and are less expensive than large single-phase machines. Generation cost for 3-Ø are less.

There are two commonly used 3-Ø systems and how to measure the electrical power of these two systems is explained as follows:

(1) <u>3-Ø, 3 Wire Circuit</u> In a 3-Ø, 3 wire circuit, power measurement is accomplished with a 2-element wattmeter connected as shown in Figure V-1. The current coil connected in Line 1 provides flux proportional to the vector sum of the

currents from phases a and c; the current coil connected in Line 3 provides flux proportional to the vector sum of the currents from phases b and c. The two potential coils, connected across phases a and b, provide flux which reacts with that of the current coils to produce, in the combination of the two elements, torgue proportional to the total power of the circuit.

(2) <u>3-0, 4-Wire Circuit</u> The best choice for measuring power in a 3-0, 4-wire circuit is usually accomplished with a two-element wattmeter mechanism commonly called a 2-and-a-half element instrument, as shown in Figure V-2. In this mechanism, current coils are connected in each line but potential coils are provided for only two of the three phases. It is assumed that the voltages of the three phases are equal and symmetrical.

(3) <u>BLONDEL'S Theorem</u> "The power in a circuit of N lines can be metered by N elements with the potential circuits connected from each line to any one common point. If the common point is on one of the lines, the power can be metered by N-1 elements."

This explains the fact that a 2-stator meter is necessary for a 3-wire, 3-0 circuit and a 3-stator meter for a 4-wire, 3-0 circuit.

Referring to Figure V-3, we have Power = $e_1 i_1 + e_2 i_2 + e_3 i_3$, where e and i represent phase voltages and currents.

$i_1 + i_2 + i_3 = 0$ so $i_2 = -(i_3 + i_1)$

Hence: $P = i_1 (e_1 - e_2) + i_3 (e_3 - e_2)$

Thus, if a common point of potential is made on Line 2, add line-to-line potentials used with line currents, a 2-stator meter will correctly measure a 3-wire, 3-0 circuit.

C. Electric Power, Energy and Demand

Let us begin our discussion with some definitions:

(Definition 3) - Electric Energy: Electric energy or work is the total utilization of electricity over a period of time.

(Definition 4) - Electric Power: Electric power is the rate at which electrical energy is used.

(Definition 5) - Watts: The basic unit of measurement for electric power is the watt.

(Definition 6) - Power Factor: The meaning of power factor is illustrated in Figure V-4. The power factor is automatically included in the measurement because the torque developed in the wattmeter is always proportional to the product of the instantaneous values of current and voltage. Consequently, the instrument gives a true indication of the power.

(Definition 7) - Kilowatt-Hour (KWH): This is the product of the watts of a circuit multiplied by the total time, in hours, during which electricity is used in the circuit.

(Definition 8) - Demand: Kilowatt demand is defined as the kilowatt load averaged over a specified interval of time, as shown in Figure V-5. The equivalency of the 2 areas shows that the demand for the interval is that value of power which, if held constant over the interval, will account for the same consumption of energy as the real power.

The consumer's watthour meter is read (usually) once a month. The demand meter can measure the maximum demand for power during the month. There are 2 types of demand meters to be introduced here.

D. Integrating Demand Meter - This is the most widely used type of demand meter. It is essentially a watthour meter with a timing element added. The meter sums up the kilowatt-hours of energy used in a specific time interval -- usually 15, 30, or 60 minutes, and sometimes even 5 or 10 minutes. The demand meter thus indicates energy per time interval, or average power, expressed in KW.

E. Lagged Demand Meter - The lagged (thermal) type demand meter's pointer is made to move according to the temperature rise produced in elements of the meter by passage of currents. The lagged meter responds to load changes in accordance with the laws of heating and cooling, as in general does electrical equipment. The demand interval for the lagged meter is defined as the time required for the temperature-sensitive device to achieve 90 percent of full response when a steady load is applied.

F. An Example of Calculation of Demand KW

Let us assume a very simple facility consisting of three electrical loads. Suppose the power company in the area is free to choose three demand measurement intervals, namely 15 minute intervals, 30 minute intervals and 60 minute intervals. For a 60 minute load record, one can see the average KW per interval varies quite a bit as shown in Figure V-6. This is the reason why a power company can raise the cost of the electrical power by changing the interval of demand measurement. (This will be clarified in the next lecture.)

The following load configurations were selected to show conveniently the impact on consumption and demand (See Figure V-7.)

(1) Load sizes:

Load A = 10 KW
Load B = 20 KW
Load C = 30 KW

(2) Load states:

First 10 minutes ----- Loads A and C
Next 5 minutes ----- Load A only
Next 5 minutes ----- Load B only
Next 5 minutes ----- All loads
Next 10 minutes ----- Loads B and C
Next 5 minutes ----- Load B only

Next 5 minutes ----- Loads A and B

Last 5 minutes ----- Loads A and C

Consider now the consumption impact. The equation for determining the consumption is:

$$\text{KWH} = \frac{\text{KW X Minutes On}}{60} = \frac{1}{60} \text{ (KW - Minutes On)}$$

The kilowatt hour graph shows the KWH consumption for this sixty minute interval. The total KWH for this problem is 33.33 KWH as shown in Figure V-8. The instantaneous peak demand was 60 KW and it occurred only once for a duration of 5 minutes, out of 60 minutes. However, the power company would not charge for a 60 KW demand in this situation. The method used by most power companies for measuring demand over a fixed time interval is to accumulate the KWH during the interval and multiply this accumulation by the number of intervals in one hour.

The equation for calculating average KW per interval follows:

$$\text{Ave. KW (per interval)} = \frac{\text{(KWH/interval)}}{\text{(No. Minutes)/interval}} \text{ X } 60$$

$$= \frac{\text{KWH/interval}}{\text{No. of hour/interval}}$$

In our case;

$$\text{Ave. KW/interval} = \frac{\text{33.333 KWH/interval}}{\text{1 hour/interval}} = \text{33.333 KW}$$

Hence, the bill from power company would be only 33.333 KW instead of 60 KW. In actual practice, the demand section of the meter is geared to a 1:1, 2:1, 4:1, or 12:1 ratio corresponding to intervals of 1 hour, 30 minutes, 15 minutes or even 5 minutes.

A dry contact closure occurs each time a certain number of KWH has been recorded on the consumption meter. The power company will give you your meter scale factor.

References and Suggestions for Further Reading

(1) Energy Management Seminar. Charlotte, North Carolina: Process Systems Incorporated.

(2) Manual of WATTHOUR Meters. General Electric, Inc. GET-1840C.

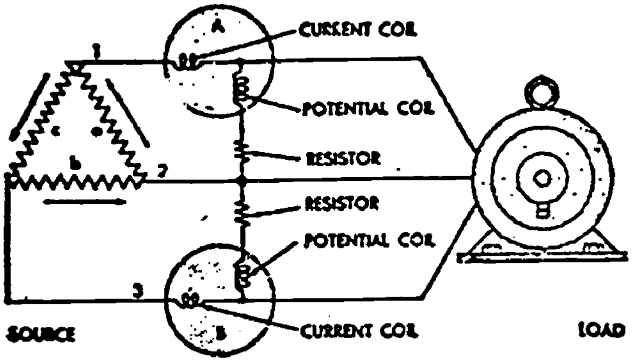


Fig. V-1. *Simple three-phase, three-wire circuit with two-element wattmeter measuring load*

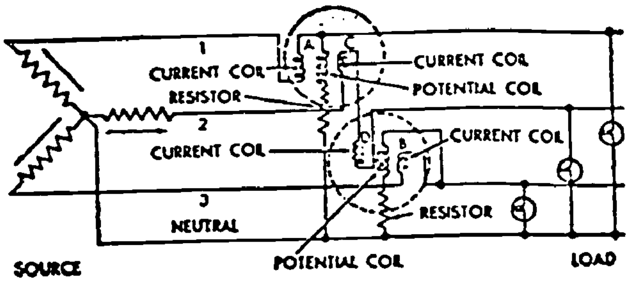


Fig. V-2. *Simple three-phase, four-wire circuit with modified two-element wattmeter measuring load*

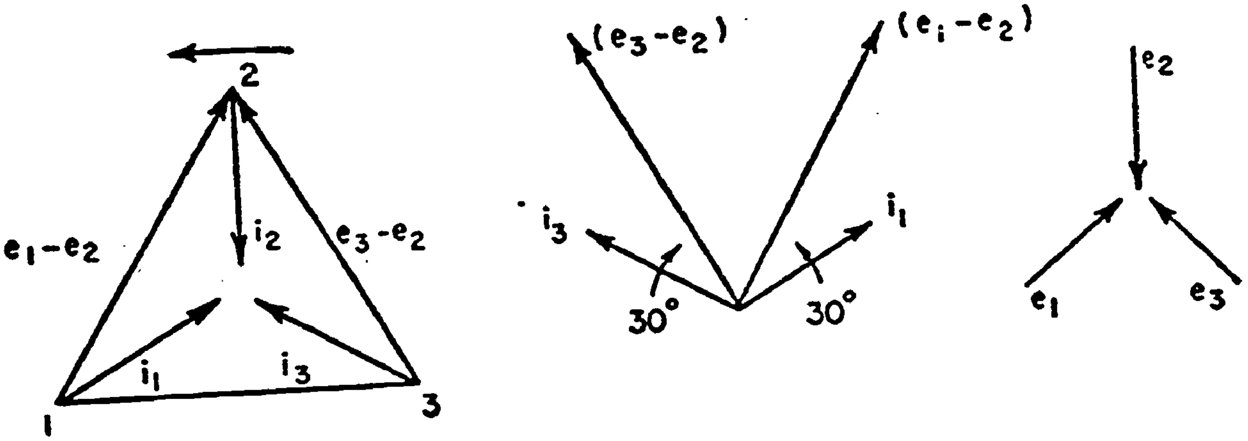
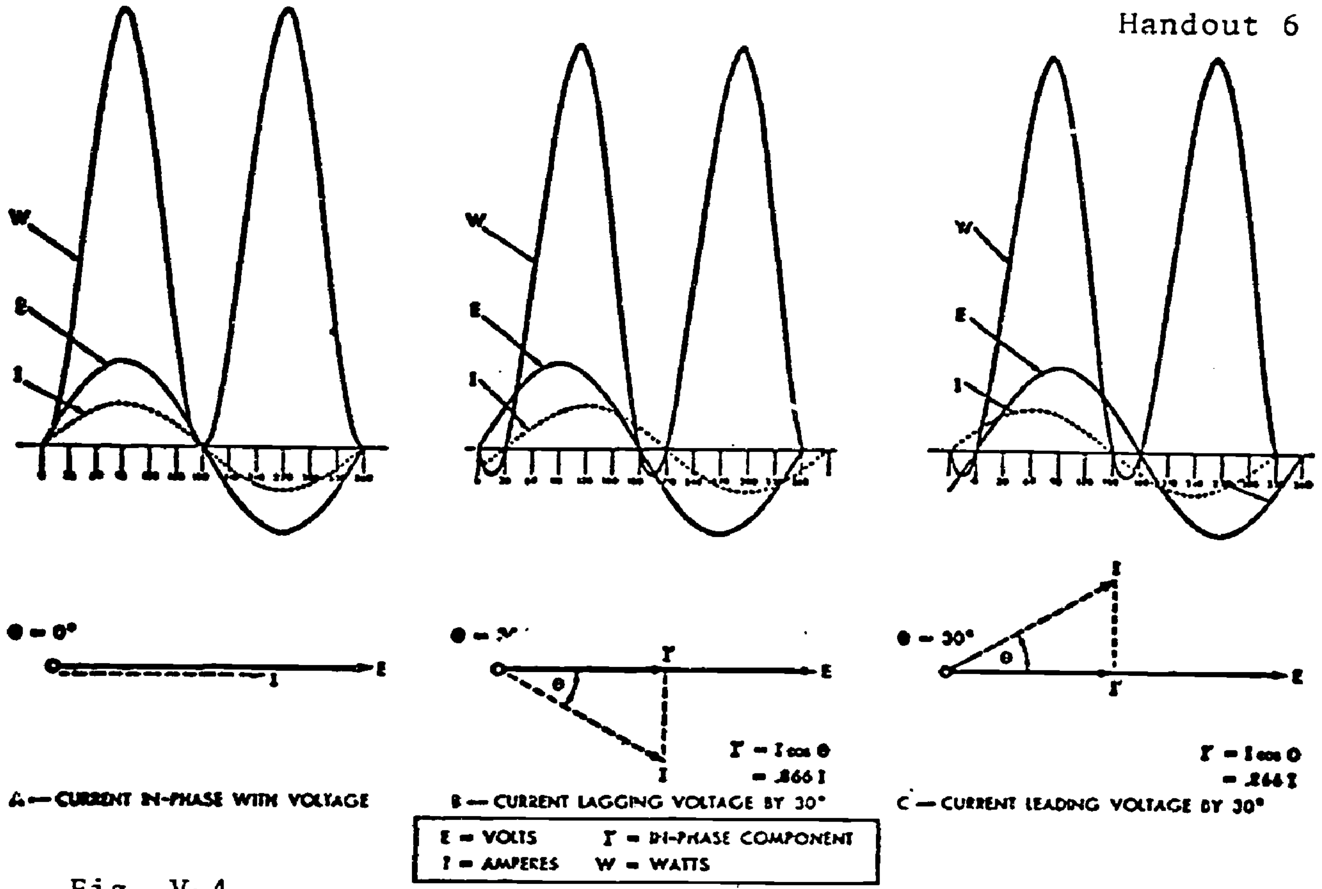


Fig. V-3. *Vector proof of Blondel's Theorem.*

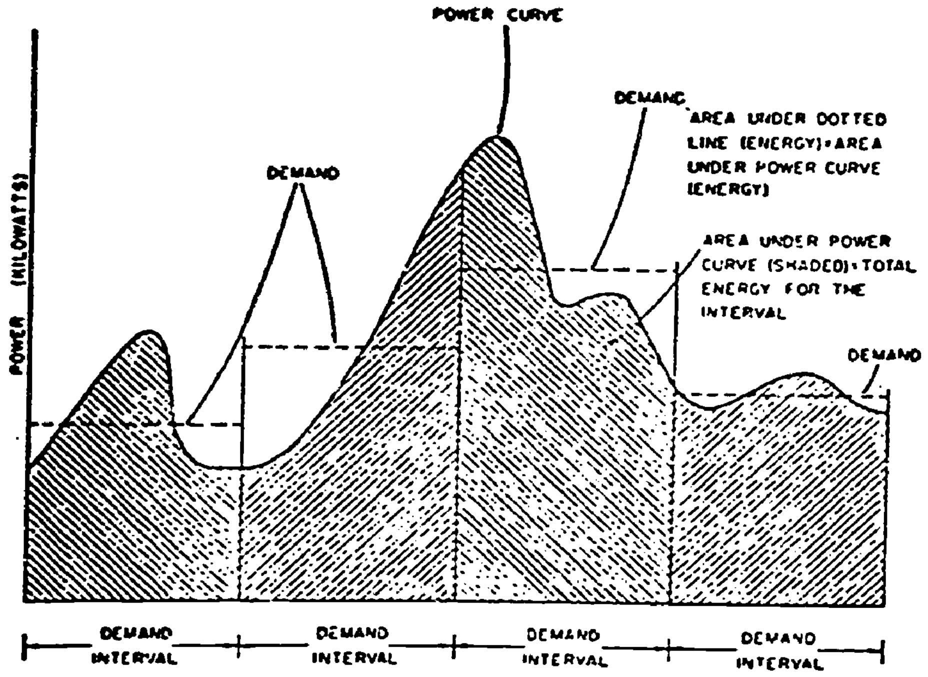


A — CURRENT IN-PHASE WITH VOLTAGE

B — CURRENT LAGGING VOLTAGE BY 30°

C — CURRENT LEADING VOLTAGE BY 30°

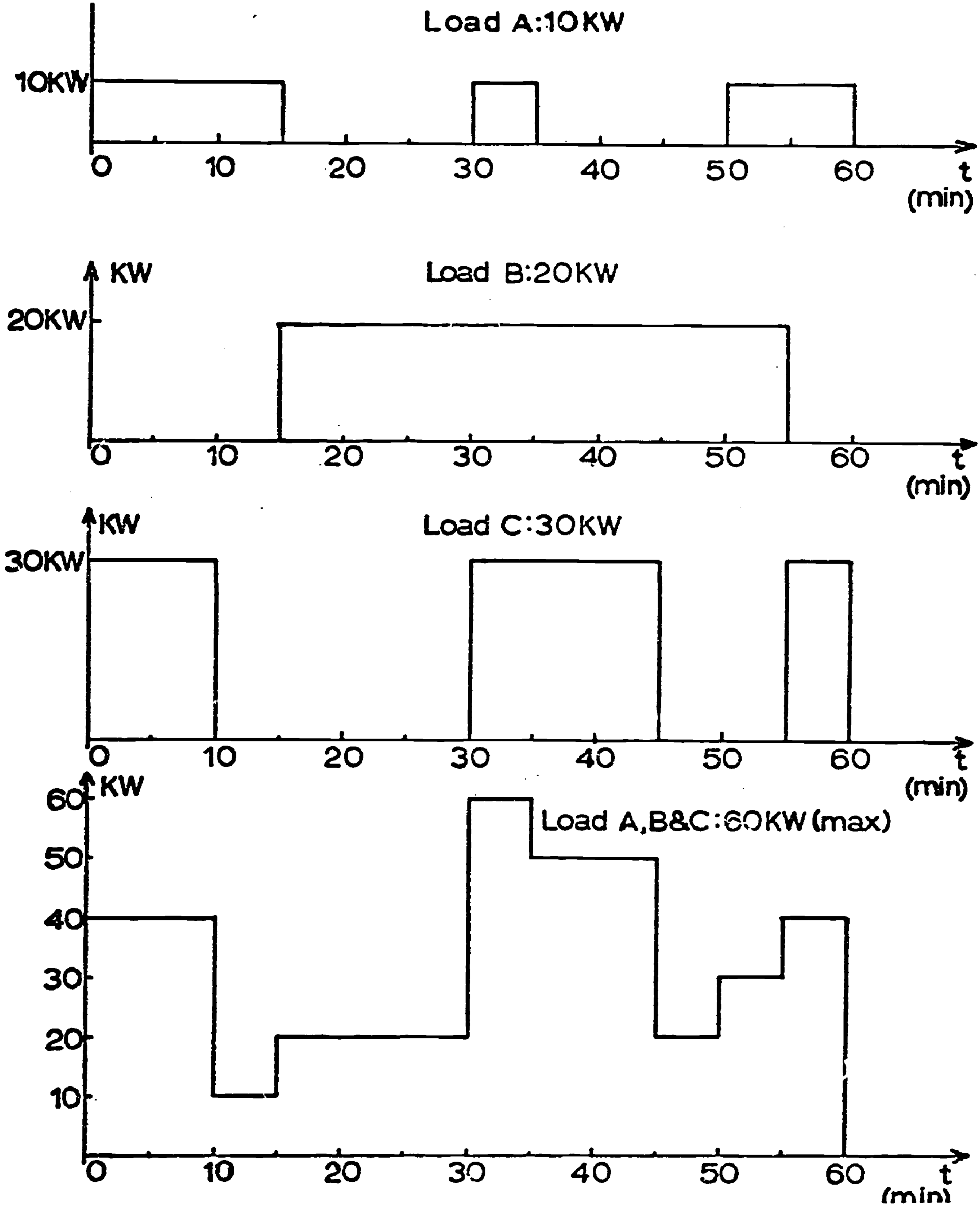
Fig. V-4. Curves and vector diagrams showing the relation between voltage, current, and power in alternating-current circuits: A) at unity power factor; B) with lagging power factor; C) with leading power factor



DEMAND FOR EACH INTERVAL = AVERAGE POWER OVER THE INTERVAL.

Fig. V-5. Power curve over four successive demand intervals

GURE V-6
LOAD PROFILES



Handout 8

FIGURE V-7
AVERAGE DEMAND PER INTERVAL

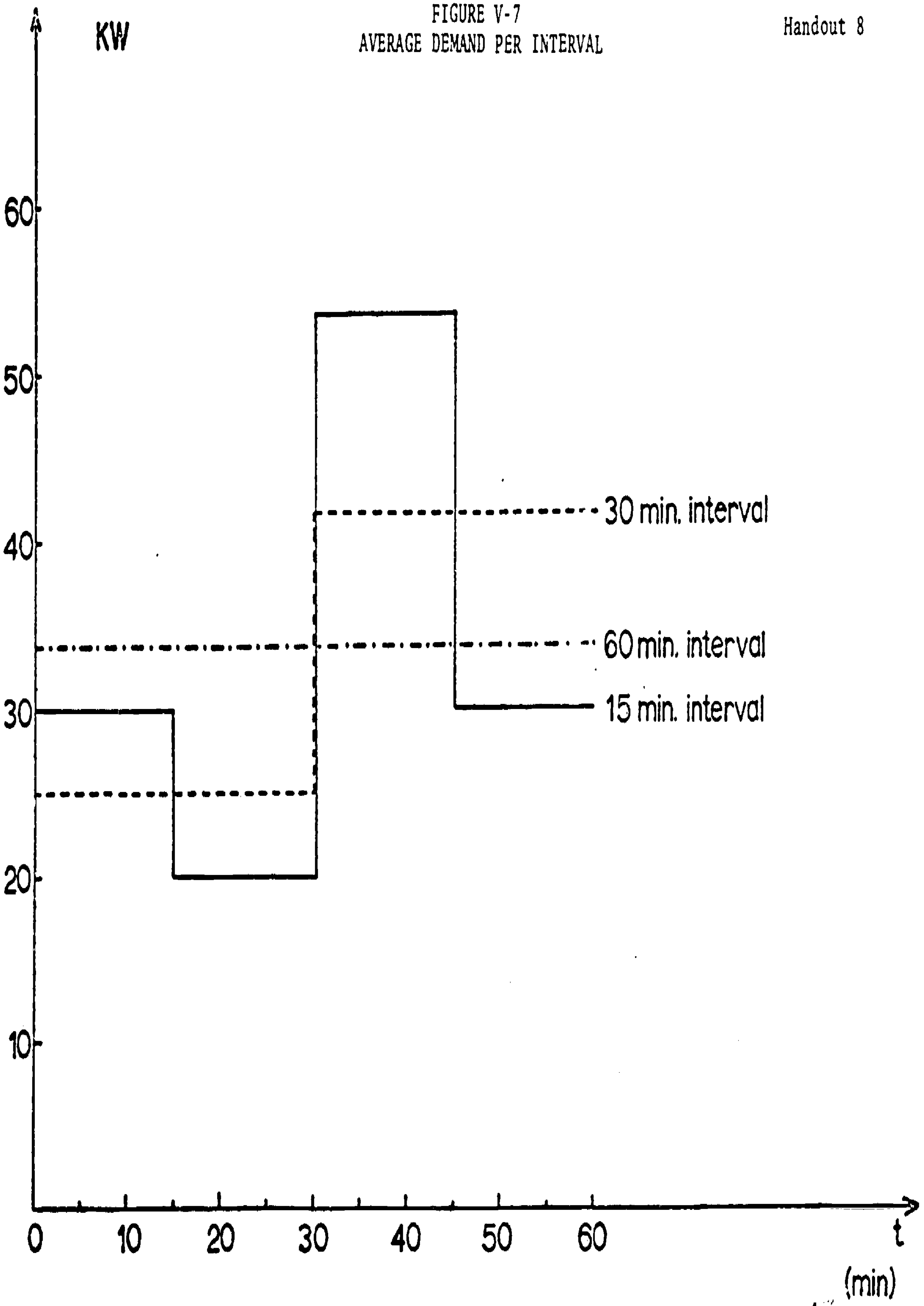
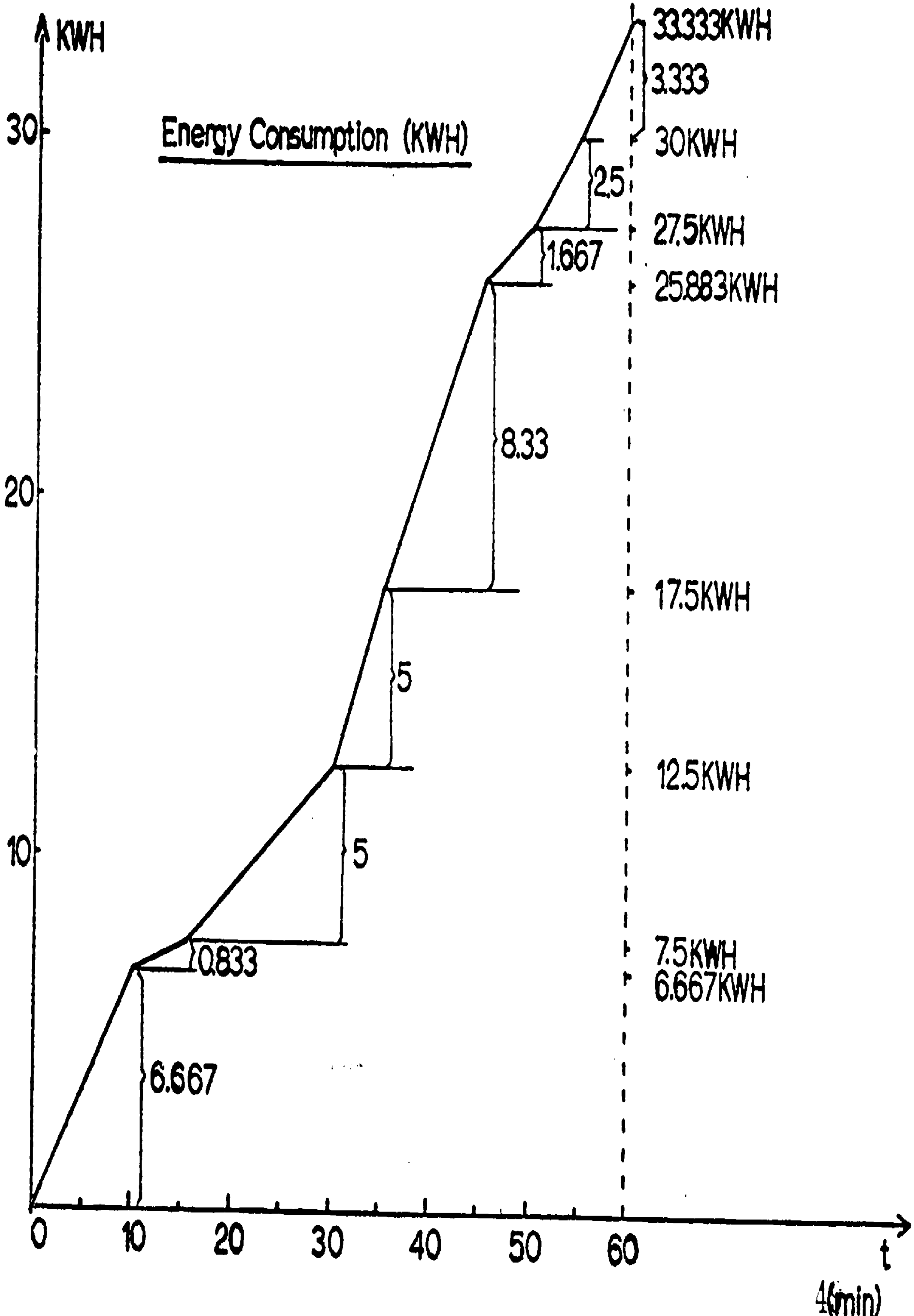
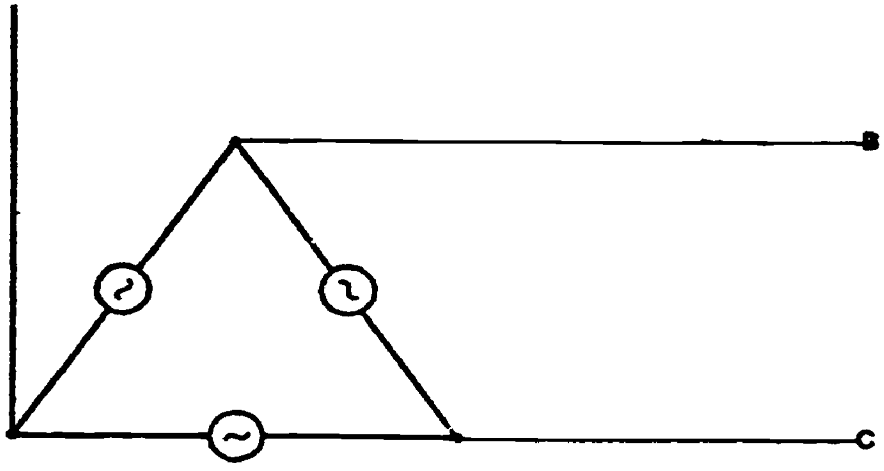
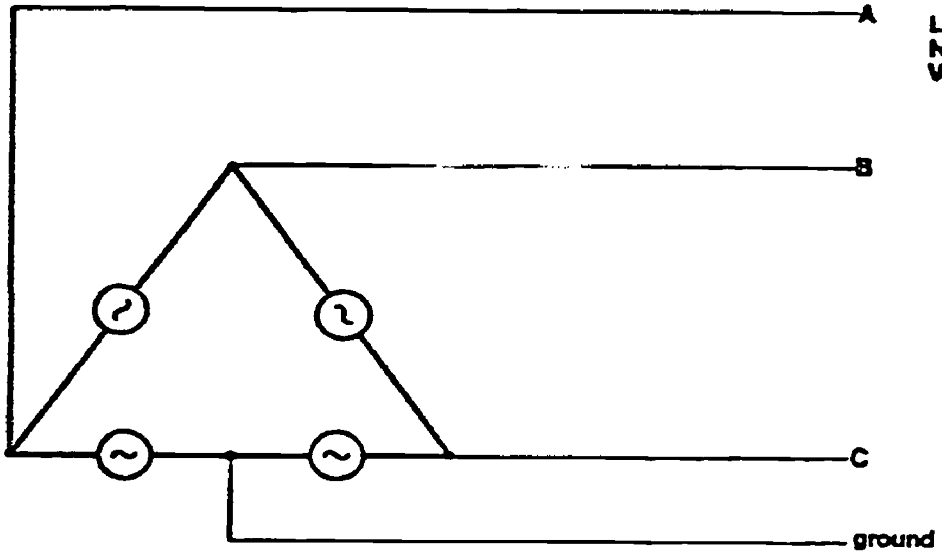


FIGURE V-8


KWH
Energy Consumption (KWH)
30
20
10
33.333KWH
3.333
30KWH
2.5
27.5KWH
1.667
25.883KWH
8.33
17.5KWH
5
12.5KWH
5
7.5KWH
6.667KWH
0.833
6.667
0
10
20
30
40
50
60
t
(min)

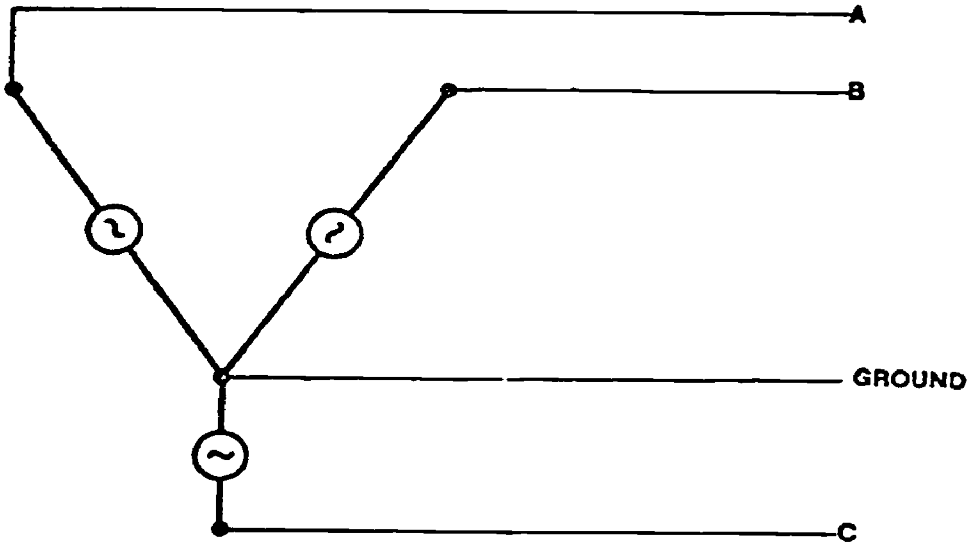


3Φ DELTA SYSTEM, 3-WIRE



Line Voltage AB, AC, BC
Note:
Voltage from line to ground = $\frac{\sqrt{3}}{2}$ x Line Voltage

3Φ DELTA SYSTEM, 4-WIRE



Line Voltage AB, AC, BC
Phase Voltage A ground, B ground, C ground
Note:
Line voltage = $\sqrt{3}$ phase voltage

3Φ WYE SYSTEM, 4-WIRE

LECTURE VI: ELECTRICAL LOADS MANAGEMENT

We have discussed in previous lectures about load profiles, especially from the utility's point of view. The increasing importance of the optimal loads management will be introduced in this lecture.

A. Power Factor and Power Cost

When the power factor is less than unity, the kilovolt-amperes are greater than the KW. The lower the power factor, the higher the KVA rating of equipment must be in proportion to KW delivered. Higher KVA produces a proportionately high temperature rise in the utility's equipment for every KW of useful power. Therefore, a low power factor means that the utility will have to install proportionately larger and heavier equipment to supply its consumers. For this reason, most utilities, in addition to billing on the basis of demand and energy, include in their rate schedules charges to larger consumers for excessively low power factor.

B. System Off-Peak Loads

The importance of a consumer's maximum demand depends partly on its time of occurrence in relation to the peak load of the power system as a whole. System peaks may be seasonal, daily, weekly, yearly, or a combination of these. In the winter, for example, lights in houses, stores, offices, and factories are turned on in late afternoon, before electric power used in manufacturing is shut off for the night, thus creating a daily peak. A year-round Monday-through-Friday peak may occur when motors are started up at the start of the first shift in a large number of factories. In resort areas there will be holiday peaks. Sometimes, unpredictable peaks may occur, as when some event of national importance brings large numbers of people to their television sets during a period when the system is already loaded heavily.

The importance of time of occurrence of peak loads has led utilities to encourage off-peak loading to improve the system load factor. A typical example is domestic water heating, which has become an important and desirable off-peak load. The water heater, being a storage-type device, can be controlled so that all heating is done during off-peak period and the water heater is turned off at times when other loads are causing peaks.

Strictly speaking, more should be done in this area and that is exactly the reason why we need these lectures. An example of some serious research efforts in this direction can be found in the document prepared by Denning. (p.56, Reference 1)

C. Matching Utility Output to Customer Demand

The reasons for the higher power bills for consumers are:

(1) The increased capital costs of system expansion.

(2) Higher operational costs.

(Definition 9) - Load Management: To control or shift the peak electric demand in order, possibly, to reduce fuel requirements and to reduce the need for system expansion.

(Definition 10) - Load Management (by Edison Electric Institute): The design of energy supply facilities to meet customer load as well as the control of a utility's load shape.

To meet the improvement of energy supply facilities, utilities have employed various means of supply management. Examples:

(1) Installation of pumped-storage hydro projects.

(2) The use of seasonal diversity arrangements with interconnections to neighboring utilities.

(3) The utilization of other types of contractual power arrangements with interconnected utilities.

Results: These standard procedures can postpone or preclude the installation of new generating capacity and thereby optimize the overall system supply management.

(Definition 11) - Load Management Systems:

The arrangements which provide for load interruption (or load shedding) at the utility's discretion can be effective.

Direct Control: The utility controls end-use devices such as water heaters by means of supervisory control.

Indirect Control: Load shifting is left to the discretion of the customer by the provision of price incentives - such as preferential rates for off peak use.

In addition to these utility-sponsored load-management programs, many large commercial and industrial customers are investigating the possibility of using computer-controlled equipment to monitor and regulate their own electric usage. Perhaps a new definition is warranted. For certain types of industrial processes that are heavy power consumers, process management to control peak demands has been a standard practice for some time. There are ongoing and experimental programs, and other techniques being considered for load-management control.

D. Impact on Utility Companies in the Future

An increasing degree of control over load shape will not only help utilities to plan generation resources to meet the load, but also may have an opportunity to modify the load shape and load characteristic to meet the characteristics of a particular mix of generation resources.

Field Test: Field testing programs must be conducted over a period of several years to provide a significant data base on which to predicate accurate impact predictions.

E. Examples of Load Management Projects

(1) Detroit Edison Company - It installed about 200,000 radio-controlled switches on customer water heaters in 1968.

(2) Buckeye Power - 40,000 (same type as above)

(3) New England Electric System - has 93,000 time clock controlled water heaters and 50,000 double dial meters.

(4) Northeast Utilities System - about 102,000 electric water heaters on either time clock or radio control.

(5) Tucson Gas & Electric and Sacramento Municipal Utility District - Both utilities, have adopted a summer rate differential.

(6) California and Wisconsin - Both states recently established "Life Line" or flatten rate schedules in their utility rate schemes.

Historical Note: Load management is not a new idea. In fact, in Europe it dates back to the post-World War II era, when the concept came into practice in the face of serious electric power shortages.

There is hardly a consensus on the definition of "load management." We present here the latest definition from ERDA.

(Definition 12) (ERDA) - The role of load management is to improve the efficiency of energy systems; shift fuel dependency from limited to more abundant energy resources, reduce reserve requirements of generation and transmission capacity, and improve reliability of services to essential loads.

In the eyes of a utility expert, load management's entire objective is to save generating capacity. On the other hand, the entire objective of the customer is to pay a lower bill to utility companies.

The newest technique in load management is two-way communications systems. These systems are bringing automation in power distribution closer to realization through automatic and remote reading of kilowatt hour meters, and through their ability to monitor and control power distribution networks.

References and Suggestions for Further Reading

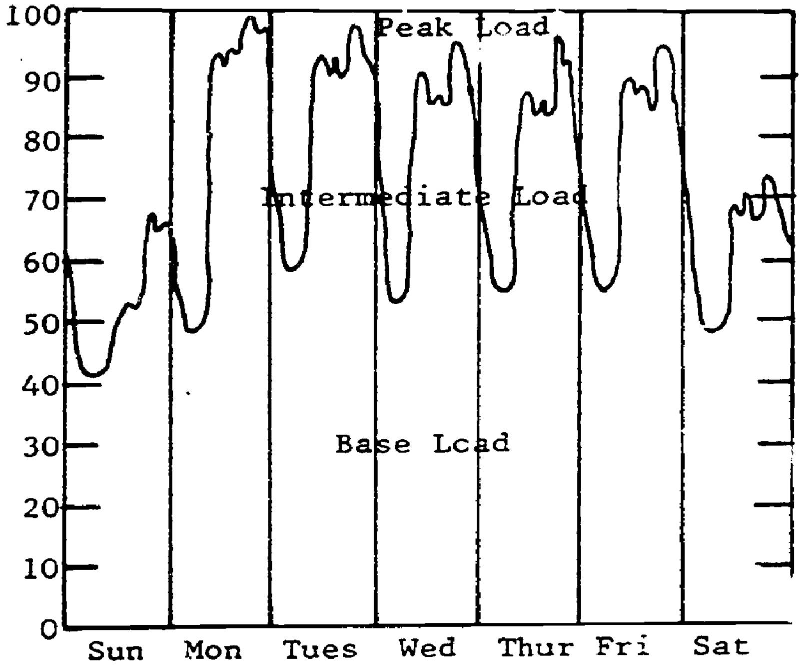
(1) Denning, Carsie K. "Thermal Storage to Achieve Off-Peak Electrical Loading for the Heating and Cooling of School Buildings," Research Proposal. Division of Plant Operation, North Carolina State Board of Education, July, 1976.

(2) Friedlander, Gordon D. "Matching Utility Output to Customer Demand" IEEE Spectrum, September, 1976, pp. 50-53.

(3) Kaplan, Gadi "Two-Way Communication for Load Management" IEEE Spectrum, August, 1977, pp. 46-51.

(4) Manual of Demand Meters - Theory, Economics, Operation and Application. General Electric, Inc., GET-2327C.

TYPICAL POWER PLANT WEEKLY LOAD CURVE



LECTURE VII: THEORY OF RATES

A. Background and Requirements of a Rate

It has been mentioned that the electric utility derives its revenues directly from the customers it serves on the basis of monthly billings. The customer's meter readings are put into the rate structure and the amount due from that customer determined. From the public's standpoint, the rates should meet the following conditions:

(1) Rate schedules should be simple.

(2) Rate schedules should be uniform over large territorial areas. Persons in one community frequently are paying on one basis, and those in the neighboring community on another which is so different as to be unintelligible to the first.

(3) Direct service from producer to customer. This requires the elimination of the energy jobber, subcontractor or middleman.

(4) Distribution of costs in such a way that persons creating a desirable and relatively inexpensive type of load may enjoy the full use and benefit of electrical appliances.

Scientific electric rate-making might be said to have originated with Dr. John Hopkinson, in 1892. His rate theory was based on two charges: one a fixed annual charge per KW of maximum demand, the other a small unit charge against each KWH of energy used.

During the first half century of public electric service, many rate forms were tried, of which the following received some considerable application.

(1) Block Meter Rate: A certain specified price per unit is charged for all or any part of a block of such units, and reduced prices per unit are charged for all or any part of succeeding blocks of units, each such reduced price per unit applying only to a particular block, or portion thereof. This is now the form for the majority of residential and small commercial customers. Its principal defect is that it lacks a measure of the customer's demand.

(2) Block Hopkinson Demand Rate: A demand charge based on a maximum KW per month, plus a follow-on energy block rate.

Example:

Demand Charges	$2.40 per month per KW for the first 50 KW of maximum demand $2.00 per month per KW for the excess of the maximum demand over 50 KW
Energy Charges	5¢ per KWH for the first 1000 KWH used per month, 3¢ for the next 4000 KWH used per month and further block steps where desired.

With this rate, any size of customer can receive an equitable charge compared to other similar customers. As a demand meter is required, it is not well suited to the small residential customer.

(3) Three Charge or "Doherty" Rate. Any of the foregoing types of rates may be modified by the addition of a customer charge. When such a charge is introduced in the Hopkinson Demand rate, which consists of a customer, or meter, charge, plus a demand charge, plus an energy charge.

The principal objections to it are that the charges are in three classes and it requires two meters. It is better suited for industrial than for residential customers.

B. Special Features of Rate Schedules

Since rate limitations are prescribed by commissions and since investors in electric companies are to have a "fair" return, rates often contain clauses automatically revising the rate in the event operating costs vary. There are also special provisions of steady loads, seasonal effects, etc.

(1) Higher demand charges in winter.

(2) Fuel price adjustment to provide a rate change when fuel prices deviate from a standard.

(3) Special energy rates for electric water heating for controlled off-peak service.

(4) Penalties or bonuses for power factor deviation from an 80% standard.

Item 3 has been a subject of intensive investigation as described in our last lecture. For example, the idea of thermal storage, conceived by Carsie Denning, is a case of particular interest. (See Lecture VI, Reference 1, p. 56)

C. Making-Up Rate Structures

A rate should be sufficient to obtain from the customers sufficient income to meet the costs and provide the allowable return on the capital basis, whatever that may be. We show here an example of rate problems simplified to show how the rate is devised to return the necessary income. (An actual problem, of course, is much more complicated.)

A city of 150,000 customers (commercial customers being reduced to equivalent domestic customers on the basis of about 50 KW hours per month per customer) is served by a 30,000 KW plant through the medium of a 15-mile transmission line. Cost of the plant is $145 per KW; salvage value at the end of an 18-year useful life, 10% of its first cost. Cost of the primary distribution system is $2,000 per mile; salvage value at the end of a 25-year useful life, 30%. The secondary distribution system has a capital cost of $3,250,000 and an estimated salvage value of 20% at the end of 15 years.

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Interest rate, 6 1/2%; taxes plus insurance, 5%. Labor costs for the power plant and primary distribution system:

30 men at $150 month
16 men at $200 month
8 men at $350 month

Management cost is $68,000 annually; maintenance and repairs, $50,000 annually (10% for fixed element, 90% for energy element); oil, waste, and supplies, $25,000 annually. Cost of franchise and publicity, estimated $1 per customer. Collecting revenue, $225,000 annually; operating secondary distribution system, $110,500 annually; cost of coal, delivered to plant, $4.90 per ton.

Fixed Element:

Capital Cost = Cost of plant + cost of transmission line.
Capital Cost = 145 X 30,000 + 15 X 2000 = $4,380,000
Depreciation = Capital cost - Salvage value
Depreciation (plant) = (145 X 30,000) (1.00-0.10) = $3,915,000
Depreciation (line) = (15 X 2000) (1.0-0.3) = $21,000
Annual Depreciation; $217,500 + $840 = $218,340
Plant Depreciation Reserve = 3,915,000/18 = $217,500
Line Depreciation Reserve = 21,000/25 = $840
Interest, taxes, and insurance (0.065 + 0.05) X 4,380,000
= $503,700
Maintenance (10% of 50,000) = 5,000
Management = $68,000
Total Annual Cost for Fixed Element $795,040

Energy Element:

Coal consumption (71,000 tons) corresponding to 95,000,000 KW hr.

Labor Cost = 30 X 150 + 16 X 200 + 8 X 12 mon. = $126,000

Fuel Cost = 71,000 X $4.90 = $347,900

Oil, waste and supplies = $25,000

Maintenance (50,000-5,000) = $45,000

Total Energy Element Charge $543,900

Customer Element:

Dep. of the secondary distribution system =

(1.00-0.20) X 3,250,000 = $2,600,000

Annual depreciation reserve 2,600,000/15 = $173,333

Interest, taxes and insurance = (0.065 + 0.05) X

3,250,000 = $373,750

Operating Costs = $110,500

Franchise and publicity 150,000 X $1 = $150,000

Cost of collecting revenue $225,000

Total customer element charge $1,032,583

Investor's Profit:

Assume annual profit on capitalization, over and above interest, to be 8%

Cost of plant, primary, and secondary distribution systems:

Capitalization = 4,380,000 + 3,250,000 = $7,630,000

Profit Element = 0.08 X 7,630,000 = $610,400

Straight Line Meter Rate:

Summing the various elements of cost:

Fixed Element	$ 795,040
Energy	543,900
Customer	1,032,583
Profit	610,400
Annual Production Cost	$2,981,923

Assuming 80% of the plant output to be registered on the customers' meters (20% energy losses in line, transformers, etc.)

Rate $= \frac{\$2,985,000}{95,000,000 \times 0.80} = 0.0392$, Say, a 4 cents per KW hour rate.

This is how a power company comes up with a rate in an approximated economic model.

References and Suggestions for Further Reading

(1) Morse, Frederick T. Power Plant Engineering. 3rd ed. D. Van Nostrand Company, Inc., 1953.

LECTURE VIII: RATE SCHEDULES AND BILLING

A. "Demand" Charge and "KWH" Charge

In the last lecture, we introduced the theory behind rate schedules. (Economic and political structures are dynamic and rate schedules will surely change as time moves along. The theory which provides the fundamental concept and serves as a useful guide remains pretty much the same.) In this lecture, the rate schedules and billing are discussed from the consumer's viewpoint, in other words, how the power companies charge them. Almost all electric utility companies charge based on some combination of four parameters:

(1)	Consumption	(KWH)
(2)	Demand	(KW)
(3)	Fuel Adjustment	(KWH)
(4)	Power Factor	KVAR

The rate schedules are all different among the utility companies. The following are some basic definitions:

(Definition 13) - Actual Demand: The highest average demand measured during the current billing period.

(Definition 14) - Billing Demand: Same as actual demand unless a ratchet feature is stated in your rate schedule. Under a ratchet clause, the billing demand would be derived from previous actual demands by a stated formula.

(Definition 15) - Ratchet Clause: Provides for billing demand to be determined by examining previous actual demand over a specified period of time and taking all or part of the highest demand as the billing parameter. Examples: Let D_i represent the current actual demand and $D_0, D_1, D_2, \ldots, D_{i-1}$ represent the previous period of actual demands (12 month period if i=12). Some examples in practice are shown as follows:

(1) Billing Demand

$$B_i = \text{Max. } D_1, D_2, \ldots, D_{i-1}, D_i$$

(2) Billing Demand

$$B_i = \text{Max } D_i, 1/2 \text{ Max. } (D_0, D_1, D_2, \ldots, D_{i-1})$$

(3) Billing Demand

$$B_i = 1/2 \; D_i + \text{Max. } (D_0, D_1, D_2, \ldots, D_{i-1})$$

(4) Billing Demand

$$B_i = 1/3 \; (D_i + D_{i-1} + D_{i-2})$$

(Definition 16) - KWH Charges: The total number of kilowatt hours used during the current period. These charges may be a fixed rate per KWH or the most common technique is to base these charges on a sliding scale.

(Definition 17) - Hours Use of Demand: If the KWH is divided by the current period actual demand, the resultant value is the hours use of demand. Say, "200 KWH per KW billing demand." This simply means 200 hours use of demand.

(Definition 18) - Load Factor: L.F. has been defined in a previous lecture. It is the quotient of KWH divided by the product of the current period actual demand and the number of hours in the billing period.

B. Type of Tariffs

The actual tariffs take several forms, but they may be grouped into four basic techniques:

(1) Simple demand charges

(2) Hours use of demand charges

(3) Surcharge addition

(4) Mixed simple demand charges and hours use of demand

C. Fuel Adjustment Charges

This is something newly introduced within the last five years when fossil fuel charges commenced to vacillate rather rapidly. The state utility commissions could not act swiftly enough to provide rate reviews and approvals within this rapidly changing price situation. They now allow the power companies to charge or credit a fuel adjustment factor based on fuel cost variations around a base price. Sometimes two such adjustment factors may be in effect at the same time. In the Pacific, Gas and Electric System in California, fuel adjustment factors have increased because of the current water shortage causing a reduction in hydroelectric power generation.

D. Utility Company Profiles

Most rate schedules state that either 85% or 90% power factor must be maintained. Very few additional charges for lower power factors are invoked because the utility company cannot justify the cost of adding metering equipment to those facilities which have minor power factor variations.

References and Suggestions for Further Reading

(1) Energy Management Seminar. Charlotte, North Carolina; Process Systems Incorporated.

(2) Morse, Frederick T. Power Plant Engineering 3rd ed. D. Van Nostrand Company, Inc., 1953.

Table I

SIMPLE DEMAND

Carolina Power and Light Company
Schedule G-3C, North Carolina Only
Effective 02-20-76

Given: 4,000 KW Demand, 1,728,000 KWH

Demand Charges

Amount	Rate/KW	Cost
1,000 KW Billing Demand	$3.90	$ 3,900
3,000 KW Billing Demand	$3.75	11,250
4,000 KW		$15,150

KWH Charges

Amount	Rate/KWH	Cost
1,728,000	0.0137	$23,673.60

Total = $15,150 + $23,673 = $38,823

HOURS USE

Duke Power Sample Calculation
Schedule I (SC)
Effective 01-13-76

4,000 KW Actual Demand 1,728,000 KWH

125 x 4,000	=	500,000 KWH	$12,352.36
275 x 4,000	=	1,100,000 KWH	12,534.00
400 x 4,000	=	128,000 KWH	1,331.20
		1,728,000 KWH	$26,217.56

For the first 125 KWH per KW Billing Demand per month

Amount	Rate/KWH	Cost
100 KWH	$ .0706	$ 7.06
1,170 KWH	.0487	56.98
1,730 KWH	.0392	67.82
27,000 KWH	.0335	904.50
30,000 KWH	.0315	945.00
30,000 KWH	.0300	900.00
410,000 KWH	.0231	9,471.00
500,000 KWH		$12,352.36

For the next 275 KWH per KW Billing Demand per month

Amount	Rate/KWH	Cost
140,000 KWH	$ .0146	$ 2,044.00
60,000 KWH	.0128	768.00
900,000 KWH	.0108	9,720.00
1,100,000 KWH		$12,532.00

For all over 400 KWH per KW Billing Demand per month

Amount	Rate/KWH	Cost
128,000 KWH	$ .0104	$ 1,331.20

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PEAK BILLING
PACIFIC GAS AND ELECTRIC SCHEDULE A-17

4,000 KW Peak Period Demand   1,728,000 KWH Total Usage

Period 3 (1 October through 30 April)

On Peak:	4:30 PM to 8:30 PM	Weekdays	(88 Hrs/Mo Typ.)
Partial Peak:	8:30 AM to 4:30 PM	Weekdays	
	8:30 PM to 10:30 PM	Weekdays	(276 Hrs/Mo Typ.)
	8:30 AM to 10:30 PM	Saturdays	
Off Peak	10:30 PM to 8:30 AM	Mon.-Sat.	(356 Hrs/Mo Typ.)
	Sundays and Holidays		

Demand Billing:	Demand	Rate	Charge
On Peak:	4,000	2.30	9,200
Partial Peak:	3,500	.28	980
Total			10,180

Usage Billing:	Usage	Rate	Charge
On Peak:	299,633	.01218	3,649.53
Partial Peak:	822,290	.01018	8,370.91
Off Peak:	606,077	.00818	4,957.71
Totals	1,728,000		16,978.15

Customer Charge	715.00
Demand Charge	10,180.00
Usage Charge	16,978.15
Energy Cost Adjustment	25,436.16
- Fuel Balance Adjustment	- 725.76
Total	52,583.55

SUMMARY RATE CALCULATIONS

4,000 KW Demand 1,728,000 KWH

FIGURE	UTILITY	DEMAND	ENERGY	TOTAL
2-1	CP&L	$15,150.00	$23,673.60	$38,823.60
2-2	Duke (SC)	8,246.36	17,971.20	26,217.56
2-3	Ohio PC	12,862.96	15,597.45	28,460.41
2-4	Ga. Power	13,220.00	13,842.40	27,062.40
2-5	PG&E A-17 (B)	10,180.00	42,404.00	52,584.00
2-6	PG&E A-17 (A)	14,780.00	42,706.00	57,486.00
2-7	PG&E A-13	23,211.00	39,916.00	63,127.00

RATE SCHEDULES AND BILLING

Based on some combination of:

1.	Consumption	KWH
2.	Demand	KW
3.	Fuel Adjustment	KWH
4.	Power Factor	KVAR

Some definitions in rate schedules

1. Actual Demand
2. Billing Demand
3. Ratchet Clause
    a. Max. actual demand for previous 12 months.
    b. Max. $\left\{\text{current actual demand, 50\% of Max. (actual demand over 12 months.)}\right\}$
    c. Billing Demand =

$$\frac{(\text{actual demand})_{i=13} + \max_{i} \left\{(\text{actual demand})_i;\ i=1,2,\ldots,12\right\}}{2}$$

    d. Billing Demand =

$$\max_{j} \left\{(\text{actual demand})_j;\ j=i,\ i=1,\ i=2\right\}$$

4. KWH Charges: a fixed rate/KWH or on a sliding scale.
5. Hours Use of Demand:

$$= \frac{\text{KWH}}{\text{Current period actual demand}}$$

6. Load Factor

$$= \frac{\text{KWH}}{(\text{current actual demand}) \cdot (\text{no. of hours})}$$

LECTURE IX: DEFERRABLE LOADS IN PUBLIC SCHOOL BUILDINGS

A. Saving Analysis

Even though public school buildings are our primary topic of discussion, we will examine some other types of load profiles in order to enhance our understanding and to use them as a basis for comparing the differences among load profiles.

In Fig. IX-1, this profile of a manufacturing facility running on a three shift operation, shows a one-hour cyclic effect of the cooling system for the batch fermenter tanks and a temperature sensitivity of about 15 KW per degree temperature change. The target selected for demand control is 5,500 KW. This was realistic because 30,000 gallons of chilled water storage was available to use during peak demand periods.

Figure IX-2, a commercial office facility has a different profile. The load profile for a public school building is very close to this figure. It shows two peak periods per day based on sun loading. Relatively speaking, this load profile is quite smooth, but it certainly exhibits tremendous potential for energy conservation because some of the loads contributing to the peaks can either be shed or be deferred. However, it is impossible to analyze the control potential for a facility by using only daily profile graphs.

B. Demand Histogram (Demand Distributional Frequency Function)

The daily profile represents an instantaneous variation, but offers insufficient information to design an effective control policy. By reorganizing data on the daily profiles, over longer periods of time, one can determine the efficient operating point of a facility and the estimated demand savings. This task can be accomplished by introducing the reorganized data called "Demand Histogram" or "Demand Distributional Frequency Function." Let us look at a few examples:

Figure IX-3, shows a demand histogram for a manufacturing plant. This plant can be controlled to 5,530 KW without reducing productivity or product quality. To achieve this level of control required less than 20% interval control.

Figure IX-4, shows a different type of histogram from a medium size multimode metal fabrication plant. The nature of the facility certainly reflects on the histogram as one can see a multimode function. The control point in this case may be set at 1800 KW. In other words, all the demands above 1800 KW (threshold) will be the targets to be shed. If the threshold of 1800 KW is not a realistic one, then one may change this threshold.

Another example in Figure IX-5 shows a forest products manufacturing facility. The histogram for this case has an envelope which is monotonically decreasing. In other words, the numbers of occurrence for high demands are actually not high. However, this does not mean that the bill will be lower because the maximum demand is 17,330 KW. On the other hand, 800 KW could easily be saved on this plant.

C. Principle of Load Sheddings

In general, a load management and control system operates on the "instantaneous rate" principle. A solid state unit converter eliminates the requirement for direct connection to the utility demand meter. The current-to-pulse converter measures the input from customer provided current transformers and generates an input frequency to the demand control logic proportional to the rate of energy consumption. The input frequency is converted to actual demand rate, and compared with a programmed peak demand limit. The output control logic automatically sheds loads until the actual demand is reduced below the lower demand limit, the output control logic automatically restores loads. Demand measurements and computations are performed at least 100 times per demand interval so that for a 15 minute demand interval, loads are shed or restored one per nine seconds.

This is the basic design concept adopted by Gould Inc. as shown in Figure IX-6. The effect of demand control can be seen from the demand meter recording as shown in Figure IX-7. The design philosophy for other manufacturers will be discussed in later lectures.

References and Suggestions for Further Reading

(1) Energy Management Seminar. Charlotte, North Carolina; Process Systems Incorporated.

FIGURE IX-1
FLAT MANUFACTURING FACILITY PROFILE

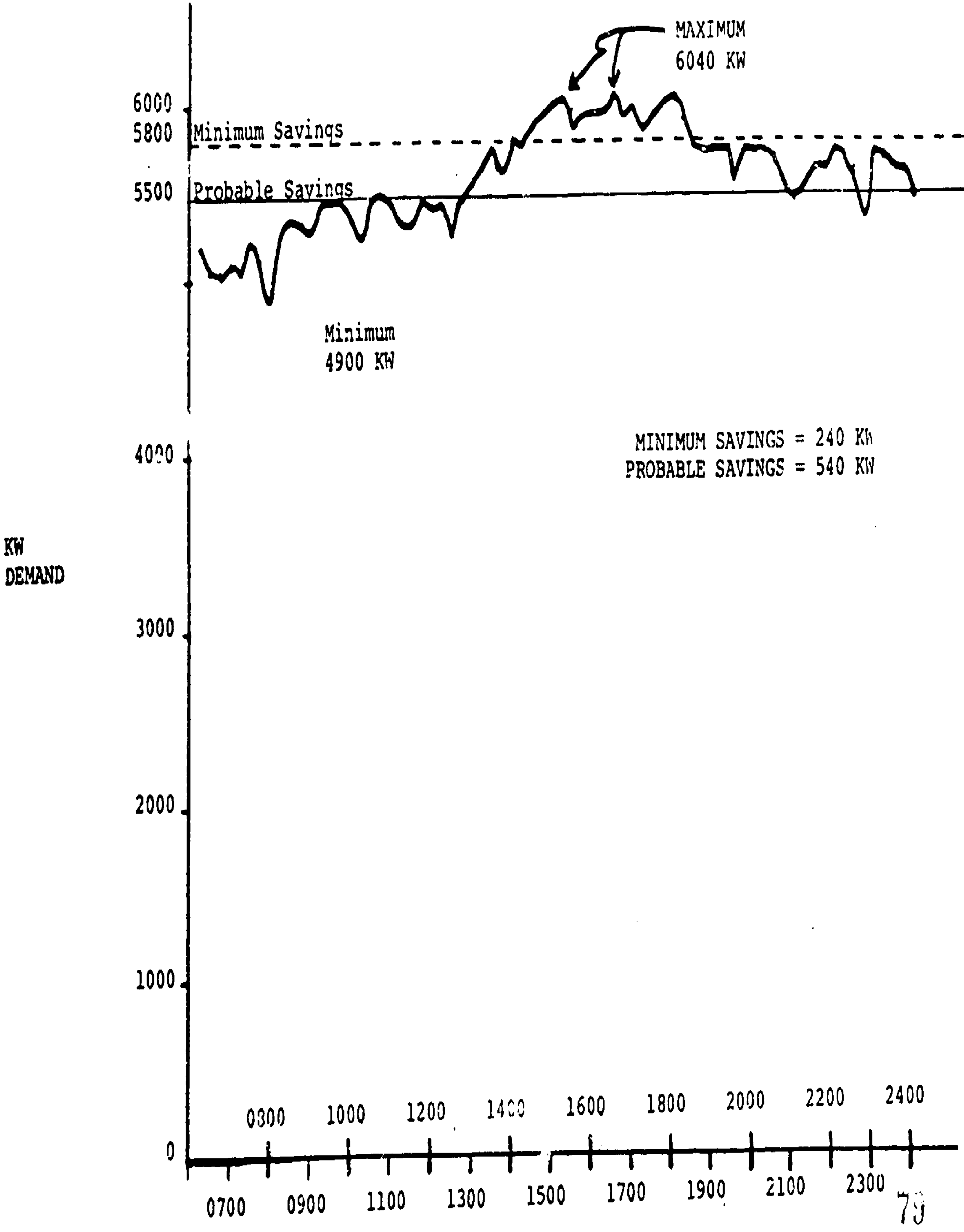


FIGURE IX-2
COMMERCIAL OFFICE BUILDING
June 6, 1976

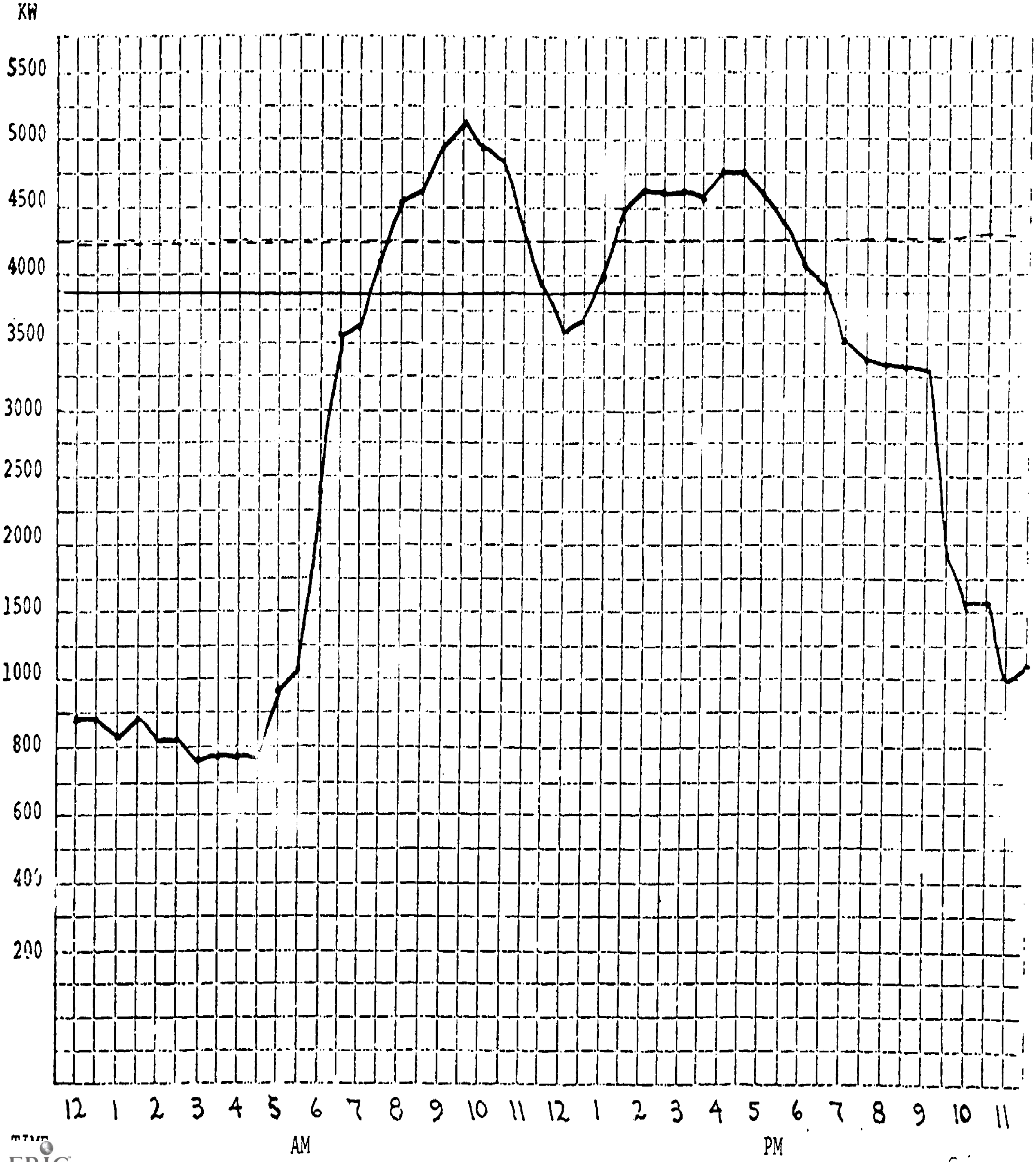
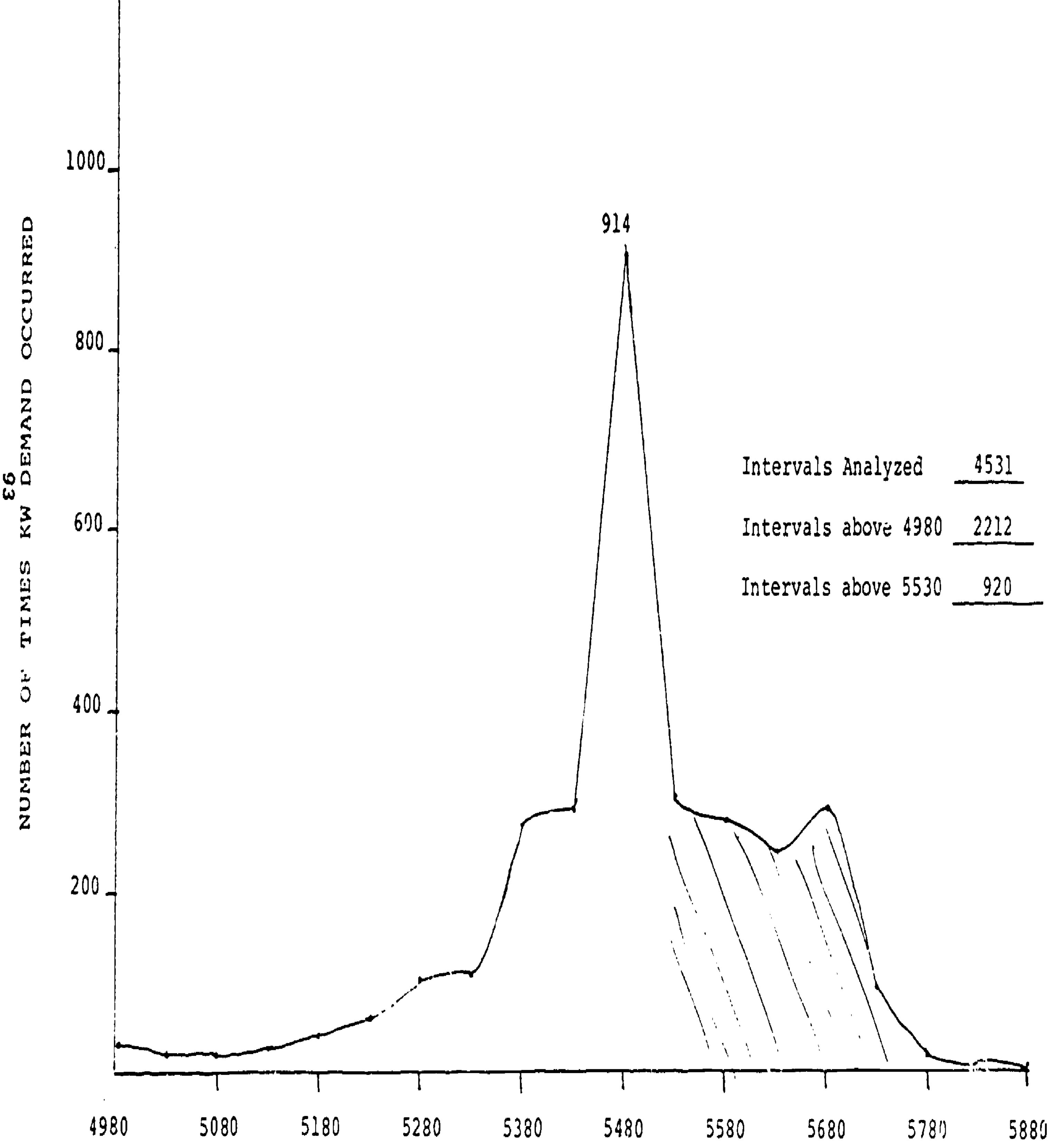
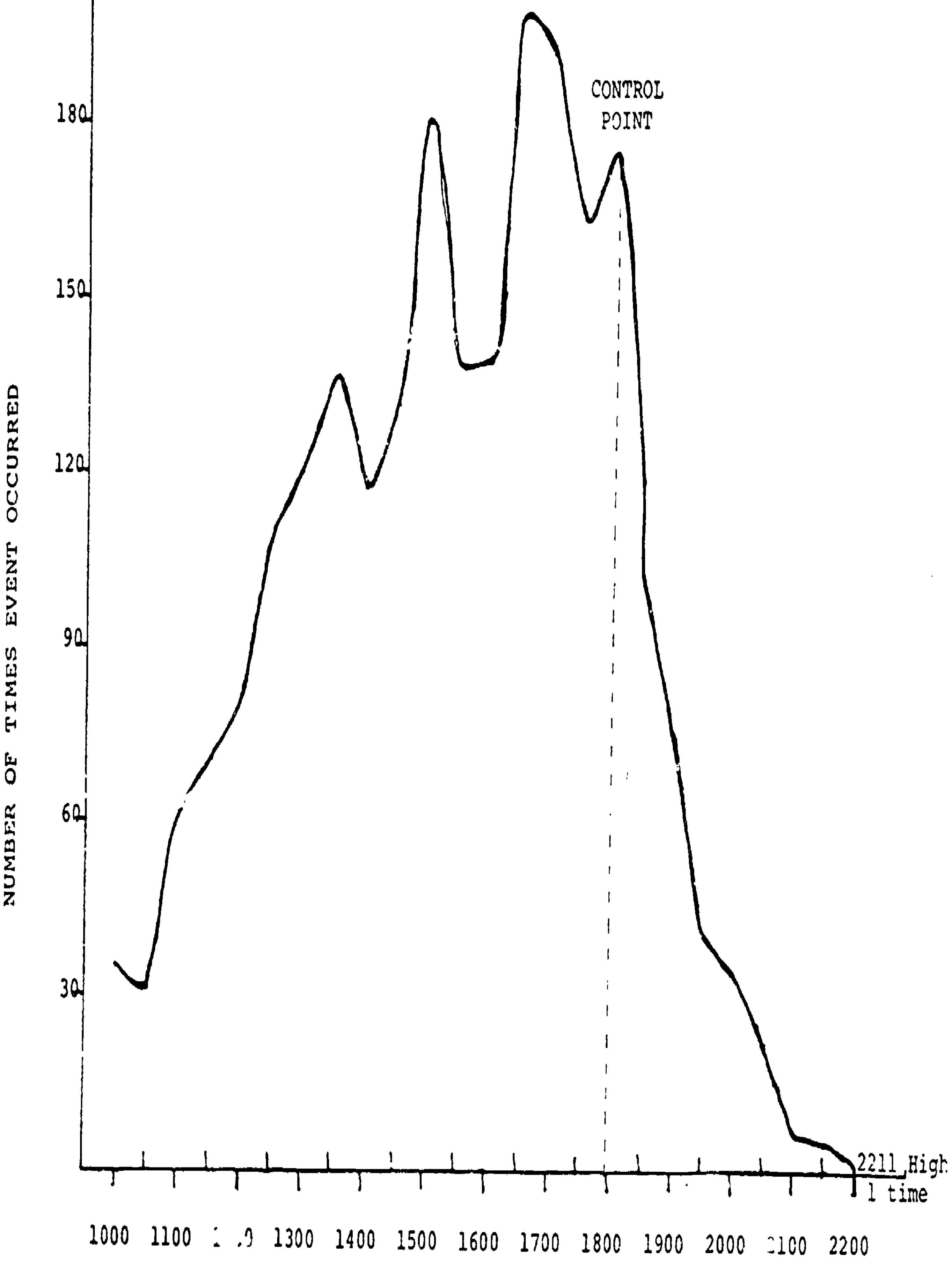


FIGURE IX-3
Medium Size Grey Mill
Demand Spectral Analysis
June 1, 1976 thru September 26, 1976



12-09-76 Marguerite Maddock

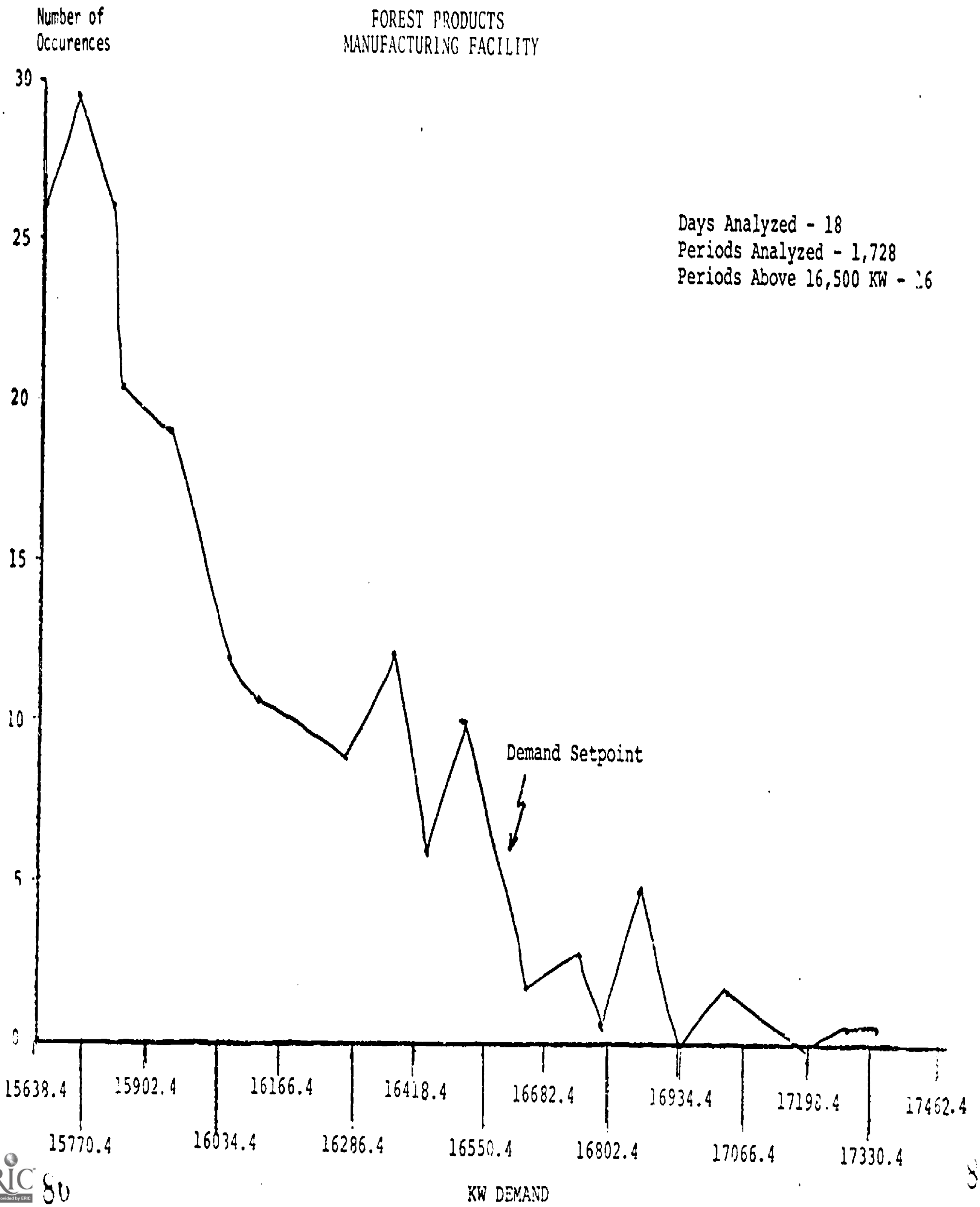
FIGURE 4
DETERMINATION OF CONTROL POINT



KW DEMAND

Handout 21

FIGURE IX-5
DEMAND SPECTRUM



FOREST PRODUCTS
MANUFACTURING FACILITY

Days Analyzed - 18
Periods Analyzed - 1,728
Periods Above 16,500 KW - 16

FIGURE IX-6
Demand Control Operation

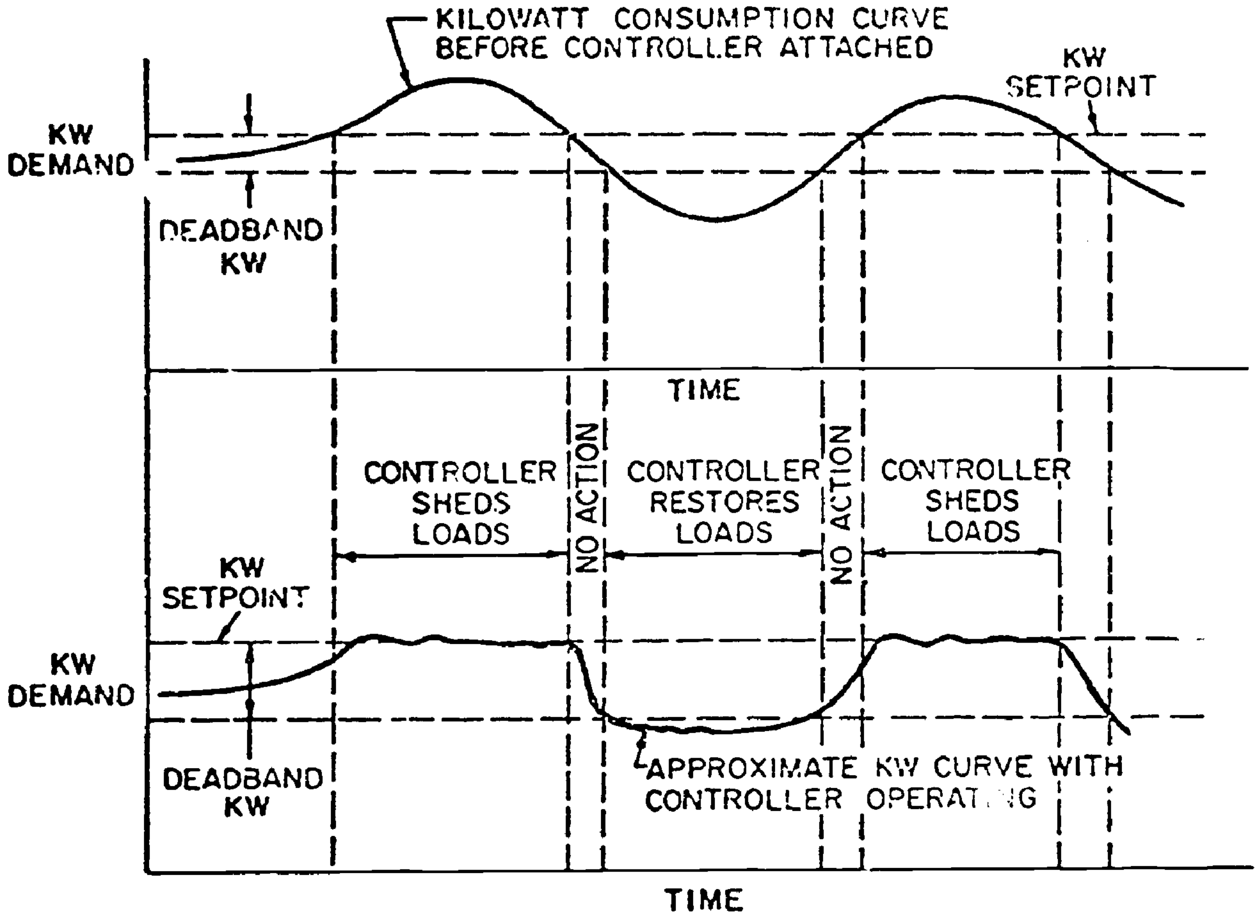
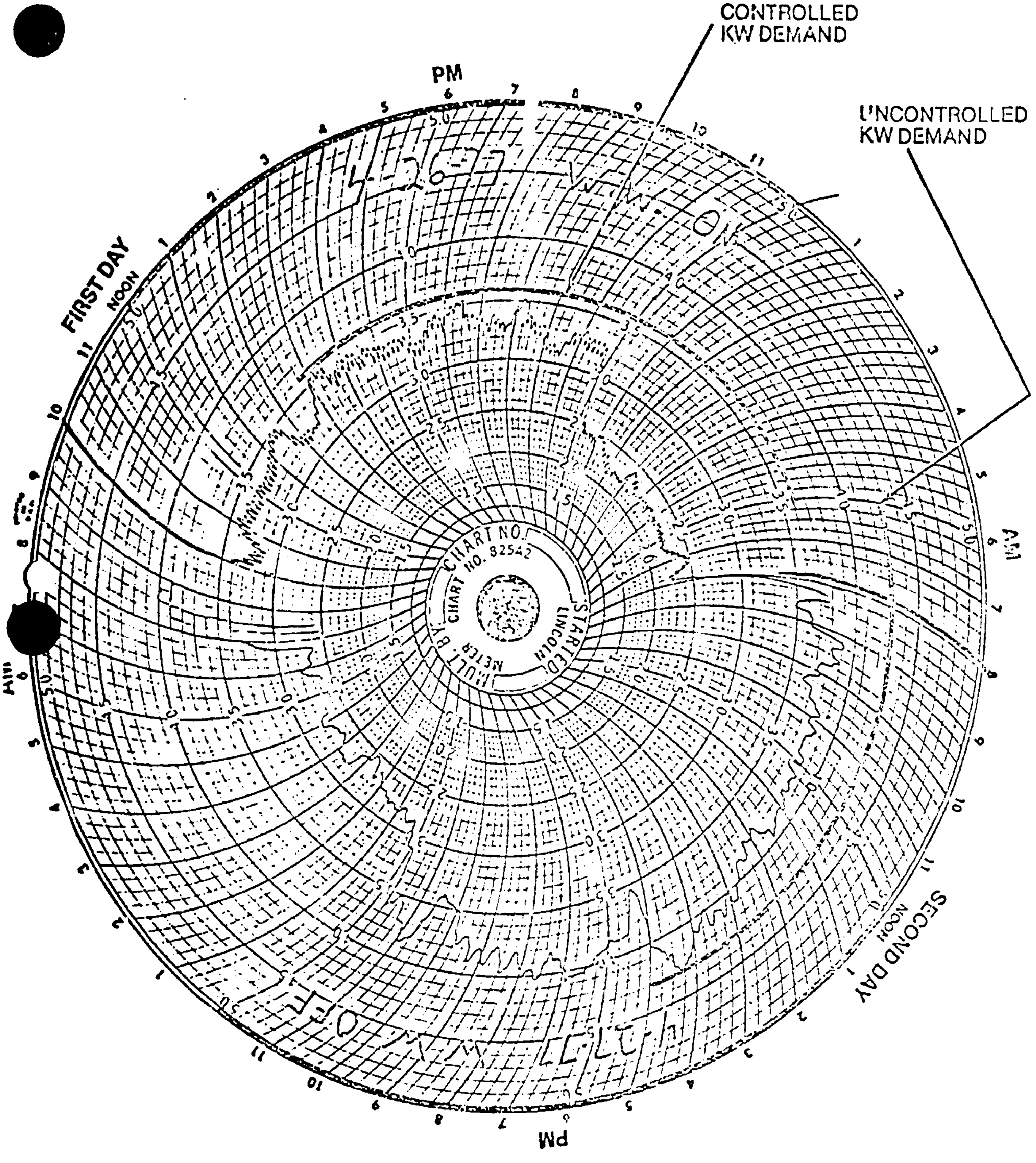


FIGURE IX-7
Effect of Demand Control



A. Introduction

To manage and control [illegible] energy management systems is a complex problem because the physical plant itself is a complex physical dynamic system and there are large numbers of choices available for optimal control.

To be sure that the system can be properly adjusted for any facility, three variables must be included in the system. They are:

(Definition 19) - [illegible]: The demand setpoint establishes the threshold below which no control is exercised.

(Definition 20) - Loop Gain: Loop gain is controlled by "Minimum on" and "Minimum off" times for each load group.

(Definition 21) - Damping: Damping of the control loop is adjusted by controlling the "integration time constant" of the demand predictor algorithm.

B. Loads Classification

There are many different kinds of loads for public school buildings and facilities and they all have a different impact on demand and consumption. The most important aspect of studying the characteristics of all the loads is that some of them can be deferred and others can't. Even for those that can be deferred, another question is brought up of how long they can be deferred because this has great, significant impact upon our optimal control strategies. The optimal control problem in this case would be to allocate the deferrable loads in different periods of time. Therefore, it is a control problem on the temporal axis. We shall discuss this problem in the next section. A chart (p.107) is included which summarizes the classification of all load candidates.

C. Optimal Control of Deferrable Loads on Temporal Axis

Our primary objective here is to allocate the deferrable loads optimally simply by shifting the loads at different time intervals. This differs drastically from peak load sheddings. The following discussions summarize the type of controls under different circumstances. Basically, there are seven classes of problems to be tackled. (Assuming that any load profile can be approximated by piecewise linear functions within a uniform small time interval called T).

(1) The time interval T associated with a relocatable piece of load (with finite demand, KW) equals to the demand meter's demand period. (Say 15 minutes, 30 minutes, etc.) Under this scheme, the total KWH is a constant number.

(2) The time interval T equals to the demand period, but the amplitudes of the multiple controllable loads are variables to be decided even though the total KWH is also fixed.

(3) Time interval T equals to the demand period, but there is only one controllable load with fixed amplitude.

(4) Time interval T equals to the demand period, and there are multiple controllable loads with fixed amplitudes for each controllable load.

(5) The time interval T does not equal to the demand period and there is only one controllable load with fixed amplitude. In general, the demand period is considered to be longer than T.

(6) Time interval T does not equal to the demand period, and the multiple controllable loads have fixed amplitude.

(7) Time interval T does not equal to the demand period and there is a single controllable load with an amplitude which is a variable.

It would be difficult to describe all the original results here, but we can simple say that the optimal load control is a manageable problem via digital computers.

It is worthwhile to reiterate here once more that peak load shedding is not the only approach. One may move the deferrable loads around simply to avoid the occurrence of a high peak.

According to past experiences, some vendors will push a single system channel for each separate load to be controlled. This is unnecessary and usually results in poorer control of your demand.

In the electrical distribution system for your facility, loads are constantly being turned on and off causing perturbations. Any system which attempts to control these momentary perturbations will over control or under control, i.e., causing non-critical damping. Critically damped systems, which provide the smoothest and most effective control for your facility, will require a minimum smoothing time for nulling out these perturbations. This smoothing period will be 10 seconds minimum with typical values of 20 to 30 seconds.

Empirically, the minimum shed value on each system channel should be about 1/3 of the highest value of on/off load in your distribution network.

References and Suggestions for Further Reading

(1) Energy Management Seminar. Charlotte, North Carolina; Process Systems Incorporated.

(2) Wang, P. P. and Wang, C. Y. "Theory of the Optimal Electrical Load Allocation," Unpublished Notes, Department of Electrical Engineering, Duke University, Durham, N. C.

9

Loads have automatic control systems.	Can be deferred?	For long or short period of time?	Examples (Loads)
No	yes	long	1. Lighting 2. Aesthetic displays 3. Fountains 4. Training equipment 5. Shop equipment, machines, arc welders
May have	yes	long, must be recovered	1. Personnel hot water heaters 2. Battery chargers 3. Water tower pumps 4. Sump pumps and aerator pumps 5. Cafeteria equipment
Have	yes	short mandatory recovery	1. Circulation and exhaust fans 2. Electric boilers 3. Electric ovens 4. Air compressors 5. Air conditioning 6. Freezers and refrigerators
Have or may have Can be controlled differently	yes	short or long	1. Cafeteria equipment 2. Circulation fans and exhaust fans 3. Ventilation and air conditioning systems 4. Heating equipment

LECTURE XI: AN INTRODUCTION TO DIGITAL COMPUTERS

A. Computer Industry Today

The computer industry continues to be the fastest-growing major industry. The sales of large computers increase every year, and the size of the overall computer industry has been further supplemented by the booming minicomputer market and the introduction of microcomputers to the market.

Minicomputers and microcomputers make possible exciting new application areas for computers because of their low cost, reliability, small size, and low weight. One of the newer application areas is energy management and control. These small computers are able to calculate at a rate of hundreds of thousands to millions of operations per second and offer computing power which was available in only the larger computers as recently as 10 years ago. The places where small computers can be used appear endless; such areas as process control, medical monitoring, production testing, scientific instrument recording, programmed check out systems, and automobile test and evaluation systems were among the first to appear. The subject matters to be discussed here, the computer energy management and automatic control systems, utilize the mini- or micro-computers both as monitoring and process control systems and in energy management functions similar to applications in the business world. When we are ready to talk about an energy management computer system for the public schools of a whole state, then even a large computer system, time-shared, may be used advantageously.

B. Some Different Types of Computer Systems

(Definition 22) - Batch Processing: The most familiar use of computers is in operating programs punched into cards (or recorded on paper or magnetic tape) and run by a computer which then prepares printouts, checks, or some form of data presentation recording the results.

(Definition 23) - Online Interactive Systems: Users interact with the computer directly, inserting and receiving the data as desired. For instance, an airline ticket agent wishes to make a reservation. The agent types the desired aircraft flight number and passenger identification on a special typewriter which communicates, via the telephone lines, with a computer. The computer looks in its memory, sees if the flight is full, and if not, enters the passenger's name on its list for the flight, and then communicates this fact back to the airline ticket agent. If no seats are available, the computer sends this information to the ticket agent. In this way an airline connects all its ticket agents together, keeping a constant record of flights, passengers, and payments and doing all the bookkeeping.

The development of these systems has progressed in parallel with the development of keyboard input devices, as well as output devices for users of various types, including TV displays printers, and other data display devices.

All the available commercial energy management and control systems are on-line interactive type.

(Definition 24) - Teletype: This is an example of a keyboard which is "typewriterlike," generating a printed record when used, but also generating electrical signals which can be used as computer input. Similarly, electronic signals from a computer can be used to control the teletype, and the teletype will type, under the computer's control, the results of calculations.

(Definition 25) - Modem: Modem is a special attachment which makes it possible to transmit the electrical signals generated by the teletype to the computer and receive the computer's response back over telephone lines. At the computer another modem is located which can also transmit or receive, and this pair of modems allows communication in both directions over telephone lines.

(Definition 26) - Time Sharing System: When a number of users share a computer, using the computer, often via telephone lines, at the same time, the computer is said to be time shared. Time sharing means that the computer is able to alternate and interleave the running of its programs so that several jobs or users can be on at the same time.

C. Digital Computers in Control Systems

The ability of digital computers to make precise calculations and decisions at high speeds has made it possible to use them as parts of control systems.

(Definition 27) - <u>Real-Time Control System</u>: In a real-time control system, information must be processed and decisions must be made in real time. When a computer is used to process business data or to perform most scientific calculations, time is not as critical a factor. In real-time systems, the computer must "keep up," processing all data at high speeds in order to be effective.

Most real time control systems require an important device known as an analog-to-digital converter. The inputs to these systems in many cases are in the form of analog quantities such as mechanical displacements (for example, shaft positions) or temperatures, voltages, pressures, etc. Since the digital computer operates on digital rather than analog data, a fundamental "language" problem arises which requires the conversion of the analog quantities into digital representation. The analog-to digital (A/D) converter does this.

The same problem occurs at the computer output, where it is often necessary to convert numerical output data from the computer into mechanical displacements or analog-type electrical signals. For instance, a "number" output from the computer might be used to rotate a shaft through the number of revolutions indicated by the output number. A device which converts digital type information into analog quantities is called a digital-to-analog converter.

Basic elements of a Control System using a digital computer:

(1) The data-gathering devices which perform measurements on the external environment and, if necessary, also perform A/D conversion on the data from the system which is to be controlled.

(2) The digital computer itself, which performs calculations on the data supplied and makes the necessary decisions.

(3) The means of communication with, or control over, certain of the elements in the external environment. If no person aids the computer in its calculations or decisions, the system is considered to be fully automatic; if a human being also enters the control loop, the system is defined as semiautomatic.

As an example, the energy control and management system using a digital computer system can measure, test, analyze and control functions as they occur because of its high speed.

D. Special-Purpose and General-Purpose Computers

In general, there are two types of digital computers.

(Definition 28) - Special-Purpose Digital Computer: which performs a fixed and preset sequence of calculations. This type of computer may be constructed more efficiently in that it can be lighter and smaller and may consume less power than the general-purpose computer. Small special-purpose computers are used with such factors as weight, power consumption, etc., as in aircraft control systems, missile guidance systems, special checkout equipment for military devices used in the field, etc.

(Definition 29) - General-Purpose Digital Computer: The sequence of instructions which the machine follows is generally read into this type of machine and stored in the memory of the machine. The machine can be made to follow another sequence of instructions by simply reading in the desired set of instructions. Since the sequence of operations performed by the general-purpose digital computer may be easily changed, the machine possesses great flexibility.

Most computer energy control and management systems commercially available today employ general purpose digital computers. The general-purpose computer can process a specific energy management and control program; and then, after another program has been read into it in order to take care of, for example, a new season variation, or holidays agreement, it can perform the new tasks. The general-purpose computer may be used to solve a wide variety of problems, the details of which may have been unknown when the machine was designed. The special-purpose computer is generally only capable of solving a special type of problem.

References and Suggestions for Further Reading

(1) Bartee, Thomas C. *Digital Computer Fundamentals.* 4th ed. McGraw Hill Book Company, 1977.

(2) Weiss, Eric A., ed. *Computer Usage Fundamentals.* McGraw Hill Book Company, 1969.

LECTURE XII: HARDWARE AND SOFTWARE OF A DIGITAL COMPUTER

A. Basic Components of a Digital Computer

There are five major operational divisions of an electronic digital computer. Although presently available machines vary greatly in the construction details of various components, the overall system concepts remain roughly the same.

A digital computer may be divided into the following fundamental units:

(1) Input: The input devices read the necessary data into the machine. In most general-purpose computers, the instructions which constitute the program must be read into the machine along with all the data to be used in the computations. Some of the more common input devices are punched-card and punched-paper-tape readers, magnetic-tape readers and various manual input devices such as toggle switches and push buttons.

(2) Control: The control section of a computer sequences the operation of a computer, controlling the actions of all other units. The control circuitry interprets the instructions which constitute the program and then directs the rest of the machine in its operation.

(3) Memory: The memory, or storage, section of the computer consists of the devices used to store the information which will be used during the computations. The principal or high-speed memory devices for a computer are divided into pieces of equal size, each of which is then identified with what is called an address, or location in memory. If the control unit is looking for a specific piece of information or an instruction located in the memory section, it calls for it by means of its address. Common storage devices are magnetic cores, integrated circuit memories, magnetic drums, magnetic tape and magnetic disks.

(4) Arithmetic-Logic Unit: The arithmetic-logic units of most computers are capable of performing the operations of addition, subtraction, division, and multiplication, as well as some "logical operations" which will be described. The control unit tells the arithmetic-logic unit which of these operations to perform and then sees that the necessary numbers are supplied.

(5) Output: The output devices are used to record the results obtained by the computer and present them to the "outside world." Most output devices are directed by the control element, which also causes

the necessary information to be supplied to them. Common output devices are card-punching machines, magnetic-tape machines, special electromechanical typewriters, cathode-ray tubes, and high-speed printing devices. There are also many unusual types of output devices, such as lights, buzzers and loudspeakers.

B. Programming Systems

There are various types of programming languages which greatly facilitate the actual writing of programs. One of the first things the programming profession discovered was that the greatest aid to programming was the computer itself; it was found to be capable of translating written programs from a language which was straightforward and natural for the programmer into computer, or machine language.

As a result, programs were written whose purpose was to read other programs written in a language natural for the programmer and translate them into the machine's language. There are two types:

(1) Assemblers

(2) Compilers

The assembler and the compiler are intended for the same basic purpose. The assembler or compiler is read into the machine first, and is then followed by the program to be translated.

The purpose of this procedure is to enable programmers to write the operations they want the computer to perform in a manner which is simpler than machine language.

An assembly language differs from a compiler language in that most assembly language closely resembles machine language, primarily because each instruction to the computer in assembly language is translated into a single computer word. In compiler systems, a single instruction to the computer may be converted into many computer words.

C. Assembly Languages

Each instruction to the computer in an artificial programming language is called a statement. Each statement is translated by the assembly program into a single machine instruction word. As a result, an assembly language somewhat resembles machine language.

(1) Mnemonic Operation Codes

The programmer can write instructions to the computer using letters instead of binary numbers, and the letters which designate a given operation are arranged into a mnemonic code which conveys the "sense" of the instruction. The assembler would translate mnemonic codes such as ADD, MUL, etc. into the correct machine binary or binary-coded-decimal numbers and "package" these into the instruction words constituting the object program.

(2) Symbolic Referencing of Storage Addresses. One of

the greatest facilities offered the programmer is the ability of the computer to name the different pieces of data used in the program and to have the assembler automatically assign addresses to each name.

(3) Convenient Data Representation. The assembly program will convert the data from letters to decimal numbers in the form required for machine computation.

(4) Program Listings: An important feature of most assemblers is their ability to print for the programmer a listing of the source program and also a listing of the object program which is in machine language.

(5) Error Detection: An assembler program will also notify the programmer if an error has been made in the usage of the assembly language.

D. Compiler Languages

More advanced types of programming languages are called compiler languages, high-level languages, or problem-oriented languages. These are the simplest languages to use for most problems and are also the simplest to learn. These languages reveal very little about the digital machines on which they are run, however.

The designer of the language generally concentrates on specifying a programming language which is simple enough for the casual user of a digital computer and yet which has enough facilities to make the language and its associated compiler valuable to professional programmers. In fact, many languages are almost completely computer-independent, and programs written in one of these languages may be run on any computer which has a compiler or translator for the language in its program library.

The most famous language is FORTRAN, which is the earliest of the languages and has been regularly updated. For example, the IBM's energy management systems (IBM System 7 as well as their new system of IBM Series I) use FORTRAN language. A program written in FORTRAN can be run on most commercial computers which have a memory size large enough to accommodate a FORTRAN compiler because most manufacturers will prepare a FORTRAN compiler for their computer.

About all that can be said is that there is no truly universal programming language but that there are several good languages. Fortunately, there is no staggering difference in these languages from a conceptual viewpoint, and when one of the languages has been learned, learning another presents no great problem.

References and Suggestions for Further Reading

(1) Bartee, Thomas C. Digital Computer Fundamentals. 4th ed. McGraw-Hill Book Company, 1977.

(2) Weiss, Eric A., ed. Computer Usage Fundamentals. McGraw Hill Book Company, 1969.

LECTURE XIII: COMPUTERIZED BUILDING AUTOMATION SYSTEM

In this lecture, a specific computerized building automation system, Johnson Control JC/80, is introduced here as an example. We could have chosen any other systems of merit. A partial list of commercially available systems will be presented at the end of this lecture.

A. Basic Functions

All building automation systems perform three basic functions.

(1) Monitoring of 2 state devices (fans, fire alarms, lights, etc.,) and variable conditions (temperature, BTU, power consumption, etc.)

(2) Control of 2 or 3 state devices and variable conditions by manual operation, time programming, or response to a change in monitored conditions.

(3) Provide information about monitored conditions automatically.

The system is a real time, general purpose digital computer that will allow the system to grow and expand with needs. Continuously on line, the computer makes decisions previously left to the control center operator.

B. Digital Communications Loop

The basic unit of all JC/80 systems is the general purpose digital communications loop. It consists of one or more loop remotes (data collection terminals) (LR) and a central processing unit (CPU) connected together with a coaxial cable.

Each loop remote (LR) contains plug-in printed circuit cards called point modules. The point modules connect the various field sensors, contacts and relays into the general purpose digital communications loop.

The central processing unit (CPU) is a general purpose digital computer that controls all information flow on the loop by generating computer words called data frames. These data frames direct commands and requests to specific points. Any loop remote terminal having information to send back to the computer can capture an empty frame and fill it in with the desired information. As many as 7000 data frames are generated each second. The binary pulses are generated at the rate of 500,000 per second. There are no less than 5 parity checks in each data frame to insure error free transmission.

Monitoring of binary (contact closure) inputs is accomplished through both a field interrupt technique and a scanning technique.

There can be as many as 31 loop remote terminals in a single loop, each with as many as 62 point modules. On the average, there are 4 points per point module.

Average Loop Capacity = 31 X 62 X 4 = 7688 points.

C. Leased Line Capability

There are three levels of telephone line communications capability in the JC/80 loop.

(1) The first level allows the transmission of the status of seven contacts over one pair of telephone lines to any loop remote terminal through the use of a binary transmitter. It is also possible to interface a device like a CRT terminal or a printer to a LR over telephone lines. Standard Bell 202R modems are used for this purpose.

(2) The second level allows a loop remote terminal to be connected into the coaxial loop via telephone lines. It has the same capabilities and capacity as the standard LR. All communications are in true digital form.

(3) The third level allows direct communications with the digital computer over telephone lines. This allows a single CPU to monitor and control multiple coaxial loops through the loop controller (LC) on each loop. This loop controller is the same computer that functions as a CPU on single loop systems. This configuration is used when several thousand inputs must be monitored over telephone lines. Since this is the only system configuration that does not scan through the

telephone lines, it is the only system configuration that can monitor an extensive number of inputs over the telephone lines without drastic degradation in system response.

These three levels of telephone line communications can be used individually or in any combination.

D. System Operation

The heart of the JC/80 single loop system is the CPU which is a real time general purpose digital computer. All communications through input/output (I/O) devices, such as teletypes, CRT terminals, is controlled by the CPU. It controls the flow of information between I/O devices, the sending of commands to all field points and the flow of alarm messages to the various I/O devices.

Lectures XI and XII are applicable to JC/80 because it is a computer system in the true sense.

E. A Partial Listing of Commercially Available Computerized Building Automation Systems

(1) JC/80 Computerized Building Automation System, Johnson Controls, Inc.

(2) Mini-16 "Watt-Watcher" Energy Management System, Gould Inc.

(3) Modicon Model 1084, Modicon Division, Gould, Inc.

(4) Sentry 1260, Process Systems, Inc.

(5) Sentry 1270/1280, Process Systems, Inc.

(6) Sentry 1290, Power Demand Control System, Process Systems, Inc.

(7) IECS Computerized Energy Management System, International Energy Conservation Systems, Inc.

(8) System/7, Power Management, IBM.

(9) Series/1, Power Management, IBM.

(10) Reality, Microdata Corporation.

(11) Central Supervisory Control System, Robertshaw Controls Company.

(12) Power Regulator Company

(13) Honeywell, Inc.

APPENDIX

Slide Narration and Slides*

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*Slides are present only in instructor's copies of course initially presented to institutions. Slide Narration is included in all copies to serve as a list of suggested conservation actions.

SLIDE NARRATION

This collection of slides is divided into two sections. Slides 2-18 are suggested as an introduction to this course. Slides 19-29 illustrate a specific problem in electrical load management and a possible solution. This section of slides is suggested for use with Lecture VIII, "Rate Schedules and Billing," but they may be used as the instructor judges appropriate.

1 Title Slide.

2 DEMAND METER - A demand meter is identified by its having two scales, one of which indicates instantaneous power demand or KW. Usually, there will be no difference in the KWH indicator from that of the regular home electrical meter. In this meter the four small dials indicate energy in KWH and the long single meter indicates power in KW.

3 The electrical load profile of an all-electric school closely resembles that of the utility company. This load profile was made from an actual chart recording of one of the North Carolina all-electric schools for a 24-hour period in February. Obviously, this school would add greatly to the peak load of the utility company.

4 These are copies of actual charted electrical loads of Duke Power Company for one summertime 24-hour period and one wintertime 24-hour period. Note that the curve on the right is very similar to the load profile of the all-electric school. Note that the peak for the utility and for the school occurred at about 9:00 A.M. The load profile on the left was made during August, with the utility company peak occurring at about 6:00 P.M. Usually, this peak occurs at about 5:00 P.M. It should be obvious that this peak comes about due to the air conditioning load. Here to, the peak occurs shortly after that of an air conditioned school, but the utility load would have almost peaked when the school peak was reached.

5 On the left is a copy of the actual charted load profile for February 7, 1975 for the West Iredell High School which is all-electric. Note the peak has been reached by 9:00 in the morning and that the major portion of the electrical load occurred during the high demand portion of the electrical utility company. The chart on the right depicts a hypothetical load profile that could come about if electrical energy could be stored so that electrical power could be used at a time when the unit cost would be lowest. Normally, the white portion

would be across the entire bottom portion of the chart if maximum load shifting could be obtained. The profile indicated could be programed if power could be purchased between midnight and 7:00 in the morning at a cheaper rate than during the remaining hours of the 24-hour period.

6 This mechancial equipment room contains four 53 KW water heaters with very little storage capacity (two heaters are shown). It should be obvious that very little load shifting can be achieved here. Look at the savings that could be achieved if this 212 KW instantaneous load could be removed from the peak for any one month. In some cases this 212 KW load would cost $1,060 a month as penalty at the rate of $5.00 per KW. Take note that this is paying for no energy.

7 Here is shown a water heater having a 1,000 gallon capacity. In this particular school three such water heaters were installed. In this case it will not be necessary to heat water or to use electrical power for that purpose during any portion of the daylight period. The 3,000 gallon storage capacity for domestic hot water will permit this school to program the use of electrical power for heating water during hours that would provide the lowest cost.

8 Shown here are two water thermal energy storage tanks under construction. This type of construction can be employed by school systems so that electrical energy can be used at night to create heat for use the next day. Obviously, tanks must be extremely large if enough energy is to be stored for comfort heating.

9 Here, an underground storage tank is being filled with water. This tank, on the campus of Stanford University, will be used to store 4,000,000 gallons of chilled water. The installation of this tank made it unnecessary to install $2,000,000 worth of chilling equipment even though the Stanford campus was being greatly enlarged. Here is an example of electrical load management in which many millions of dollars will be saved.

10 Here is a view of the parking lot, street, and tennis court located above the Stanford University thermal energy storage tank.

11 Basic electrical recording instruments are necessary as working tools in electrical load management. Techniques being stressed in this course cannot be implemented until accurate records of existing electrical conditions are established. Shown here is a simple amperage recording meter. While not showing KW profile, it will show identical

profiles that are relative to the KW profile and can be used simply by locking the probe around one of the conductors. Obviously, it will be better to have a probe for each load-carrying conductor.

12 The design of energy management control systems for sophisticated school plants is no simple matter and requires expertise of the highest order. Equipment such as shown here can be programed so as to bring about great dollar-savings if options are available. Loads may be shifted or lessened. Hardware and software being taught in this course can be employed to achieve the lowest operation cost as high energy consuming equipment is managed.

13 Electrical load management may employ elaborate control systems or some degree of management can be obtained through the use of simple 7-day program time clocks. Shown here is a console in which the operator can observe the operation with the use of schematics while the computer may be actually monitoring and controlling the equipment.

14 Usually, electrical load management control equipment can be applied to existing controllers. Shown here are conventional electro-pneumatic devices that will work well in conjunction with energy management controllers.

15 It is necessary that existing systems on the market be evaluated carefully to avoid the installation of equipment that may be oversold by high pressure salespeople. Control equipment should be selected on the basis of need rather than ready availability.

16 Management systems may be relatively compact,

17 or it may be appropiate to install more sophisticated systems.

18 Comfort heating and cooling and general electrical loads required to operate public schools must be employed by school administrators and technicians in such ways that costs can be held to a minimum without sacrificing good educational environment. It is important that electrical energy generated by such a plant as shown here be utilized without the unnecessary penalties that must be employed if poor electrical load management is exercised by school administrators. We benefit by the proper use of electrical energy; we lose by poor management.

To illustrate rate schedules and some of the methods used in determining electrical bills, an actual example has been developed showing how demand charges might be reduced by using a technique such as thermal storage. This example illustrates demand charges, energy charges, ratchets, and other clauses with which one working with electrical load management should be familiar.

19 The rate schedule used in this example is Carolina Power and Light schedule GS-3. The various demand and energy charges are as shown in the slide.

20 In addition to charges as indicated, this particular rate schedule includes what are normally referred to as ratchet clauses. Under a ratchet clause, the billing demand would be derived from previous actual demands by a stated formula. Ratchets on this rate schedule are based on 80 percent of the maximum peak reached during the summer months and 60 percent of the peak which occurs during the November - June period. The higher ratchet figure during the summer months is probably due to the fact that this power company is peaking during the summer months and is therefore penalizing a customer for high summer peaks.

21 If the winter peak demand is 866 KW and the summer peak is 304 KW, then the minimum billing demand for a period of one year after such demand is set would be 520 KW and 243 KW respectively.

22 A bill that a school received is 127,125 KW-HRs usage with an actual demand of 866 KW. Using the GS-3 rate schedule the bill can be determined.

23 Costs for both demand charges and energy charges have to be determined. Using the schedule, the demand charge would be $3208.37.

24 The energy charge was to be computed as indicated and the total bill is $5394.92.

25 A school is not a good customer for the power company according to the demand that they put on the power company facilities. Schools typically use electricity during high demand periods and are not easily able to spread their use of electricity over a period of time. One method that can be used is thermal energy storage of water to be used for heating or hot water at a later time. Generally, the demand for electricity by school can be cut in about half by shifting heating and hot water loads. If the same bill was figured using thermal storage, the demand charges would be $1589.11 and the total bill is $3805.81.

26 This slide shows how yearly bills might be affected by actual and billing demands. Actual billing information is included in the chart. Notice how the 520 KW demand ratchet is the billing demand for several months during the summers.

27 If the same bill is refigured on a yearly basis with thermal storage, the cost of electricity is greatly reduced.

28 Savings for a one-year period by limiting demand through the use of thermal storage is $12,793.62.

29 The average cost per KW-HR is $.042 without thermal storage and $.029 with thermal storage.

30 Credit Slide.