NEEDS, APPLICATIONS AND TECHNIQUES OF LOAD FORECASTING APPLIED TO OPERATING AND CONTROLLING A POWER UTILITY

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ABSTRACT

This Major Technical Report summarizes the results of a literature search in the field of forecasting methodologies applied to the needs of planning and operating a power utility. The purpose of the study is to present 1) the "what is" and "how to" in load modeling and forecasting, and 2) a synthesis of the most common techniques being evaluated or implemented by different specialists. It is proposed to discuss load forecasting in terms of related subjects and applications by developing a progressive analysis of the power industry in terms of growth, managerial concepts and computer utilization. Advantages and disadvantages are discussed logically and objectively in order to assist an interested person in the selection of an appropriate technique for his particular need. Analysis of various procedures results in recommendations for subsequent studies.

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CHAPTER I

SCOPE

This Major Technical Report summarizes the results of a literature search in the field of forecasting methodologies applied to the needs of planning and operating a power utility. The purpose of the study is to present 1) the "what is" and "how to" in load modeling and forecasting, and 2) a synthesis of the most common techniques being evaluated or implemented by different specialists. Advantages and disadvantages are discussed logically and objectively in order to assist an interested person in the selection of an appropriate technique for his particular need. New procedures are not introduced.

It is proposed to discuss load forecasting in terms of related subjects and applications by developing a progressive analysis of the power industry in terms of growth, managerial concepts and computer utilization. This format helps to emphasize and to place in proper perspectives the increasing importance of an effective forecasting methodology in the control and operation of a power utility in our fast growing computer age. Areas requiring additional research and development became evident during the study and these form the basis for recommendations. The author also believes that the paper is perhaps the only one which reviews by means of the progressive analysis, described above, all of the typical forecasting methodologies. The Reference and Bibliography reflect some of the most serious papers and complement the presentations of various procedures.

CHAPTER 2

INTRODUCTION

Load forecasting, in our context, refers to peak load demand. The term is general and it applies to peak consumer demands, residential or business, to peak area interchange demands and to peak contractual demands. An accurate forecast is essential for short and long term system planning since it represents a barometric reading reflecting both generation needs that is, capital expenditures, and sales forecasts, that is, annual revenues. Hourly, daily, weekly, monthly, and/or seasonal forecasts, are desirable and effective for different applications. Twenty-four hour forecasts guide an operator in planning short term generation needs. Seasonal requirements will assist the planner in recommending new transmission lines, additional generating capacity and, together with other indicators, such as economic trends, he can most efficiently and confidently guide the development of the industry to better use of available resources and to provide a continuing improving service to consumers.

Section 3. describes the power utility as one of the largest and ever growing industry in North America and abroad. With results from surveys and predictions from well known observers, the first phase in our progressive analysis is presented. Section 4. introduces some fundamental concepts considered essential in managing the technical side of the business. Area regulation and economic dispatch as automatic control applications are discussed, as well as other indicators.

Demand and energy forecasts begin to take shape as a tool to good management. Section 5. contains a brief exposé of the evolution of computers in operating the utility. Applications, trends, real time system, central-satellite concept and economic impact are discussed.

Having developped the necessary concepts in the first sections, Section 6. now converges on load forecasting techniques. Methodology, types, contingencies, applications and limitations are presented in detail and discussed from the point-of-view of different authors in the field. The impact of computers and their growth in the power industry is emphasized.

Section 7 concludes with a discussion of the present state of the art, reaction to automating load forecasts, and areas requiring further research and development.

CHAPTER 3

THE POWER UTILITY - A GROWING INDUSTRY

3.1 The Power Industry Today

Describing one of the largest industries in North America in a manner that would do it justice reflects a task beyond the capabilities of the author and it is not the intention to do so here. However what is important as a foundation to the proposed progressive analysis is to develop a moderately good picture of the size of the industry in terms of economic impact and growth performances.

A considerable portion of the economic growth and industrial strength of the United States and Canada relates to the growth of its electric power industry. In recent decades the industry has been growing at a rate of about 7% per year, more than doubling its generating capability every ten years. This increasing rate no doubt results from a demographic evolution, increase in the standard of living which incites to more comfort and to a desire by more and more women to lessen their household chores by going electrified. The social pressures of pollution has accentuated the trend. Also more energy is and will be needed for purposes such as: (Ref. 1)

1) to increase productivity, substituting more mechanical equipment for human labour;
2) to conserve materials; to change to less material! Intensive designs requiring more energy in their fabrication; to recover and reprocess used materials rather than continuously using new material; to

develop synthetic and substitute materials for scarce natural ones;

3) to improve communications, meeting increased desire to travel in a world that becomes more and more integraded;

4) to provide greater recreational opportunities;

5) to substitute for the decreasing availability of other energy demand as the level of a country's population increases.

However the relation between energy use on a per capita basis and population growth is not necessarily directly proportional. Energy use is very much dependent on a country's "state of development" and it is noteworthy to mention that Canada has almost the highest energy use per capita in the world. Only the U.S.A. is ahead of Canada with the closest runners-up being Norway, Sweden, Czechoslovakia, United Kingdom and East Germany. Corresponding with the high use of energy, the rate of growth of energy used per capita in Canada is low-about 2% per annum. Countries using only much less energy per capita have growth rates several times as high. Energy consumption can be considered as an economic indicator.

In the past twenty years, we have witnessed a rise in line voltages resulting from a rise in power loads. Transmission lines of say 120, 69 and 46kV have been declassified and are now considered subtransmission lines. However, distribution line networks are now of the 12, 25, and 34kV classes. To satisfy the ever increasing demands is one of the great challenges now facing power engineers.

One is tempted to conclude, and the statistics confirm this, that the economic impact on a society is that of a billion dollar industry. As the demand and the forecasts continue to rise, the generating capacity, the transmission and the distribution lines must correspondingly be adjusted to satisfy the need. Figure I provides an example of past and future requirements in U.S. generating capacity. Notice that in the past ten years the MW output has nearly doubled and it is expected to reach a new requirement of close to 850 millions of kW (Ref. 2) by 1980.

3.2 Some Future Expectations

In order to develop a further appreciation of the growth of the industry, let us explore briefly some of the transmission expectations for the 70's. By transmission, the author refers to lines with a voltage capability exceeding 115 kV.

For understanding the growth of transmission capability, and the actual level of this growth, the term "megawatt miles" has been developped (Ref. 2). The use of this term implies two facts: 1) lines of each voltage, e.g. 135, 230 or 500 kV, can be assigned megawatt ratings, and 2) transmission system capability is related to the distance power is transferred. The product of circuit loading and circuit length provides the megawatt-mile capability. Figure 2 summarizes some transmission capability by voltage class. (Ref. 2) The term is a simple convenient measure of gross capability.

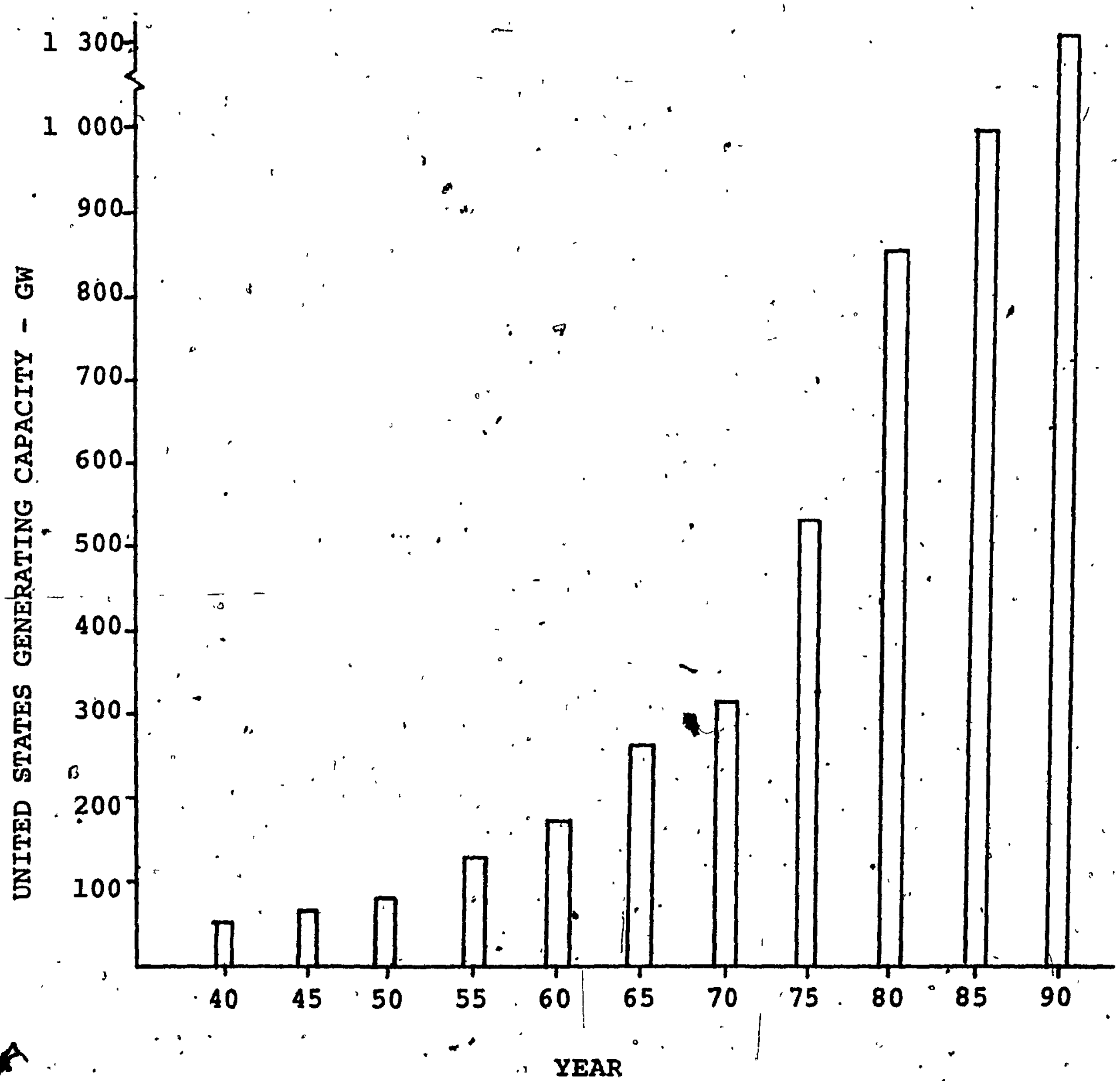


FIGURE 1

Past and Future Requirements in U.S. Generating Capacity.

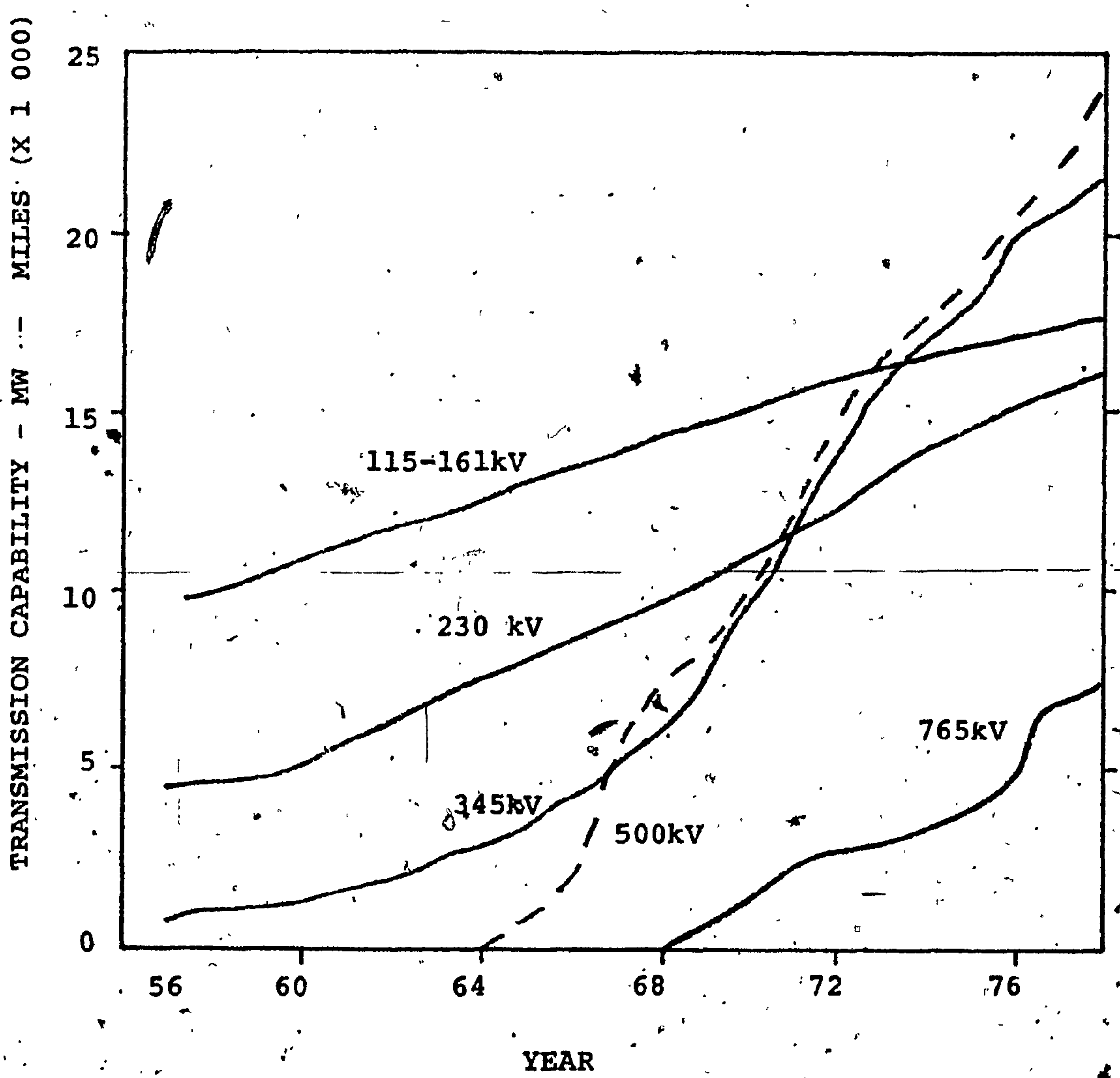


FIGURE 2

Transmission Capability by Voltage Class Shows the Important Roles of EHV in Moving Bulk Power in the U.S.A.

Total growth of transmission capability in megawatt-miles through 1978, for the U.S., is compared with generating capability in Figure 3 (Ref. 3). As the two curves plotted together show, generation and transmission capability followed almost the same pattern until 1965. The curves then diverged, with transmission capability increasing more rapidly. A rational explanation for the excursion and the transient movement between 1965 and 1970 is the large growth in EHV (Extra High Voltage) and the move to pooling of systems. Since the Northeast Power Failure of 1965, the utility industry has placed much greater emphasis on transmission for interconnecting systems and pools together as a mean of improving reliability. It is behond the scope of this paper to elaborate on reliability and let it suffice to say that reliability is an expression of "availability" and "security", and hence of performance.

The growth necessitates considerable capital investments by the power industry for new generating stations, transmission and distribution lines, and associated hardware. The charts in Figure 4 reflect the capital spending from 1961 to 1970 in the U.S. (Ref. 4). The growth is expected to continue. Consumers appear to develop an never satisfied thirst for the benefits derived from electricity. However forecasts and consequently budgets, are a function of how well planners can predict future demands. This is a billion dollar market

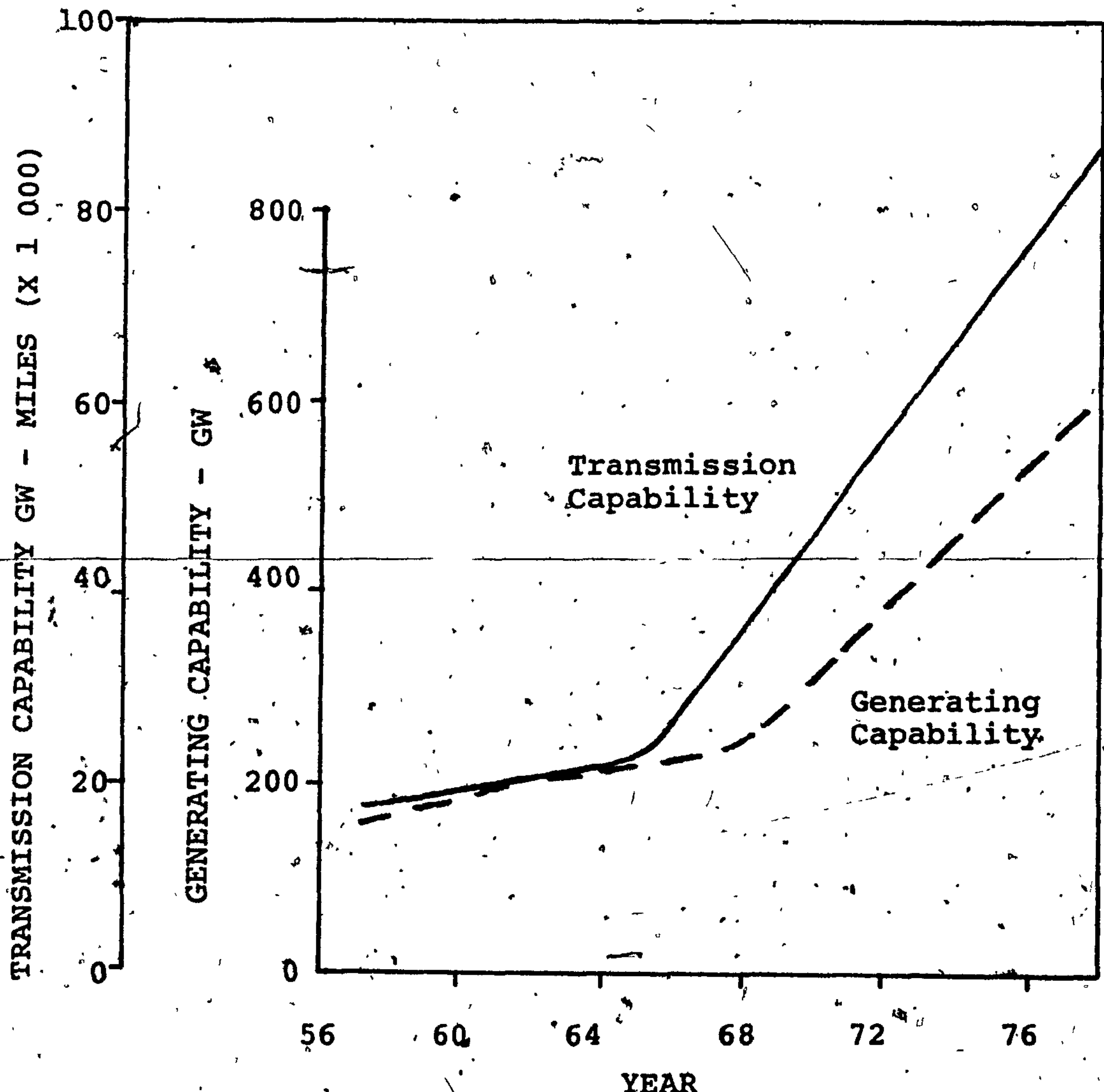
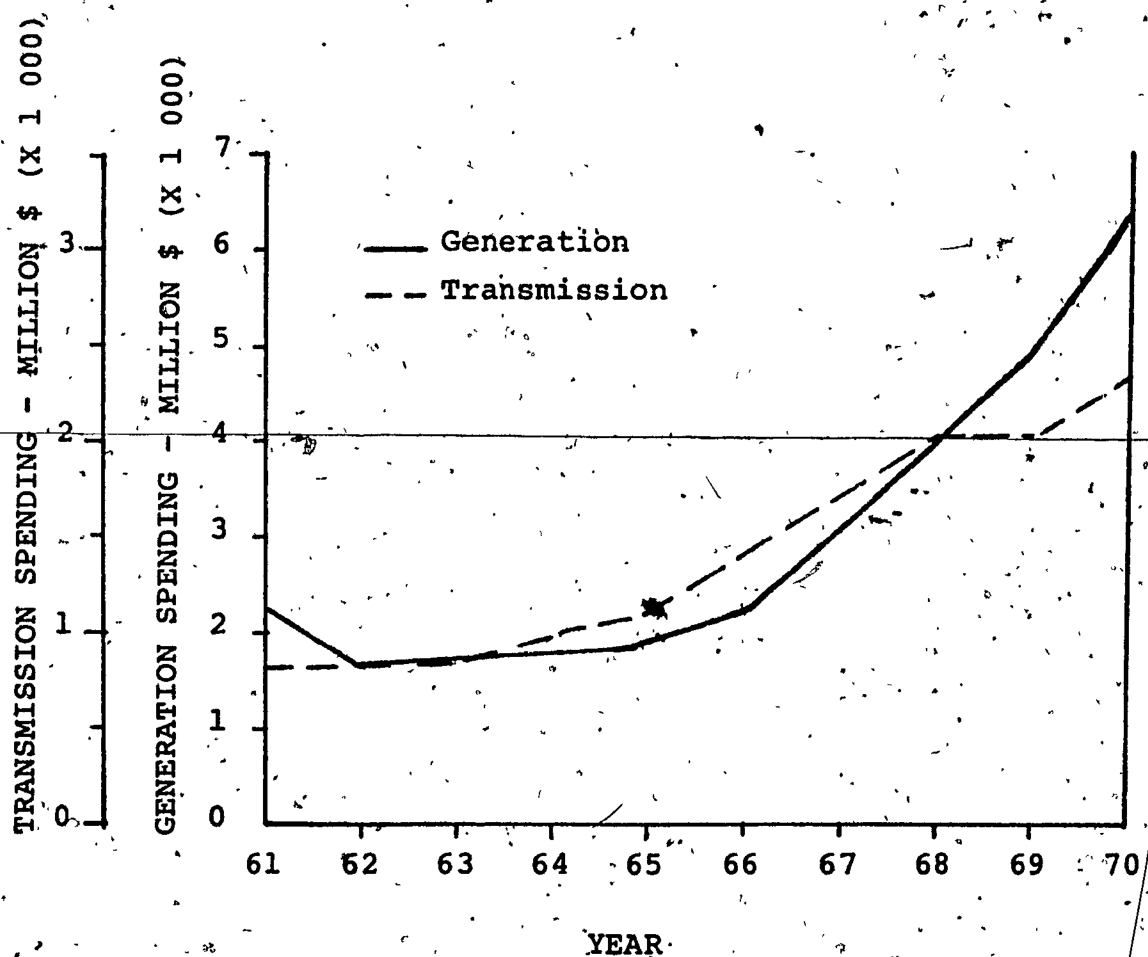


FIGURE 3

Growth of Transmission Capability (GW - Miles) is Compared with Generating Capability for the U.S.



<u>FIGURE 4</u>

Capital Expenditures for Generation and Transmission.
The Trend is Expected to Continue.

and because of the high cost of money today, managers cannot afford the luxury of inaccurate load and generation forecasts. We will discuss forecasting and confidence levels in greater detail in a subsequent section.

During the next 20 years, the electric utility industry will face a challenging era of tremendous electrical load growth. By 1990 some experts predict summer peak demands to exceed 1000GW and installed capacity to be in excess of 1300GW (Ref. 2). To make these additions in a way that is both economical and compatible with the environment is the challenge, the greatest the power industry has ever faced.

Let us now give some consideration to the planning and operating of a power utility.

CHAPTER 4

MANAGING A POWER UTILITY

This section is not intended to describe in any great details the many areas that managers or operators must consider in the control and operation of a power system. For one, the author does not claim to have such expertise. However, the discussion is important to assist the reader, or user, in the progressive analysis being developed. It introduces some control terminology. It explains managing objectives and philosophies. The need for computer utilization will become apparent.

4.1 Objectives

The primary objective of the electric power industry is service to its customers. Service or security dispatch, otherwise called operational integrity, heads the hierarchy of constraints in the control of the power industry, Security dispatch means the safe delivery of energy where it is demanded and it takes procedence over economy of dispatch, and if needs become acute, over ecological considerations as well. Engineers must monitor the pulse of circuits in order to control voltage regulation and kilowatt losses which are criteria for reliability, i.e., security. The planning of electric networks must always be based on providing adequate service to the customer. Continuity of service is a measure of the network reliability. In order to achieve this goal, network planning must generally consider the following points:

(i) Sufficient availability of generating capacity;

(ii) Satisfactory transmission and distribution networks;

(iii) Reliable equipment;

(iv) Flexible plan of operation, particularly at the distribution level, with sufficient transformer banks and circuit breakers to maintain the appropriate protection for continuity of service.

Power companies in many countries have, in fact, met these objectives with such a high degree of success that the service is now almost taken for granted with the everyday social, industrial and commercial existence very dependent upon it. The objective has actually been turned into a responsibility-continuity of high quality electric service to the consumer.

A secondary objective is economy in the production and operation of the electric power systems. This factor has been the subject of increased attention by power system engineers and managers over the past two decades. For example, today's modern generating stations are equipped with a variety of instruments, automatic controls, and computers, aimed at simplifying operator decisions and minimizing the power production cost. More developments in automatic techniques can be expected that will further improve each individual unit and station performance.

For completion, let us mention that ecological consideration is a third objective, or constraint, in the planning and control of a power utility. Minimum emission dispatch is a term gaining acceptability in view of the growing concerns towards "keep-it clean" publicity campaigns.

4.2 Operating Challenges

The previously mentioned rapid growth and expansion of electric power systems-whether they are large or small in total installed capacity and whether this capacity is composed of thermal, hydro, or nuclear generation-has also caused a substantial multiplication of operating challenges. These can be summarized as follows:

- Maintaining a balance between the generated output and the ever varying customer load;
- Obtaining the required generation at a minimum cost (or in the most efficient manner of utilization of natural resources, i.e. water, etc.);
- Establishing the present and future worth of energy exchange with neighboring power systems (for interconnected utilities);
- Establishing the optimum number of units on line and the best timing to commit units to the line to maintain the appropriate spinning capacity for system stability, security, etc., while still maintaining economic operation;
- Monitoring appropriate tie lines, feeder loads, transformer loads and temperatures, plus station and substation breaker and disconnect switch operation for stability, economic and security reasons.

4.3 Interconnected Systems

Utilities can operate within predetermined geographical boundaries. However, over the past four decades, adjacent power companies have interconnected with one another for parallel operation. By this means, generation and reserves can be shared. Advantage is taken of load diversity and of time-zone differences to transfer generation over interconnecting tie lines from an area of low demand to one of high demand. Larger, more efficient units can be purchased and their outputs shared, and rotating reserves in a given area reduced. Overall operating economies are correspondingly achieved.

One of the largest interconnection in North America includes the Midwest, the Gulf of Mexico Coast, the Eastern Seaboard and Eastern Canada. Constituent groups are the Interconnected Systems Group (ISG), the Pennsylvania - New Jersey - Maryland pool (PJM) and the Canadian - Eastern United States group (CANUSE). The more than 150 utilities of this interconnection, having a total peak load greater than 130 million kW, operate continuously in parallel and cooperatively.

4.4 The Control Problem

Coordinated control is essential to effectively meet and resolve the challenges, and to successful parallel operation. The control requirements, for isolated or interconnected companies, are basically twofold: (Ref.5)

(i) Area Regulation,

(ii) Economic Dispatch.

4.4.1 Area Regulation

Total generation within an operating area must be adjusted to follow the moment-to-moment load changes within that area, in suitable coordination with generation and load changes in all other operating areas, so that scheduled tie-line interchanges, system frequency and system synchronous time are all properly maintained. This function is referred to as "area regulation", and it is implemented by a Load Frequency Controller. Note that the word "area" can be a part of a company, a whole company, or a group of adjacant companies.

~~The heart of this control function is known as area~~ control error. It is fundamentally an error signal-calculated by either analog or digital means-which represents the number of megawatts a power system must increase-or decrease in order to fulfill its responsibility to its customers and if interconnected, to the interconnection of which it is a part.

On an isolated system, the control error is derived by combining the actual system frequency, the desired system frequency and the system regulating characteristic. However, when a utility becomes interconnected, then this signal must not only look at the frequency and frequency set point, but also at the instantaneous sum of the power flow on all of the tie lines interconnecting the individual system with its neighbors as well as the net interchange schedule and the system regulating characteristic. This is accomphished via the use of "load-flow analysis programs."

In either case-isolated or interconnected system - the area control error originated the basic control action which is forwarded to the generating units, thus maintaining the balance between the power system generated output and the ever-varying customer load.

4.4.2 <u>Economic Dispatch</u>

Optimal assignment of the total generation required at any moment from an area must be made among the many plants and units within that area to achieve optimum economy consistent with safe operation. This objective is identified as "economic dispatch". Substantial economies can be achieved by loading them optimally with respect to each other. Economic dispatch is achieved when generating sources within the area are loaded to equal incremental costs of delivered power.

4.5 <u>Demand and Energy Forecasts</u>

For management to judiciously consider all constraints in the hierarchy of controls under a coordinated plan it must be provided with accurate demand and energy forecasts. Demand, or load, forecasts are essential for short term and long term planning and for daily operations of the company. Energy forecasts reflect expected sales and provide a measure of the dollars available to support the projected expenditures. There is no doubt that energy forecasts play a leading, if not decisive role in the decisions concerning new means of production and transmission. Load forecasting techniques will be considered in detail in a subsequent section.

Managing a power company, a pool or a large interconnection requires the formation of a coordinated control philosophy whose elements have been introduced in the above paragraphs. We have reviewed generation, transmission and regulation. The following section will describe the evolution and the role of computers as a tool in managing a power utility.

CHAPTER 5

EVOLUTION OF COMPUTER UTILIZATION IN THE POWER INDUSTRY

5.1 General

The electric utility industry has traditionally embraced, and has a long history of utilizing automatic control techniques for its generating plants and transmission systems. The climate for innovation is good and the industry was among the first to realize the potential benefits, performance and economic, derived from computer applications.

In the utility industry, applications have been developed in three distinct areas. In the mid 1950's, companies quickly recognized the potential of applying digital computers to customer billing. At about the same time, the first major engineering applications were developed for large scale scientific computers. There included load flow, transient stability and short circuit studies, all of which were previously carried out on network analyzers, or analog computers. In 1958 the first control computer was installed in a power generation steam plant. (Ref.5) Its functions were logging of approximately 100 key variables, alarm scanning, performance calculations, and close-look direct control of two auxiliary temperatures. In the early 1960's the first control computers were installed for the real-time determination of economic loading of generating units i.e. economic dispatch.

Since that time, the applications in the areas of accounting, engineering and system operation have been extended to cover various related applications. More recently efforts have been turned to the development of real-time, or on-line, computer applications. In engineering, the new applications span the entire engineering activity, including system planning, design, construction and operation. With the significant technical advances in the design of computer system that characterized the 1960's, there appeared a trend in a shift from specific applications to more general information systems operating in real-time. This trend in computer application is expected dominate the 1970's.

5.2 Applications - Description

The author does not propose to review in detail what is already well documented. Mrs. Cohn and Ross, among others, have written numerous papers in the use of control theory, and the application of on-line computers to operating a power utility. First, second and third generation computers and their evolution as dispatch computers in interconnected systems are well described. (Ref. 6) Computers have indeed found applications in all areas of the electric power industry.

Power system applications can be divided into planning, operating and nonengineering functions. Let us review briefly computer uses in these various functions. (Ref. 7)

5.2.1. System Planning and Design

System analysis is taking on an ever increasing role. This results from the growing size and complexity of the systems, and a greater awareness of economic control and security requirements. At the generation level, computers assist in studies such as stability under transient, dynamic and steady-state conditions in simulation exercises. They further assist in unit selection, production cost evaluation and economic dispatch.

In transmission planning, computers are used in load flow studies, transmission line and cable design, conductor selection, radio interference calculations and right-of-way width determination.

In the distribution network design, applications are also numerous. Among the most important ones are: radial and loop system planning; secondary network analysis; capacity or applications; protective device coordination; neutral grounding; distribution transformer and secondary optimization; and new load and energy supply evaluation.

None of the above planning and design could confidently be performed without effective load forecasts. In this category, the forecasts are classified by types-industrial or residential. The analysis cover peak load, daily and seasonal and expected deviations. Forecasts are done on daily, weekly, monthly and seasonal bases. In section 6. various forecasting techniques and algorithms are described in greater details.

5.2.2 Non-Electrical Considerations

Included in this category are applications involving such items as mechanical and nuclear system analysis and heat balances; equipment considerations, and various aspects of fuel management. Civil and structural items cover items such as mechanical design. Construction design uses include equipment location for the plant, substations, line location and tower spotting. Other uses are for corporate modeling, PERT, CPM scheduling, inspection and others.

5.2.3. Operational Scheduling

The field of data acquisition and control is probably the one having received the most attention in the past decade. The technological advancement in computer systems, electronics and reliable and high speed communications channels is responsible for the small lead time between the first and third generation computers applied in the power industry. In this application are systems security, including load and tie-line frequency control; monitoring, logging and alarms; line tripping and load shedding; fault information nature; corrective strategy functions, restoration and postdisturbance review.

Equipment usage includes generator start-up and shut-down, turbine control, automatic switching, transmission system status and meter calibration checks.

On the operation side, economic dispatch, area regulation and unit commitment are other problems where the computer has made vital contributions to the solution.

The introduction of improved analytical software such as operator oriented load flow programs and the trend towards increased man-machine interface device applications has brought security dispatch and monitoring into real time operations.

5.2.4. Non-Engineering Functions

Most companies use their computers for customer and company billing, payroll, records, surveys of appliance usage, job estimates, rate calculations, and many other non-technical administrative functions.

5.3 Application - Examples

According to the saying, "the proof of the pudding is in the eating", let us explore some current applications of computer control technology in the power industry. More detailed references can be found in the Bibliography.

5.3.1. The possibilities of using computers for power system control are being reviewed by Britain's Central Electricity Research Laboratory (CERL) (Ref.8).
Load prediction and automatic load scheduling programs are being actively investigated. The rapidly increasing data handling and information display problems confronting operators have been partially overcomed by the installation of a large scale computer at the National Control Centre in London. British power engineers are now turning to computers to assist in their protection coordination plans.

In Britain computers have gained most ground in the control of power generating stations. This includes start-up and shutdown procedures, application of load, efficiency calculations, planning of maintenance schedules and other managerial operations.

5.3.2 The Central Power and Light Co., Texas, U.S.A. (Ref.9) is successfully operating an IBM 1800 system for economic dispatch control. The system was designed to satisfy the objectives of expandability, ease of operation, and avoidance of start-up problems. Because of the expandability criterium, the digital control computer was implemented in modules. System now handles, (1) economic dispatch of 22 generating units, (2) dispatcher's console, (3) system log's, (4) peak-load forecasts, and (5) engineering case studies (eg., load-flow program.

5.3.3 The applications of the Public Service Electric and Gas Company, Newark, N.J., load dispatcher's computer include, among others, a number of uses related to service quality or security. (Ref.10) Through its special "Bulk System Security" and "Scheduling of Outages" programs, the system is one of the first to perform in a real-time environment the following functions:

(i) Recommendations for system changes to improve security;

(ii) Security-oriented calculations concerning the present condition of the system;

(iii) A security analysis of the effect of possible future contingencies;

(iv) A security analysis of proposed switching operations required for maintenance;

(v) Recommendations of steps required to improve system voltage conditions.

5.3.4. The Bonneville Power Administration (BPA) is opening this year its new William A. Dittmer System Control Center, and its center of operation will be a system known as Real-Time Operations, Dispatch and Scheduling (RODS) (Ref. 11) Among the many features, it is noteworthy to mention some of the most important ones:

(i) An on-line optimal power-flow analysis will provide a voltage profile on a system-wide basis;

(ii) Routines will compute and provide stream-flow analysis, load forecasts, and operations planning;

(iii) System security monitors will output present and expected power system status.

The BPA believes that the computer-directed hydro-load scheduling and management can add over 500MW capacity that is unattainable with current manual and semiautomatic methods.

5.3.5 Another interesting application of computer control has been experienced by two utilities in Oklahoma, U.S.A. (Ref. 12).

A dynamic programming algorithm has been developed and is successfully applied to the optimization of power generation schedules for the utilities participating in a coordinated agreement. The control dispatches power from several alternative sources, including conventional hydro plants, thermal generation plants, pumped-storage units, and interchange contracts. The objective is to schedule hourly generation of these sources such that generation costs are minimized over the entire year.

5.4 Trends (Future Development)

Analysis of surveys (Ref.7,13) performed among the largest North American power companies indicates a strong trend towards preference for large scale, direct digital control (DDC), computer utilization. There is some divergence of opinion of the use of mini-computers for the central-satellite control-type of operation. Mini-computers, combine with high speed data acquisition networks can be effectively integrated in an overall computer-control power system.

In the operation of interconnected systems, the use of DDC will expend, and hierarchical computer arrays will regulate generation and power flow relationships between pools, areas and stations. Centralized computers will play an increasingly important role in monitoring and achieving system security.

Computer functions are manyfold and functions implemented are related to company size, priorities and progressiveness. Figure 5 (Ref. 7) represents the most common utilization of computer use in the power industry, and it indicates present and future uses. The trends appear to single out load frequency control and economic dispatch as primary functions. Very significant is the predicted increase in computer use for load forecasting.

An interesting conclusion reached as a result of another survey in 1971 (Ref.13) is that computers are not being applied fast enough to energy management, from planning through normal operation and emergency situations, to

FUNCTION	Present(1970)	Future
Area control error	2	
Automatic switching		1
Billing	3	10
Control	1	13
Cost calsulations	2	5
Economic dispatch	56	31
Economy interchange	7	1
Energy pricing	1	2
Fuel contract administration		2
Gas distribution forecast		5
Hydro-thermal coordination	2	5
Interchange scheduling	6	9
Line tripping		1
Load forecasting	4	14
Load frequency control	60	26
Load schedding		2
Logging	13	16
Maintenance scheduling	1	3
Monitoring	8	16
O.C.B. logging	3	
Off-line load flow	4	9
On-line load flow	2	12
Penalty factors or transmission loss calculation	4	4
Postdisturbance review	2	2
Production costs	3	
Relay setting check (short-circuit program)		1
Reserve monitoring		2
Security and alarm	15	27
Spinning reserve	1	4
System analysis		3
System status	1	3
Tie-line flow	5	5
Tie-line frequency control	2	
Unit commitment	3	17
Unit scheduling	1	5
Voltage control		2
Water resources management	1	

FIGURE 5

PRESENT AND FUTURE COMPUTER FUNCTIONS

Functions extracted from results of a survey (1970) of 118 companies (Ref. 7) of the present and planned use of computers for monitoring and controlling power systems.

prediction of long-range demand. There is still too much human intervention. The question, "Can computers do it under critical situation" is the common criterion among compagnies in the decision making when considering expansion of their existing partially computer control operations. However the trend to maximum computerization is irreversible and one great challenge facing control engineers in the 1970's is the "proving in" of load forecasting algorithms so that they can be confidently applied to an optimum management of a power utility via computer-control.

Load forecasting algorithms will now be discussed in greater detail.

CHAPTER 6

LOAD FORECASTING

6.1 General

In the previous section, we have demonstrated how computers, from analog to direct-digital control, have ascended to a podium of critical importance as tools to effective management of a power utility. Concurrent with the development of computer control systems, control engineers have been and are still giving much attention to applying and improving control theories. The objective is to maximize real-time computer-control of their network, both at the generation and transmission-distribution levels. Considerable work has been carried out on problems concerned with load-flow analysis, economic generation scheduling and system-security checking in power systems. An aspect of the overall problem which has not received enough attention is that of forecasting electrical load demand.

6.2 Load Forecasts

An essential component of a comprehensive, real-time control center for power systems is a method for the calculation of load forecasts-short, medium or long-term forecasts. The method must be accurate with optimum confidence level, have operational simplicity and based on a model which reflects the real system. Power system load forecasters are concerned with identifying future needs for both energy and peak power. Energy forecasts provide a basis for estimating future revenue, a most important factor in corporate financial planning. Forecasts of anticipated peak power demand basically determine company investment in additional generating and transmission facilities in order to assure an adequate supply of electrical energy.

6.2.1 Long Term Forecasts

Specifically, five to seven year forecasts of seasonal peak demand are required for planning future system capacity, i.e. to assess:

(i) increase in generating capacity required year by year to meet the growth in demand and the best geographical location for new plant;

(ii) provision of main transmission links between generating plant and supply point;

(iii) necessity for establishing new supply point;

(iv) extension and reinforcement of the distribution system connecting the supply points to consumers.

6.2.2 Medium-term Forecasts

The one to three year forecasts of weekly and seasonal peak demands are required to:

(i) prepare maintenance schedules;

(ii) develop power pooling agreements;

(iii) select peaking capacity;

(iv) provide data required by certain reliability coordinating centers.

6.2.3 Short-term Forecasts

Shorter-term peak demand forecasts are necessary for:

(i) on-line solution of scheduling problems, such as unit commitment and economic dispatch;

(ii) security analysis, such as on-line load flow solutions.

Last but not least, it must be stated that there are potential economies to be gained from a well organized forecasting methodology. Demand forecasts are up-dated quarterly or annually by electric utility companies and this could result in several man-months of efforts. The inadequacy of the forecast for a particular application may cause several departments of a company to become involved in forecasting with the danger of duplication, redundant data files, and consequent loss of efficiency in meeting the total forecasting needs of the company. Furthermore forecasts can lead to savings or to unnecessary expenditures in the capital investment programs, depending on the accuracy of the technique used.

Flexibility in the methodology permits several departments, e.g. long term planning and operation, to use the same basic algorithms with variations easily implemented through different sub-routine packages. The final procedure must reflect, as stated above, the needs of the user(s). The financial departments require revenue forecasts to guide short-and long-term capital expenditure requirements. The operation group, i.e. schedules, security, and network supervision, insist on short term peak demands as guides to formulation of schedules and support data in network supervision to insure security of power.

Having identified the growth pattern of this primary industry, established the perspective of computer evolution and utilization, and having defined the reasons for load forecast requirements, we can now appreciate that a sound forecasting methodology is a critical requirement in the effective operation of the utility. The evolution of digital computers, developments in control and probability theories, advancement in application of electronic technology and in high-speed, reliable telecommunication data acquisition systems, are some of the catalists responsible for the greater awareness among system engineers to develop reliable load forecast techniques.

The following sections will review the methodology, types, contingencies and applications of load forecasting algorithms.

6.3 Load Behavior and Patterns

A priori, the behavior of the load would appear to be a complex phenomenon with no apparent pattern. The load being the useful or real part of that which is generated and distributed, its behavior reflects the whims of the consumers. Consumers are by far non-homogeneous with respect to the needs. Commercial, residential and rural users have different requirements and also exhibit varying cycles of consumption.

However, contrary to the uninitiated and to the good fortune of planning engineers, load patterns are not completely random. That is, load behavior is highly correlated with historical patterns, with known events and with other measurable processes such a temperature, wind, etc. There is also an uncertainty associated with this behavior resulting from unknown events, and the incompleteness of mathematically representing these processes. It is these uncertainties that motivate different system or control engineers in developing either deterministic or probabilistic models for load forecasting algorithms.

An accurate definition of a desired load behavior could be obtained by continuously monitoring a bus, a node or some other convenient location in a power grid and by relaying the measured information to a control centre for visual presentation. This method requires an extensive data-acquisition (DAC) system, and it does not provide the manager or operator with a forecast of what to expect tomorrow, next week, or next year. DAC systems are employed to monitor the pulse of a network in order to maintain reliable and efficient service. Because of needs, such as information required for load flow analysis, contingency studies and economic dispatch, the data acquired from DAC system can also be useful to planning engineers in load forecasting. As described in a subsequent section this data base becomes often the key to success in developing a valid model for forecasting purposes.

Before reviewing some trends and evolutions in the development of realizable forecasting procedures, a physical explanation of load behavior is in order.

With the exclusion of the loads that are due to known events, e.g. Christmas season, sport events, there are basically two interrelated processes which cause the load to have its special characteristics: (Ref.14)

1. the process that describes the aggregate customer requirements;
2. the weather process which influences the level of these requirements.

6.3.1 Aggregate Customer Requirements

The characteristics of the aggregate customer requirements are directly reflected in the load and are the main reason for being able to identify existing patterns. The French Power Administration, among others, have observed interesting correlations between yearly power consumption and generation within defined serving area and they are using the pattern in some study of load forecasting. (Ref.15,16)

Broadly speaking an annual electricity demand can be considered as a time series, whose points represent daily demands, with peaks and valleys corresponding to seasonal demands. Erratic fluctuations are superimposed on this base line and represent variations of daily and weekly demands and weather constraints.

The load pattern can be considered as composed of low frequency and high frequency components. The low frequency components reflect the aggregate customer requirements in terms of weekly, seasonal and growth components. The high frequency components represent the random and more probabilistic events affecting load behavior and they reflect weather processes and unpredictable events.

The long term pattern is basically an annual pattern superimposed on a rising trend line whose slope reflects the rate of power demand and generation increase.

Let us explore in more details these patterns and observe some plausible causes. It should be noted that in our context as well as in most of the literature covered, a load pattern reflects a weighted or average behavior of all types of customer demands. That is, one recognizes that commercial, residential and rural requirements produce different patterns. However, when considering load behavior with the objective of developing forecasting procedures to assist in load generation, scheduling and other managerial functions, it is accepted that a weighted pattern of all effects is sufficiently representative.

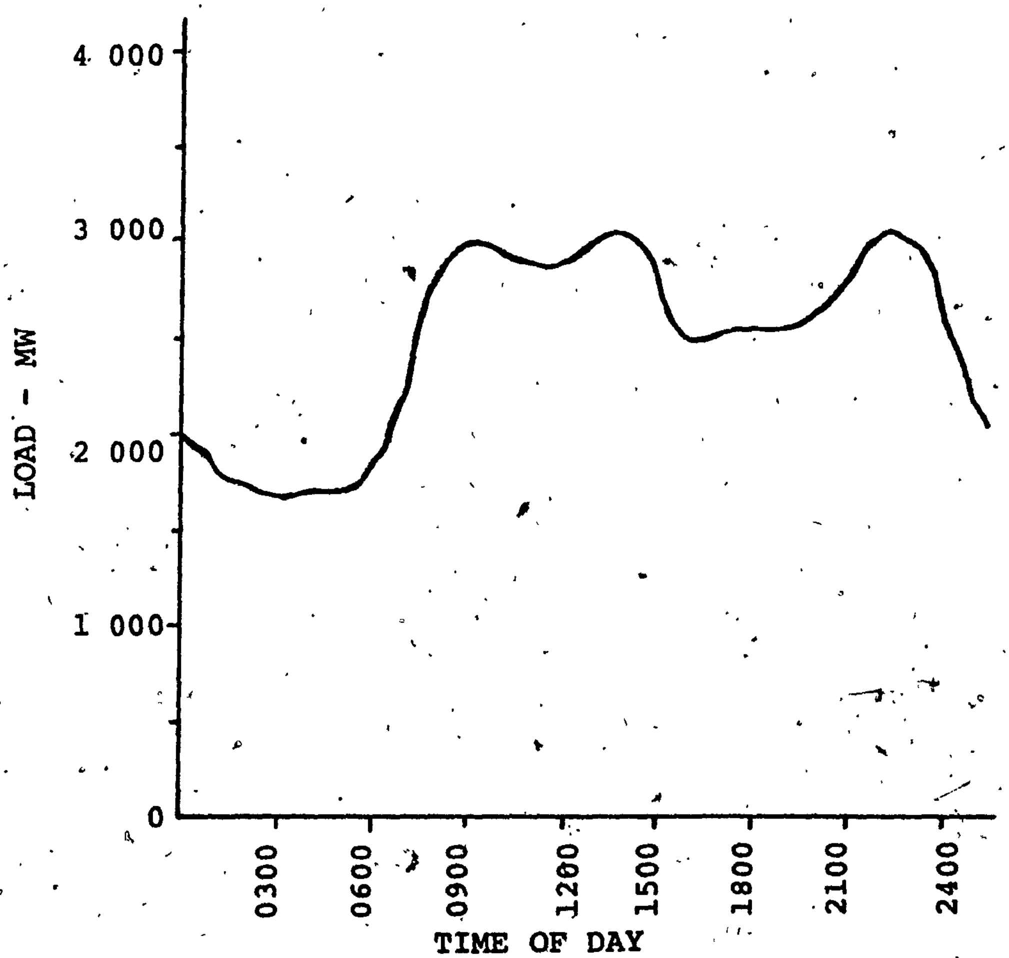
First, there is a daily pattern. This behavior reflects the difference in activity level during a given day of the week. These requirements start to increase in the morning to reach a morning peak. After decreasing in the afternoon, they reach a peak again during the dinner hour after which they gradually decrease to reach a low value during the night.

A most interesting characteristic is that this pattern is nearly periodic over a 24 hour period. Figure 6 depicts a typical daily load curve (Ref. 17).

Some authors(E.g. Ref. 18,19,20) consider short term patterns and forecasts by expanding daily variations into hour or minute behaviors. These variations can be erratic since the causes are often attributed to transient phenomena originating in the system or by customers. Examples could be temporary line faults and machine start-up, respectively.

Second, there is the <u>weekly</u> pattern. This reflects a changing business activity level throughout the week. On weekends the requirements are, on the average, lower than on week days. Within the week there is a gradual change with requirements starting to rise on Monday and to lower again on Friday. The daily patterns, however, remain the same. An exception to the two-part weekly cycle is observed when a holiday occurs. The level of this pattern depends on the nature of the holiday. Figure 7 depicts a typical weekly load curve (Ref. 21).

Third, there is a <u>seasonal</u> pattern. As descrived previously an annual load pattern is characterized by valleys and peaks reflecting summer and winter requirements, respectively. The transitions correspond to Spring and Fall. Winter behavior represents heating requirements while Summer loads basically represent air conditioned usage. Superimposed on this trend line are the high frequency components which portray daily and weekly changes together with erratic



<u>FIGURE 6</u>

A Typical Daily Load Curve

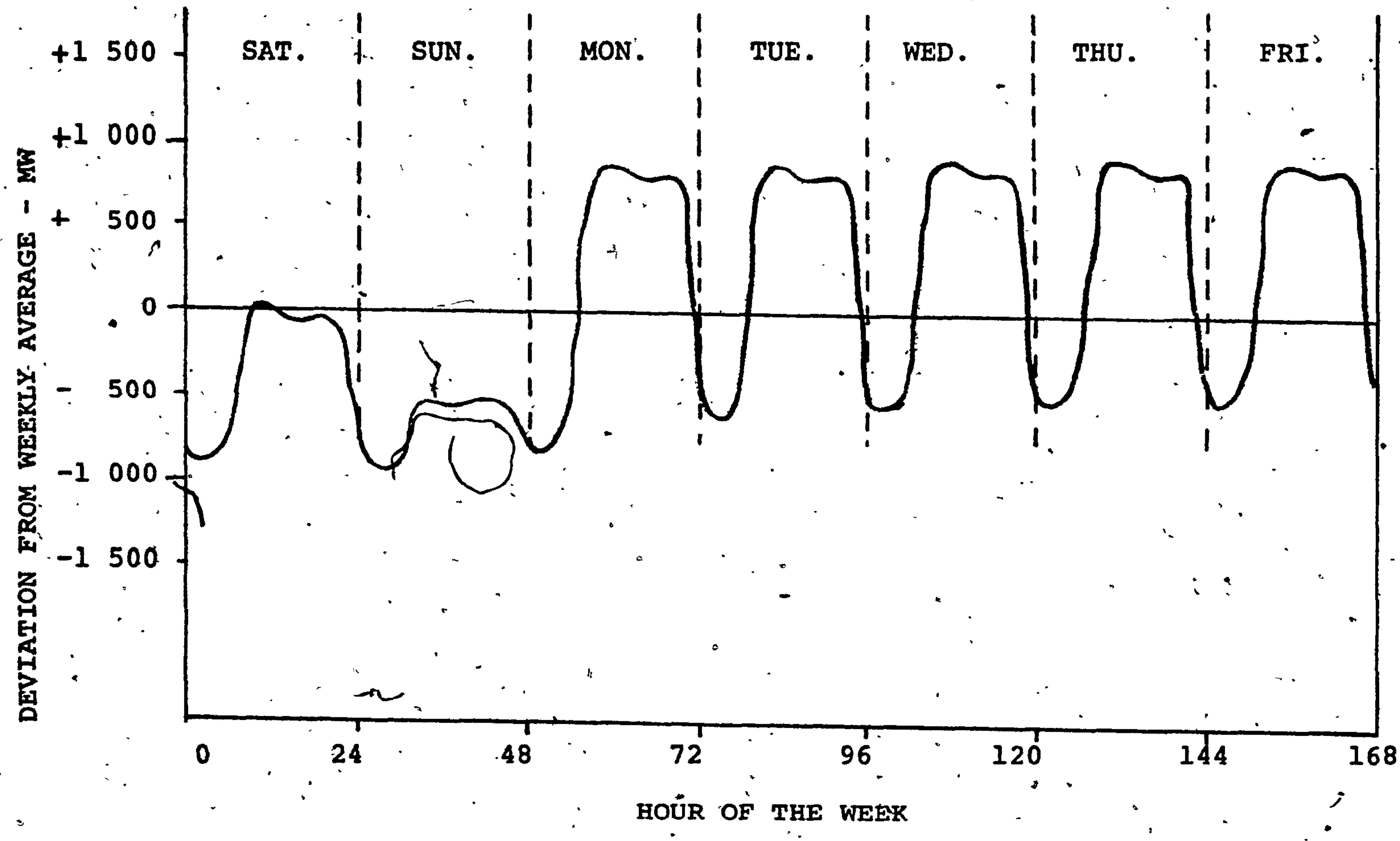


FIGURE 7

Typical Average Weekly Variation In Hourly Load About Some Base Load.

weather behaviors. Figure 8 is a typical load curve for one year. (Ref.17)

Fourth, there is a <u>growth</u> pattern. This pattern in the requirements reflects the increasing load over time either as a result of an increase in the number of customers demanding power or of an increased demand for power per customer. This pattern is detectable over years and this type of behavior in load forecasting becomes useful for long term planning studies.

The growth factor should be included in an algorithm that generates forecasts with a lead time of several years. The trend line results from a basic aggregate requirement, reflecting an increasing demand for electricity, and it is usually upward and exponential.

Figure 9 is atypical long term load curve representing seasonal variations superimposed on a long term growth curve. (Ref.19)

6.3.2 <u>Weather Process</u>

The second process which influences the levels of the above mentioned load curves is the weather process. The weather process is one the variables which affects the load demand curve in an irregular manner (Ref.22) That is, the resulting variations can be explained after the fact in terms of causes and may be of either short or long duration. Warm or cool spells will result in increased power demand. Special television events result in a short term above average

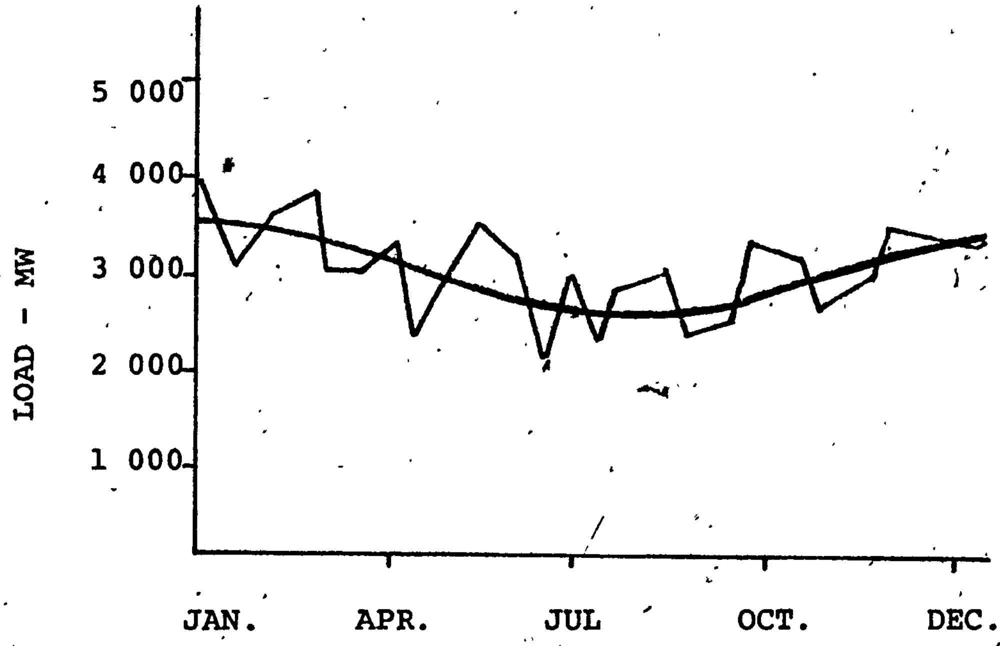


FIGURE 8

Typical Load Curve for One Year

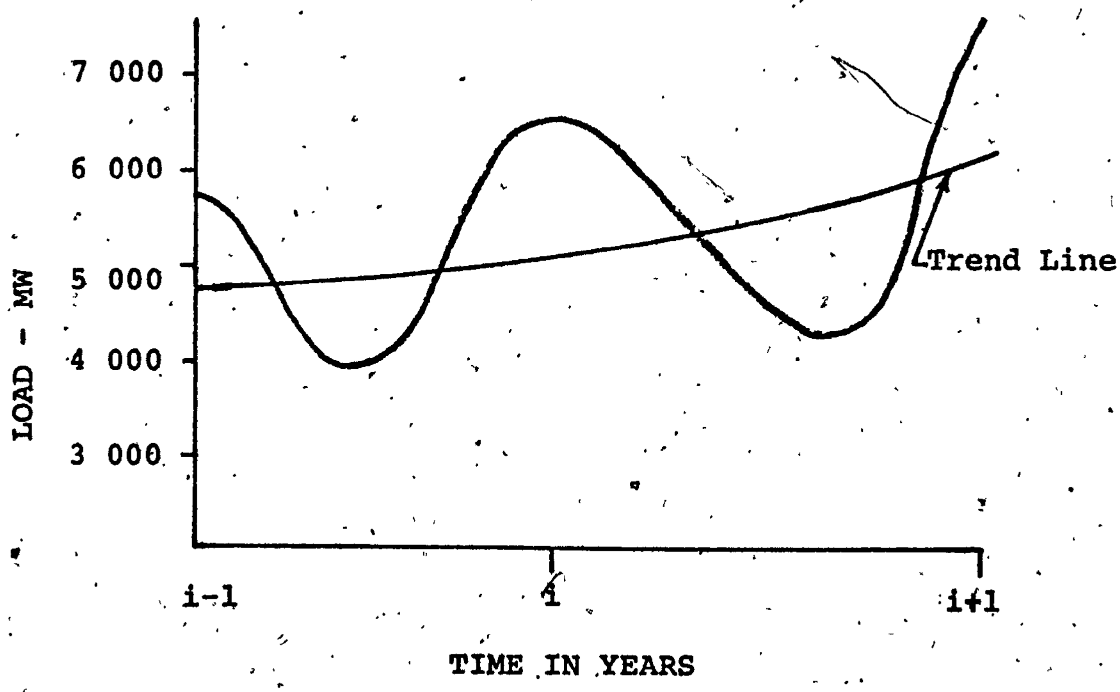


FIGURE 9

Typical Long Term Load Curve

demand. Over the past four decades we have witnessed a growing sensitivity of peak demands to weather with a corresponding growing immunity to economic conditions. One reason is that industrial loads have been growing somewhat less rapidly than other sectors of demand, and consequently this cyclically sensitive demand is becoming a smaller portion of the total. Much of the more recent growth in the demand for electric energy has come from heating and cooling applications, and this is reflected in substantially increased sensitivity of the system to temperature.

The most important meteorological factors found to affect the demand may be summarized as follows: (Ref.14,17)

(i) temperature
(ii) cloudiness
(iii) wind velocity
(iv) visibility
(v) precipitation

The characteristics of each of these processes are reflected in the load requirements although some more than others. The yearly variation in the temperature causes the requirements to follow a seasonal pattern. In general, high requirements correspond to low temperatures in the winter and lower requirements to higher temperatures in spring and summer. The influence of the daily variation in temperature as well as the influence of other weather variables are reflected in the daily load curve by changes in the level of the average daily load and in the relative shape of the curve. This daily influence of the weather causes variations in the load which can be viewed as variations around an average pattern corresponding to a normal seasonal temperature. For example, a Monday in the winter will normally have high loads, but if the temperature for a particular Monday is much lower than the normal for the season, the loads will also be higher.

6.4 Methodologies of Load Forecasting

Methodology refers to the act, or art, of defining load forecasting procedures. A prediction algorithm, i.e. the tool to obtain a forecast, is first based on modeling or estimating the system in mathematical terms as accurately as possible so that its behavior can be followed from the model. The accuracy of any forecast will very definitely depend on the accuracy of the load models used. Recalling that load forecasts can be grouped into three sections, namely, long-term, medium-term, and short-term forecasts, it is reasonable to expect a priori that for a desired accuracy, each forecasting period, or lead time, would require a different modeling forecasting procedure.

The modeling of a load forecast should therefore be done by considering the following items: (Ref. 19)

(i) Forecasting period

(ii) Object of forecasting

(iii) Available information

(iv) Required accuracy

(v) Forecast Stability

The "forecasting period" refers to the lead time of the forecast. Do we want a ten minute or hourly forecast for a 24 hour lead time, or daily peak load forecasts for a lead time of one week, or monthly forecasts for a lead time of one year, etc.

This requirement is a function of the "object of the forecast". Long-term construction and capital requirements call for yearly forecasts with lead times ranging from 3 to 15 years. Operational requirements to maintain system security and to perform load flow analysis and contingency studies will call for very-short (10 minute or hourly) to medium-term forecasts with lead times varying according to the immediate need.

The "available information" determines the complexity of the modeling procedure. What quantity of load measurements is available, over what period, can the data supply be maintained, is it available off-line or on-line, how much weather information is available. All these questions affect in some sense the type of model chosen or developed. Moreover the availability and the quality of the information are very much responsible for the accuracy of the forecast.

Irrespective of the complexity of the modeling forecast, the "accuracy" of the results is much dependent on the accuracy of the available information. Measurement errors are a common source of forecast errors especially for on-line applications. Accuracy can be improved by simulating as many system variables in the model as possible. Different modeling schemes exhibit particular errors which serve as useful indicators, together with mean and variance, to evaluate the accuracy of a technique.

The distribution of the forecast error at one particular point in time is important. It is of equal importance to consider the path of this error with time because this has an important bearing upon the financial and physical risks associated with forecast error. Of concern is the convergence or divergence of the error with time. Knowledge of the expected path of the error within certain limits becomes more important as the planning period increases. Basically, the objective is to maintain the forecast error essentially the same for all times during the lead period of the forecast.

The user most weigh the "object" of the forecast before requesting a specific accuracy. More often than not a 95% confidence level is considered satisfactory as a performance criterion and anything to improve it, or to reduce the mean square error, can be an expensive exercise in manpower, computer space and computation time. The trend toward automatic load scheduling, automatic generation control and the growing emphasis on security, will no doubt result in higher accuracy requirements properly balanced with the costs incurred.

If a forecast is to be useful for planning purposes it must be relatively "stable". This is interpreted as indicating that, if a specific forecast for a given year is to be changed, considerable effort should be devoted to reducing the risk that the direction of change be reversed in the following year. For short term utilization as an indicator to a network supervisor or as input to an automatic generation control scheme, stability is doubly important to ensure efficient and economic performance of the network.

One of the areas of discussion is the question of whether or not weather information should be included in the modeling structure. Some authors, such as Matthewnan and Farmer, maintain that weather data is not available with any degree of accuracy and therefore would not yield significant improvement in the forecasting algorithm. Or it is reasoned that, for very short forecasting intervals, the weather fluctuates very little about some average value and can therefore be viewed as a constant parameter in an algorithm.

Authors, such as Davies, Lijesen and Saacks, reason that weather considerations are essential to insure a high degree of accuracy and confidence in the forecasts. They maintain that there exists a very high correlation (Ref.23) between load and weather data, and consequently neglecting weather processes cannot yield confident values.

There is indeed a growing sensitivity of peak load demand to weather variations. (Ref.11) As stated above the weather process is partly responsible for that irregular behavior. This process is more often than not reflected in the high frequency or residual component of load pattern.

Over a long term, weather fluctuations are random and hence unpredictable. The duration of these fluctuations is short. Hence it is reasonable to consider the effects of weather on load in forecasting from different causal phenomena:

(i) Short term forecasts - Weather processes, specificallly temperature and illumination, can be predicted and considered in the algorithm.

(ii) Medium, Long term forecasts - Fluctuations become more random and unpredictable. It becomes relatively easy, from past data, to define expected or normal weather conditions and to formulate correction factors, based on this weather conditions, to adjust the forecasting algorithm accordingly.

Irrespective of whether or not one makes use of weather-load correlation factors in forecasting, it would seem desirable to include weather sensitive variables in developing a forecasting model from past history. Under this constraint both peak load and weather information are available and can generally be correlated over the period being studied in formulating the load model. To incorporate this weather analysis could reduce the error in estimating past trends in the load pattern and hence improve predictions under conditions of irregular or average weather.

In the development of a mathematical model, the total load can be separated into two basic parts:

1. the nominal load
2. the residual load

The nominal load, also referred to as base load, is defined as the load due to the aggregate customer requirements and is influenced by the longer term, or low frequency variations such as the yearly secular trend and the periodic patterns which repeat themselves subject to slow changes. An example of the latter is the seasonal variations within a year.

The residual load corresponds to the difference between actual and nominal loads and for a large part includes the irregular and random variations of the weather, and other unpredictable events, around the nominal as the conditions are changing.

The methodology for load forecasting does not uniquely identify a forecasting procedure. The latter depends on the type of mathematical models used, the manner in which the historical data is analyzed and the type of information available at the time that the forecast is prepared. It is apparent from the definition of the nominal load that it can be modeled and included in the forecasting procedure in a number of different ways while there is also flexibility in the manner of forecasting the residual load. Therefore, the choice of the best forecasting procedure must be based on some criterion of performance.

6.5 Forecasting Procedures

The forecasting problem is that of obtaining an approximation to the future time history of the load behavior from given observations. As described above these observations are generally composed of peak load measurements and some weather information. The observations can be viewed as noisy measurements in the sence that they consist of nominal and residual components, the latter containing random, unpredictable components. We can therefore state that power load patterns represent stochastic processes in the true sense, that is, the load behavior is a process which developes in time in a manner controlled by probabilistic laws. (Ref 24)
Some authors propose procedures that account, to various degrees, for the probabilistic nature of loads. Others prefer to adopt a more simplistic view and develop models in a deterministic sense. The need, availability of data and computing facilities can serve as strong arguments for chosing any one methodology and it would be difficult to arbitrarily accept one and reject the others. This should become evident at the end of this section when several procedureshave been introduced and summarized.

One of the underlying arguments for the sustained interest in developing new, more efficient forecasting algorithms is the current objective, among power control engineers, to implement on-line automatic generation and scheduling control systems. Now, the control problem is that of determining inputs to a process in order to achieve desired goals in spite of random disturbances which could be present. It is interesting to observe how closely related are the two processes, that is, the forecasting, or estimation, and the current control systems. The forecasting is usually a necessary step in implementing a control input; it is necessary to infer a process's behavior before effective control can be applied.

A review of some of the literature on load forecasting procedures and applications identifies certain interesting observations:

1. It is an accepted fact that a load pattern should be decomposed into its two basic components, 1) nominal load, and 2) residual load. These include the yearly trend line, the seasonal variations, and other variations such as daily cycles within a week and other variations resulting from weather processes and economic conditions. These components are presented in Figures 6 to 9.
2. The weather process is a variable that is at the root of many written words and the parameter on which unanimity concerning its real effect on load is far from being achieved among the interested parties.

   The question is not whether or not it influences the load pattern. It definitely has an effect. Fog, humidity, luminosity, rain or snow storms are known to result in abnormal power demands. The differences in opinion lie in the relative worth, in terms of forecast error, of including the weather as a variable in the algorithm. Views range from total exclusion, inclusion only in modeling the load process from historical data, to inclusion as a parameter in both the modeling and the forecasting procedures.

Views also differ on the weather as a dependent variable for different types of modeling structures, that is, long-, medium-, or short term forecasts. The common objection is: How can we predict the weather accurately. The favorite argument in defence of its consideration is: The high correlation, 0.9 or better, (Ref. 23) between load and weather dictates that this parameter must be included in the procedure.

3. There is unanimity that the load behavior is a time series characterized by certain regularities and irregularities. There are, however, different approaches to modeling and predicting load demands. There range from the application of complex stochastic methods to basic least squares techniques. In mathematical terms, all procedures can be classified into essentially two group;

   (i) Probabilistic models

   (ii) Deterministic models

with or without weather process considerations.

4. Surveys indicate that power utilities are more

inclined to mechanize their load forecasting procedures in order to benefit from computational advantages offered by computers and to field trial on-line automatic generation control systems. There has developed in the past 5 years a growing awareness for the need to study and to implement more efficient and computerized forecasting procedures. The table in Figure 5 indicates that load forecasting, as a computer function, ranks sixth in terms of expected growth among computer users in the power industry.

The purpose of this section is then to review some of the procedures developed and tested. The objective of the presentation is threefold:

1. To synthesize several approaches to load forecasting under one cover as a tool to understanding the different techniques for various applications. References provide greater details.
2. To facilitate a comparative analysis of the advantages and disadvantages between procedures when investigating which technique to adopt given a set of criteria, such as available data, period of forecast, expected error, computational facilities, etc.
3. To assist in determining future areas of research and development in the art of load modeling and forecasting.

Since the weather process appears to provide a decision point in the methodology of forecasting, the techniques to be described will therefore be segregated into weather sensitive and non-weather sensitive models. Each technique is reviewed according to author, procedure, performance and application, to the extent that documentation is available.

6.5.1 Weather Sensitive Forecasting Procedures

6.5.1.1. Lijesen and Rosing (Ref. 14) developed relationships explaining the load behavior and derived a procedure to forecast hourly loads with a lead time of 24 hours based on the most recent measurements of the load as well as on a short-term weather forecast.

The load is decomposed into a nominal term reflecting the aggregate customer requirements for nominal weather conditions, and a residual term reflecting the deviations due to daily weather fluctuations. The nominal load is adaptively forecasted based on identifying a growth term (i.e. a trend line), and a seasonal and weekly pattern. The residual load is forecasted based on the daily weather forecast and the use of characteristic functions. The two components being separately forecasted, the sum provides the forecast of the total load.

The model of the load is expressed as follows:

$x(k,h) = f(k,h) + g(k,h)$; $k = 1,2\text{--},365$ and

$h = 1,2,\text{--},24$ where $x(k,h)$ is the load on day k and hour h; $f(k,h)$ is the nominal load; and $g(k,h)$ is the residual load.

The nominal component is further decomposed:

$$f(k,h) = f_1(l,h) + f_2(d,h) \; ; \; l = 1,2...52$$

and $d = 1,2...7$

where $f_1(l,h)$ is the seasonal component for week l, and $f_2(d,h)$ is the weekly component for day d. The total load forecast, x (k,h), is therefore based on forecasting each component, f_1, f_2 and g, and then summing the terms. The components f_1 and f_2 are calculated using curve fitting, averaging, extrapolation and/or exponential smoothing methods. The component "g", the residual load, is the weather sensitive load. Lijesen et al consider "g" as a stochastic process and adopt Farmer's (Ref.20) method of spectral decomposition for the modeling and prediction, with differences being in the use of the characteristic functions. This stochastic process is decomposed into a linear combination of known functions with coefficients that are random variables. The optimal approximation, in the mean square sense, is obtained by expanding "g" in terms of characteristic modes, or eigen functions.

The authors advocate simulation of different forecasting procedures and to choose the one that provides the minimum mean square forecast error. In essence this means estimates based on recent data vs. estimates based on a large amount of historical data.

It is interesting to note that both nominal and residual load contain weather information. The nominal load captures the long term dynamics, while the residual load describes the shorter term dynamics. As stated by Christiaanse (Ref.14) a useful feature of the method is that it provides a reasonable means for allocating the effects of daily weather variables, such as the average temperature over 24 hours, on hourly loads.

The methods of forecasting the components have been tested on the system load of the Bonneville Power Administration. Various methods were programmed and the results in terms of root-mean-square error indicate minimum and maximum r.m.s. errors of 1.6 and 2.8% with an average r.m.s error/day of 2.1% The average forecast error of the procedure is essentially constant for all hours during the lead-time. This is a highly desirable feature of a forecasting algorithm.

This procedure appears to be well suited for on-line computer control applications where short-term hourly forecasts are required. Various methods of forecasting f_1, f_2 and g can be run simultaneously for estimates based on recent data vs historical data and some optimum solution chosen based on a minimum error criterion.

6.5.1.2. Toyoda et al (Ref.18) applied the theory of state space analysis to develop short-term forecasting algorithms to be used specifically for on-line real-time control of power systems.

The use of state equations and application of state estimation for tracking the state of a power system has been discussed by several authors (Ref. 25). Toyoda et al suggest the use of the state concept and introduce several state estimation type modelings of load forecasting. For very short forecasts, 10 minutes to 1 hour, the authors do not consider variations due to weather processes. Fluctuations in load are accounted for by a noise component in the state equations or by another state variable to represent incremental changes.

In hourly or daily forecasting, the effects of temperature and humidity are included in the state and measurement equations.

The structure of the estimation algorithm is as follows:

$$\begin{pmatrix} X_{n+1} \\ \Delta_{n+1} \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & \alpha_n \end{pmatrix} \begin{pmatrix} X_n \\ \Delta_n \end{pmatrix} + \begin{pmatrix} 0 & 0 \\ \beta_n & \gamma_n \end{pmatrix} \begin{pmatrix} T_n \\ H_n \end{pmatrix} + \begin{pmatrix} \xi^1_n \\ \xi^2_n \end{pmatrix}$$

$$\text{and } Y_{n+1} = \begin{pmatrix} S_{n+1} & 1 \end{pmatrix} \begin{pmatrix} X_{n+1} \\ \Delta_{n+1} \end{pmatrix} + \eta_{n+1}$$

where X_n is a pseudodaily load, Δ_n is the load fluctuation because of weather conditions-temperature T_n, and humidity H_n-, S_{n+1} is the coefficient of daily standard load pattern, α_n, β_n, and γ_n are weight factors and ξ^1_n, ξ^2_n and η_n are system and measurement noises, respectively. The optimal forecasting values (*) of states using the new observed value are sequentially given by:

$$X^*_{n+1} = X^*_n + K^1_{n+1} (Y_{n+1} + (S_{n+1} X^*_n + \alpha_n \Delta^*_n + \beta_n T_n + \gamma_n H_n))$$

$$\Delta^*_{n+1} = \Delta^*_n + K^2_{n+1}\,(Y_{n+1} + (S_{n+1}\,X^*_n + \alpha_n \Delta^*_n + \beta_n T_n + \gamma_n H_n))$$

where $S_{n+T} = S_n + \delta(Y_n/X^*_n - S_n)$, $T = 24$ hours
$0 < \delta < 1$

Correcting gains K^1 and K^2 are determined for the system covariance matrices, and α_n, β_n and γ_n according to Ref. 18 Part (II).

The forecasting load is then given as:

$$\hat{Y}_{n+T} = S_{n+T}\,X^*_{n+1} + \hat{\Delta}_{n+T}$$

where $\Delta_{k+1} = \alpha_k \Delta_k + \beta_k \hat{T}_k + \gamma_k \hat{H}_k$

$k = n+1, ---, n+T-1$

$$\Delta_{n+1} \triangleq \Delta^*_{n+1}$$

and values of $\hat{T}_i$ and $\hat{H}_j$ can be obtained from a weather forecast.

The state estimation approach to forecasting involves the dual process of identification and forecasting. The identification process requires the definition of the system noise and error covariance matrices, i.e., the Q, R, and P matrices, and 2) the evaluation of the optimal estimates. The authors propose identification algorithms based on a serie of observed measurements. A dynamic or adaptive algorithm is shown to give good accuracy to the forecasting model. The forecasting process involves the computation of the forecasting load $\hat{Y}_n$.

This technique incorporates, or at least is sufficiently flexible to reflect all the critical components affecting load. The parameters α, β, γ and S can be adjusted to reflect seasonal, weekly and daily variations, as well as fluctuations due to weather processes. The accuracy, i.e. the least mean square error, is improved for both state and dynamic changes in the Q and R matrices by incorporating an adaptive feature to the identification algorithms. If computer hardware, budget and company objectives permit, the forecast values can be used for on-line real-time control of operations. For better efficiency the identification and optimal estimates can be computed, stored and updated in a large central computer, while the forecasting can be performed more economically on a smaller, possibly decentralized computer.

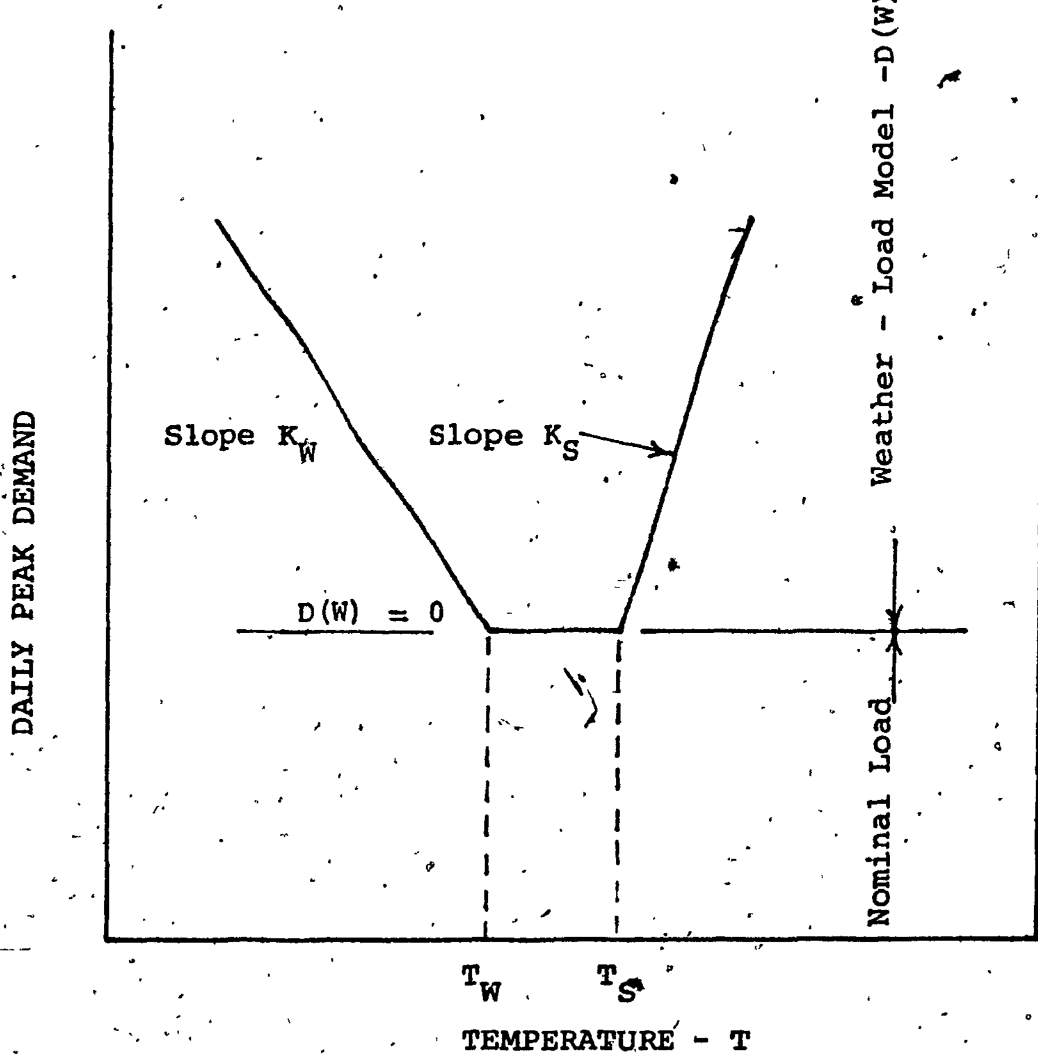
6.5.1.3. <u>Galiana</u> (Ref. 26) explored concepts similar to Toyoda et al but possibly stressed to a greater extend the use of adaptive identification techniques to estimate the parameters. Furthermore Galiana demonstrates the validity of the state estimation procedures with real data experimentation. Galiana's paper in essence reinforces the approach that authors, such as Debs, Larson, Schweppe and Wildes, and then Toyoda, have been recommending and it coincides with the capabilities of third generation computing systems being used in the power industry.

6.5.1.4. Stanton (Ref 27) developed statistical procedures for the preparation of weekly and seasonal peak demand forecasts with lead times up to seven years. The validity of the model is tested with results from different companies.

The technique involves the development of weather-load models as shown in Figure 10 from historical peak daily loads and coincident dry-bulb temperature readings. The slopes are calculated either manually from scatter diagrams or by the use of linear regression analysis. The weather load models are used to derive the non-weather demand, or nominal load. The seasonal components which remain in the non-weather demand are removed by methods recommended by Shiskin (Ref. 27, ref. 1) Exponentially weithted regression can be used to forecast the non-weather demand and, assuming a Gaussian distribution the mean and variance are calculated.

The weather-sensitive demand represented by the weather-load model is forecasted from the estimates, or growth patterns, developed for the weather-load model coefficients Kw and Ks. The modeling further assumes that the weather variable corresponding to the weekly peak demand for a particular week has a Gaussian distribution. The mean and variance are derived from historical data files.

The total weekly peak demand is therefore the sum of the forecasted non-weather and weather-induced demands. The expected value and variance are derived from the sum of the respective values. The required confidence level of the forecast is easily calculated from the cumulative probability



$$D(W) = K_S(T-T_S), \quad T > T_S$$

$$D(W) = 0, \quad T_W \leqslant T \leqslant T_S$$

$$D(W) = K_W(T-T_W), \quad T < T_W$$

FIGURE 10

Typical Weather - Load Model

distribution. A further refinement in the algorithm which could improve the accuracy would be to assign probability values to the model coefficients.

The above procedure can easily be programmed to derive weekly and seasonal peak demand forecasts. Seasonal peaks can be derived from weekly peak demands by means of a procedure described in (Ref 28) The model was tested using data from four different companies and is shown to track the actual peak demands within the 99.5% confidence level.

Some of the limitations to be aware of in using this approach are:

1. The procedure does not account for daily variations, nor does it compensate for holidays or sudden change in demand;
2. The model assumes constant temperature distributions in the forecast;
3. The forecasts of the model coefficients, Kw and Ks, are deterministic and hence are assumed independent of weather fluctuations.
4. The model is limited to temperature as a weather variable.

However these limitations can be softened by 1) assigning probability values to the KS, 2) by subdividing the weather-models into more than one, e.g. temperature-load and humidity-load models, and 3) by adjusting the factors in the exponentially weighted regression used in modeling and forecasting of the non-weather demand. The probabilistic approach of assigning distributions to the results provides flexibility to the planning engineer. Also weekly and seasonal peaks can be derived from the same computer run.

6.5.1.5 Davey and Saacks of the Louisiana Power and Light Co. (Ref. 29) are using weather-load correlation models, similar to the one proposed by Stanton, to meet their need for accurate forecasts of generation purchases, five to ten years. The flow chart procedure is shown in Figure 11. In essence the procedure uses multiple regression analysis to develop weather-load models for each area within the system from historical peak daily loads temperature, wind speed, and humidity. The forecasting procedure is based on extrapolation of the most likely peak load and the standard deviation of the load variation in time.

The model differs from other weather-load modeling procedures, e.g. Stanton's, in that the authors do not explicitly separate non-weather and weather sensitive components. The multiple regression analysis results in a modeling formula, for each season, which contains a constant component and other weather sensitive terms. The algorithm for each season, derived from its respective historical data, will contain different terms. However the procedure also accounts for long term trends, seasonal variations and shorter term variations. It further differs from Stanton's in that each algorithm includes weather term reflecting up to three previous days' fluctuations. The total system peak load is obtained as the sum of the area peaks.

As a planning tool, the procedure provides most likely peak loads and deviations as functions of time, probabilities

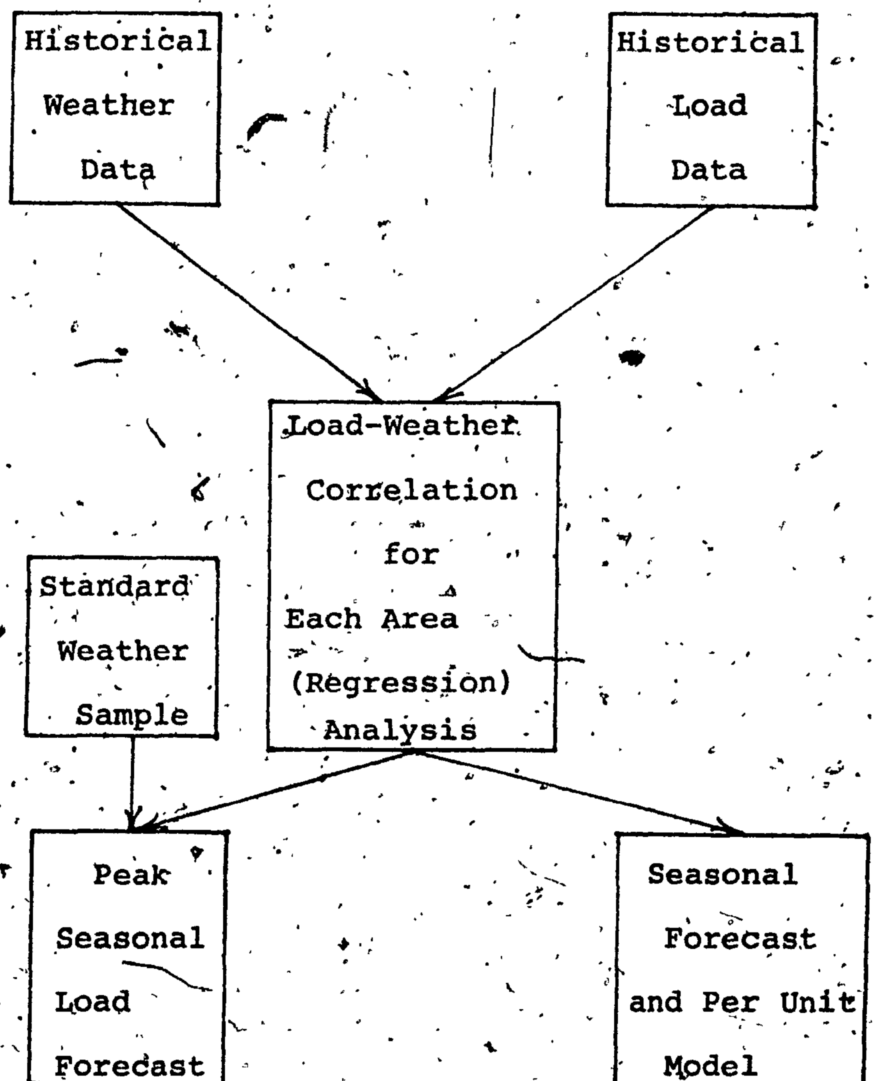


FIGURE 11

Davey et al's Weather Sensitive Load Forecasting Flow Chart of peak loads for a specific season in the future, and distributions of daily peak loads for an entire season or for any month in the season.

The forecasting procedure exhibits an error which tends to indicate growth or a parabolic trend. The growing variance of the error could be improved by including a random term in the algorithm, characterized by some mean and variance, and designed to compensate, to some degree, the fluctuations that are not necessarily weather dependant.

6.5.1.6. Calbiac et al of the French Power Administration (Ref.15), have documented an interesting forecasting algorithm to assist in medium to long term planning. The object of the procedure is to express, in a mathematical form, hourly demands in terms of an annual energy value and so called "modulation factors". The forecasting period can be extended in time as desired, as long as the extrapolation technique is sufficiently accurate.

The procedure models all important factors affecting the load behavior. These modulation factors account for seasonal coefficients, k; for annual trends τ_i; weekly weithting factors to account for weekdays and weekends, p; daily coefficients Π ; and temperature gradients, g, to account for other anomalities.

The algorithm is expressed as follows:

$$P_{hji} = \frac{W}{N} k_i \tau_i p_{ji} \frac{\pi_{hji}}{24}$$

where P_{hji} is expected load on hour h, during day j for week "i" in a given year.

W is the expected annual energy in kwh , N is a daily weight factor.

Each modulation factor is analysed from 20 years of historical data and, using regression analysis, a model is developed for each one. Forecasts are obtained by extrapolation of each factor and multiplication according to the above algorithm.

This method is limited to five year forecasts because it does not consider the reasons for the relationships between the factors and time. This limitation is evidenced in all methods reviewed in preparation for this Dissertation and no doubt accounts for errors inherent in various procedures. Calbiac et al propose to separate and to apply the modulation factor principle to each consumer sector, e.g. business, residential. Daily demand patterns and forecasts are separately calculated and the total system demand is the sum of the aggregates.

If available information permits a detailed analysis of each sector, there is then theoretically no limit to the forecast lead time.

The authors do not comment on the error performance of the procedure. The proposed concept appears unique and it accounts for all practical factors affecting load. The novelty is the modeling structure: the authors have developed a technique which is applicable to any forecasting period, up to five years. It is however very complex in terms of the number of different analysis required. As a planning tool, the forecast should be stated in terms of expected values and probability distributions.

6.5.1.7. Other authors have described techniques incorporating weather information. Matthewman and Nicholson (Ref.17) review Dryar's attempt to describe the effect which various weather conditions might have upon the load. Davies has been active defending the correlation between weather and load. Higgins (Ref.22) presents a technique, based upon an extension of seasonal adjustment, for analysing and projecting the hourly pattern of demand.

6.5.2 <u>Non-Weather Sensitive Forecasting Procedures</u>

6.5.2.1. <u>Christiaanse</u> published a very complete and comprehensive paper on the application of exponential smoothing (Ref.21) to derive an adaptive procedure with the capability of hourly calculation of forecasts with lead times up to one week.

The general model of the load is represented as a linear combination of functions of time and a noise component,

$$X(t) = a.f(t) + e(t)$$

This method implies 1) an appropriate set of fitting functions f(t), and 2) a means for estimating the coefficients, a, from observed values of load. The coefficients and fitting functions are derived from exponential smoothing analysis and Fourier serie application. The forecast model automatically adapts to the gradual seasonal changes in the weekly load cycle since the coefficients are revised each hour based on immediate past data.

The modeling procedure requires no weather information. The author reasons that since weather does not tend to "lead" load in time, observed weather data may be redundant, therefore, as they have already been reflected in the load data. Hence forecasts may not be improved because no new information about future load has been introduced.

Weather information is considered useful by the author when it controls an adaptive program in order to account for abrupt changes in the weather. The procedure is shown to provide satisfactory hourly forecasts for lead times up to one week. The error is observed to follow a normal cumulative distribution for the period tested. Because of the adaptive feature, the method should prove useful for on-line, real time forecasting. Errors can be reduced by improving the adaptive sub-routine and by adjusting the smoothing coefficients of the fitting functions.

6.5.2.2. Farmer and Potton have described and field evaluated the use of spectral decomposition techniques (Ref.20) for very short term forecasts. The technique is developed to satisfy the requirements of an automatic load-scheduling control system, i.e. a prediction scheme which provides detailed estimates of load up to two hours ahead. Weather information is not included in the model, that is, weather-load correlations are not developed. The mathematical relationship however accounts for long term trends, weekly variations and other erratic variations. It differs from Lijesen et al's approach in that the latter specifically assign a residual component to account for weather variations. The application of spectral decomposition also differs in the use of the characteristic functions and in the forecast of certain coefficients.

On-line implementation of Farmer's method proved less efficient than off-line tests. Measurement noise appears as the primary source of error. Weather data consideration could reduce forecast errors as observed by the relatively good success obtained by Lijesen. However note that his tests were performed off-line. The sensitivity of the algorithm to system noise needs further investigations.

According to Matthewman and Nicholson (Ref.17) the chief advantage of the spectral expansion method is the fact that no meteorological data are required for prediction, and consequently the need for expensive instrumentation or use of inaccurate weather forecasts is saved.

For very short term forecasts, the economies may be justified; for longer term ones, consideration of some weather sensitive adaptive program may be warranted.

6.5.2.3. Gupta introduces a stochastic procedure for producing probabilistic forecasts of monthly peak system demands for up to three years ahead. The procedure is based on concepts of prediction theory of stationary stochastic time series, which are developed to predict those types of nonstationary stochastic process, such a linear transformation is derived. The procedure yields a technique for forecasting the evolving, nonstationary and seasonal peak power demands. Gupta postulates the following stochastic model for monthly peak demand series: (Ref. 24)

$$X(t) = T(t) + S(t) + I(t)$$

where:

- $T(t)$-steadily growing component of peak demand, having a random slope over short periods of time.
- $S(t)$-Seasonal component consisting of more or less regular periodic variations whose applitude is growing with time in a random fashion.
- $I(t)$-Noise component assumed to be a stationary, Gaussian process with zero mean and variance σ_w^2
- $X(t)$-Estimate of monthly peak demand.

By considering probability models for each component of $X(t)$, the following stochastic model is developed:

$$X(t) = \frac{u(t)}{(1-\phi \sqcup)^2} + \frac{(1-\rho+\rho\sqcup)v(t)}{(1-\sqcup^{12})^2} + w(t)$$

where - $u(t)$, $v(t)$ and $w(t)$ are zero mean, independent Gaussian random processes with variances σ_u^2, σ_v^2 and σ_w^2;

- ϕ and ρ are parameters whose values vary between o and 1;
- $\sqcup$ is backward shift operator.

The method is then twofold: identification of model parameters σ_u^2, σ_w^2, ρ and ϕ and forecasting $X(t)$. In essence the identification is performed by matching the statistics for the output of the postulated model.

The forecast is obtained by using either the forecast - equation - derivation (derived by Gupta) method or the Monte-Carlo technique. The former one is computationally very tedious while the latter is much simpler. The two methods give comparable results and in both cases the error is seen to increase with lead time.

The application of pure stochastic models is still in the infancy stage. Computational complexities in the identification and forecasting procedures must be resolved before the method can receive acceptance as a managerial tool in the power industry.

6.5.2.4. Toyoda et al have written several papers on the use of state space analysis for short-term load forecasting (Ref. 18,19) Although weather variables are not included in the very-short term model, the same comments as discussed in Section 6.5.1.2 apply here. The state estimation and prediction technique appears to be a well suited procedure for on-line real-time load scheduling control systems. With a built-in adaptive program, the method should track the system within acceptable confidence limits. The off-line evaluations performed by Galiana, using a similar approach, confirm the potential of this technique.

6.5.2.5. Interested primarily in estimates of annual peak demands, Datta of the West Bengal State Electricity Board, experimented with the method of least squares and found that this simple methodology provided a suitable forecast for their needs. (Ref.30)

6.6 Discussion

The brief review of current techniques in load forecasting undoubtetly does not relfect all specialists involved in this field. The author believes, however, that the discussions presented is representative of the basic methodologies followed by engineers, scientists and economists active in developing load forecasting procedures, i.e. the modeling and estimation. In one sense or another, the load is divided into components. These are generally modeled according to some historical data, sometimes including the immediate past, and indirectly or directly the weather plays some role in the process. The model is then used to predict the future behavior of the load based on its performance in the past. Mathematical techniques to identify and forecast are probably as varied as the number of people involved in this art. No one procedure can, a priori, be arbitrarily chosen for a given system. A technique must be chosen only after reviewing elements such as, availability of historical data (weather and load), period of forecast, data acquisition system, reason for forecast, computational facility, to name but a few criteria.

CHAPTER 7

CONCLUSION

In the past 5 to 10 years, coincident with the evolution of second and third generation computers, the art of load modeling and forecasting appears to have progressed in a rather hesitant manner. In a mathematical sense, or bread-board manner, we witnessed an evolution reflecting the progressiveness of engineers and scientists of the 60's and 70's. The trend is observable from the number of papers written consistently and from the application of the theories of probability and stochastic process.

The hesitant mannerism is reflected in the restrained application of forecasting procedures to on-line real-time control systems. It was shown in an earlier section that power utilities represent one of the largest industry in North America. The business requires constant supervision and expertise planning. It utilizes the largest computers for planning and operating. Yet many managers are still hesitant to base decisions upon information provided by computers. Some engineers and economists believe this to be one reason for the restrained application of real-time load forecasting. Divergence of opinions and the resulting proliferation of techniques does not help either to convince a manager that technique X rather than Y should be implemented.

The close relationship between the control and prediction theories is believed to be the catalyst that will stimulate the industry to venture in the field-trial and implementation of automatic load forecasting.

In keeping with the objectives stated in the Scope, the importance of an efficient load forecasting methodology in controlling and operating of a power utility has been emphasized in the light of this multi-million dollar industry evolving in a third generation computer age. The nature of the dynamic load demand has been explored thoroughly and the essential factors and implications which must be considered in developing an effective and realizable forecasting algorithm have been described. Some of the most important and current applications have been reviewed with reference to well known authors.

In conclusion, the literature survey reflected in this paper leads me to identify some areas that require further investigation:

- Real worth, in terms of performance, of including weather information vs excluding weather data in a forecasting algorithm;
- Error performance with lead time;
- Sensitivity of measurement noise to forecast accuracy; this item is critical when implementing on-line real-time automatic generation control systems;
- State-space analysis for application as an on-line tool;

- Adaptive or compensation techniques in forecasting algorithm to make the latter more responsive to sudden change;
- Use of mini-large or decentralized-centralized computer systems to optimize automatic forecasting and to take advantage of some of the more complex techniques proposed by authors such as Gupta or Lijesen.

Last but not least, the author sees the need for a selection guide to assist power utilities in selecting a suitable forecasting procedure according to a series of criteria. Section 6 of this paper is proposed as a starting point for the development of such a Selection Guide Handbook.

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