SHORT-TERM LOAD FORECASTING

A DISSERTATION

submitted in partial fulfilment of
the requirements for the award of the degree
of
MASTER OF ENGINEERING
in
ELECTRICAL ENGINEERING
(Power System Engineering)

By

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CANDIDATE'S DECLARATION

I hereby, certify that the work which is being presented in the dissertation entitled, 'SHORT-TERM LOAD FORECASTING' in partial fulfilment of the requirements for the award of the degree of MASTER OF ENGINEERING in ELECTRICAL ENGINEERING with specialization in POWER SYSTEM ENGINEERING, submitted in the Electrical Engineering Department, University of Roorkee, Roorkee [India], is an authentic record of my own work carried out for a period of about six months from September,1987 to February 1988, under the supervision of Dr. M.P.Dave, Professor, Electrical Engineering Department, University of Roorkee, Roorkee, India.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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SUSHIL CHAUHAN

CONTENTS

ABSTRACT

Considerable work has been carried out in recent years on problem concerned with load flow analysis, economic generation scheduling and system-security checking in electrical power systems. An aspect of the overall problem which has not received much attention is that of short term forecasting of electrical load demand. It is, however, important from the practical point of view of economic generation scheduling and security checking to be able to predict accurately load demand several hours in advance. In this report various methods which are commonly used for short-term load prediction are discussed in Chapter-2 along with their relative merits. The method based on ref. [5] which has been adopted for probabilistic forecasting of hourly power-system loads with a lead time varying from 24-hours to one week, has been included in Chapter-3 along with necessary flow charts for developing computer programs. The forecasting is based on both historical load data and information from latest weather forecast. The developed program combines stochastic load model and adaptive weather load models optimally to yield an adaptive forecast especially suited for on line control of power systems. Adaptive capability in this context is taken to be ability of the model to update its own parameters according to its past performance, a feature that makes the forecasting procedure particularly suitable for on-line use.

The developed computer program has been run on actual load and weather variables (Temperature and humidity) records obtained from Ram Nagar Sub-station and Hydrology department of Roorkee University respectively. Results have been found satisfactory and are presented in Chapter-4 of this report. The conclusions of the study are drawn in Chapter -5.

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CHAPTER -1

INTRODUCTION

1.1 Definition of Load Forecasting [1]

Load is a general term meaning either demand or energy where demand is the time rate of change of energy. The term forecast refers to projected load requirement using systematic process of defining future loads in sufficient quantitative detail so that important powers-system expansion decisions can be made. For effective power system expansion, estimates of both powers and energy are crucial. An accurate forecast depends on the judgement of the forecaster and it is impossible to rely strictly on analytical procedures to obtain an accurate forecast. Also Good judgement alone can not be over emphasized in forecasting future requirements and analytical tools must be used.

In some cases a total forecast is obtained by combining forecast for various classes of customers such as residential, commercial, industrial, agricultural and other. For the better prediction of load it is imperative for the forecaster to be well versed with the characteristics of varieties of loads i.e. growth rate with time and effect of weather fluctuations. In many cases seasonal variations in residential component are responsible for the seasonal variations in system peak. The extent of residential influence will depend upon the percentage of total system load that is residential. Increase in per capita consumption due to wide spread use of weather sensitive devices, need to include weather effects in forecasting future requirements become imperative.

Let it be emphasized that solar energy technology may have a tremendous impact on load patterns experienced by electric utilities. It is well-documented fact that uses of solar energy technology for heating and airconditioning is well with in the state of art. If wide spread acceptance of solar conditioning occurs, it will be incumbent on the forecaster to anticipate its impact on utility industry.

Forecasting methodology to be followed depends upon period of interest for load forecasting. Short and medium term forecasting can be done using conventional procedures i.e. by extrapolation of certain factors characterizing hourly modulation of load. For long term forecasting consumption is broken down in to homogeneous sectors. The preceding extrapolation technique applied to different consumption classes makes it possible to generate individual load curves thus giving a global level by summation. This approach also makes allowance for structural deformation of consumption.

1.2 Importance of Load Forecasting [1,2,3]

Load forecasting has always been an integral part of power system planning and operation. However, it did not receive as much attention in the past as it deserves because the fuel supplies, especially hydrocarbons, were cheap and abundant and utilities could find funds for erecting enough gas/oil generation plants at relatively short lead times. In the last few years, conditions have considerably changed and the past practices have to be suitably modified. Thus load forecasting will assume greater importance in the years to come.

Long term demand forecast is used to determine the capacity of generation, transmission and distribution system additions and energy forecasts determine the type of facilities required i.e. wether peaking generating unit or base load unit should be installed as there is substantial difference in their cost. Whereas the importance of short-term forecasting is realised in service reliability and efficient operating performance of power supply system, particularly in case of thermal power plant which demands accuracy in the forecast of system load. This is necessary in order that generating capacity adequate to supply the system load, maintain system security and supply the necessary spinning reserve. The scheduling of spinning reserve as coverage for the loss of largest unit or the loss of that transmission capacity which renders unavailable the greatest amount of generating capacity, is an accepted principle of reliable system operation.

1.3 Classification of Load forecasting [1,4]

Depending on the time period of interest, a specific forecasting procedure may be classified as -

(a) Short term load forecasting

(b) Long term load forecasting.

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(a) Short term load forecasting - A technique for computing twenty four hour forecasts is essential for monitoring and controlling power system operation. Load forecasts are necessary for on-line solution of scheduling problems, such as unit commitment and economic dispatch and also for security analyses by line load flow solution.

The forecasts of these hourly loads which may correspond to a system load, an area load or a bus load are of direct value for the short term operation of the system. Total system load is needed in daily scheduling the most economic allocation between different plants. In addition for thermal plants load forecasts up to several hours in advance are needed to account for economics of starting up and shutting off various plants. Hourly bus-load forecasts are needed for number of off-line applications related to economic and system security problems. On line control requires forecasts of bus loads as input to different analysis programs that monitor and control the systems operation.

The forecast should be sufficiently accurate throughout the lead time period. Here load time period varies from hours to a week. In particular accuracy of the forecasted daily peak load and the daily minimum load is important because these forecasts are used for scheduling spinning reserve and interchanges. In addition to forecast accuracy the following consideration are also important.

(i) The computer storage required

(ii) The computer time required

(iii)The load and/or weather data required.

(b) Long term load forecasting

Forecasting techniques may be based on extrapolation or on correlation or on a combination of both. Correlation techniques of forecasting is advantageous in forcing the forecaster to understand clearly the inter relationship between growth patterns and other measurable factors. No one forecasting method, it must be emphasized, is effective in all situations. The accuracy of a forecast is crucial to any electric utility, since it dictates the timing and characteristics of major system additions. A forecast that is too low can easily result in lost revenue from sales to neighbouring utilities or even in load curtailment on the other hand, forecasts that are too high can result in severe financial problems due to excessive investment in an electric plant that is not fully utilized or, equivalently it is operated at low capacity factor. In long term forecasting lead time for forecast varies in years.

1.4 Method Adopted for short term load forecasting [5]

In present work computer program in FORTRAN IV for probabilistic forecasting of hourly power-system loads with lead times of 1 to 24 hours is developed. The forecasts produced are based on both historical hourly load data and information from the latest weather forecast. The methodology combines stochastic load models and adaptive weather load models **optimally** to yield an adaptive forecasting procedure especially suited for real time control of power systems. Being an adaptive model it avoids the frequent tuning of its parameters from year to year. The details of the method are included in chapter -3.

1.5 Data Requirements and Source

To test the developed computer program hourly load data for 102 days i.e. from Ist August, 87 to 9 November, 87 has been collected from 132 KV Ramnagar grid substation. The above mentioned data has been observed on 33 KV feeder supplying power to Roorkee town.

Daily records of weather variables, average temperature and relative humidity has been collected from Hydrology department of Roorkee University for the same period.

The processing of the historical data is done only once for initialisation of the model parameters. Once the initialisation is completed and model parameters are updated, on the basis of current load values forecastes are made using the updated model parameters and latest weather forecast.

1.6 Forecasting Procedure [5]

A highly simplified flow chart of the forecasting procedure is given in Fig. 1.1. It combines two forecasting models, a stochastic model to relate the future loads to the past loads and a weather load model to represent the effects of

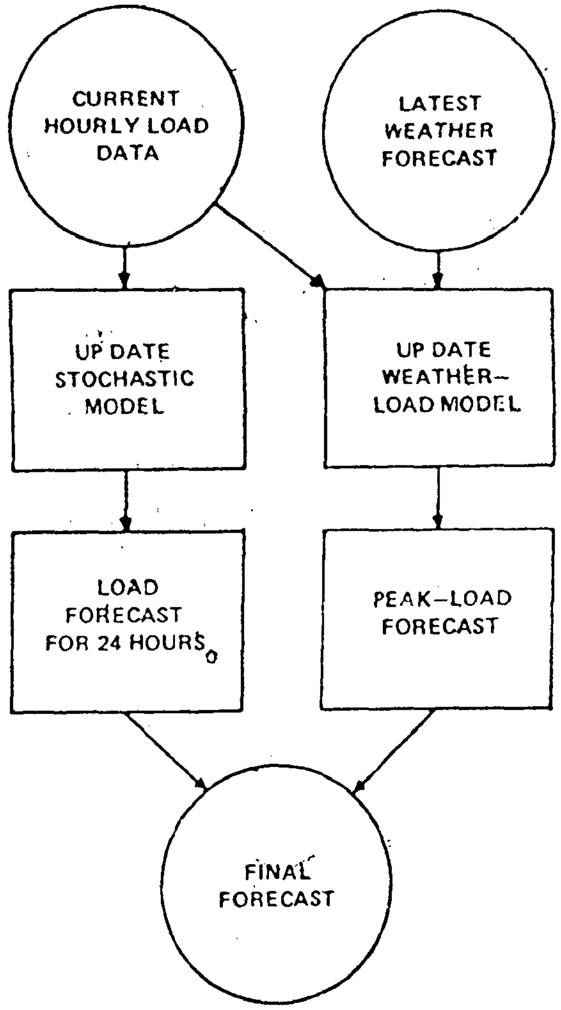

FIG. 1.1

Simplified Flow Chart For Forecasting Procedur weather variables on future loads. The models themselves are updated as the forecast are produced.

1.7 Arrangement of the details

Chapter 2, includes the discription of different techniques used for short term load forecasting. Chapter-3 presents the details of the method adopted for forecasting. Programming details are also discussed in the same chapter. Forecasting results are given in Chapter-4. Conclusions drawn on the present work are included in Chapter-5.

CHAPTER - 2

REVIEW OF THE METHODS USED FOR SHORT-TERM LOAD FORECASTING

The problem of short-term load forecasting has been the subject of several recent publications. Earlier efforts by Matthewman and Nicholson [3] were mainly directed towards performing regression studies between the load data and a number of preselected weather variables. In these studies the model used was static in nature and there was no guarantee that it would perform as well in the prediction of future loads as it did in determining past ones. In the later studies by Toyoda et.al [6] and Christianse [4] weather information has been ignored and an adaptive time series approach has been adopted. The limitation of these approaches is self evident, the weather, which plays an important role in future load swings , has no place in these models. In the later publication by Pradeep C.Gupta et al [5] a forecasting technique was adopted that avoided both the above mentioned limitations. The forecasting model contains an adaptive weather load model to utilize the weather forecast information and an adaptive stochastic model to utilize the historical load data in making the statiscally optimum load forecasts. In reference [7] pattern-recognition technique was used for forecasting hourly loads. The only drawback of the scheme is large computer storage requirements for classifying n dimensional pattern space in to separate regions or clusters. In recent publication by Martin T. Hagan and Suzanne M.Behr [8] it is shown that Box and Jenkins time series models are well suited to short term load forecasting where as in reference [9] two different adaptive and weather sensitive models are used based on the fact that different weather variables are found to be relevant in summer and winter. Adaptivity is attained through careful usage of Kalman filtering and Bayesian techniques.

The purpose of the present chapter is to present the brief discription of the different techniques used for short term load forecasting and their limitations. The literature includes the discription of the following methods.

2.1 Methods involving meteorological data [3]

If the demands for a particular half hour are plotted serially day by day, the points form a time series with a pronounced trough in summer months and a peak in winter months. Upon this seasonal trend is superimposed, a regular rhythemic variation between days of the week, together with an erratic variation which is attributable to weather fluctuations.

The meteorological factors found to affect the demand may be summarised as follows

(a) Temperature

(b) Cloud cover and visibility

(c) Wind velocity

(d) Relative humidity

(e) Precipitation.

The erratic variation of load attributable to weather fluctuation is then some function of these factors, and much efforts of prediction has been directed to determine the nature and value of this function under the prevailing meterological conditions.

Bearing these points in mind, the load demand x at any instant may be written as

$$x = a + d + G \qquad \ldots(2.1)$$

where a is the base load at a particular instant in question, d is the day-of-week correction and G is a function of the various meterological factors influencing the load. This equation forms the common starting point of three different methods of prediction [2.1(a),2.1(b),2.2] two of which are based on meterological data and one on past load data only.

(a) Method of Prediction Using Weather Weighting [3]

In the method of weighting proposed by Dryar [10], load is separated into two main components. a base load, and a variable quantity which reflects the effect of weather. The base load is determined from past records by weighting meteorological factors and applying combined weight as percentage reduction to the system load. Initially, the proper weighting of elements of the weather will only be attained after a period of trial and error.

Using a chart of base loads an accurate load estimate can be made using proper weighting of three of meteorological factors (namely temperature, cloudiness and wind velocity) based on the best available weather forecast.

Re-estimates, and any necessary scheduling adjustments, are then periodically made as more up-to-date weather forecasts are obtained. The feasibility of this method lie in the consistency of the calculation of base load. Such consistency must be evidenced in the following manner.

(i) The base load for the daily peak period must be uniform for the mid week days.

(ii) The base load for each half-hour of these days must be uniform.

(iii) Peak and hourly base loads for each Saturday and Sunday over a period of number of weeks must be consistent.

Any change in the base load from year to year on account of increased overall demand will soon become evident, and the necessary adjustment must be made.

(b) <u>Multiple Regression Methods</u> [3]

In an analysis by Davies, the meteorlogical information is reduced to a number of specific factors designated as follows

(i) effective temperature T

(ii) cooling power of the wind W

(iii) illumination index L

(iv) rate of precipitation P

In deriving the functional relationships between the variation of demand and the specific meteorological factors to which it is sensitive, the basic assumption is again made that the weather-sensitive component of the demand may be expressed as sum of functions of the respective metererological factors.

Linear regression

The first approximation which can be made is to assume a linear functional relationship. If one year data are used to derive the functional relationships, it is necessary to eliminate the combined seasonal and long term trend and also the day-of-the week effect.

A regression equation of the form

$$x = a+b_1T + b_2W + b_3L + b_4P + F(t)+d \qquad \ldots(2.2)$$

is therefore fitted to the data, where x is the demand at fixed time each day, T,W,L,P are the corresponding specific meteorological factors, a, b_1, b_2, b_3, b_4 are constants, d is the day of-the -weak correction, F(t) is a polynomial function of the time of the year for a particular week and accounts for variations in the base load with the time of the year. Thus a+F(t) is the base load at the week.

In this expression, the known quantities are the dependent variable x and the independent variables T,W,L,P,t and the object of the analysis is an estimation of the regression coefficients b_1, b_2, b_3, b_4 and the values of d. In equation 2.2 meteorological factors may be added or removed depending upon the environment condition for the time under consideration. The quantities of immediate interest in the analysis are the meteorological regression coefficients b_1, b_2, b_3, b_4, which effectively measure the change in demand per unit change of each meteorological variable, and the day-of-the week correction d. Having calculated the values of b_1, b_2, b_3, b_4 and d, the run of basic demands may be determined by adjusting the actual demands to some standard set of weather conditions and eliminating the day-of-the week variation. As relationship between demand and the specific meteorological factors to which it responds are nonlinear, the linear functions introduced into the regression analysis will yield only average effects over the range covered by the data.

2.2 Method Involving Past Load Data only [5]

Spectral Expansion- In order to develop a fully automatic power system, it is necessary and convenient to have a model of prediction utilising the most readily available data. On the basis of this consideration, Farmer [12] has developed a theory using past load data only.

Since the basic pattern of load demand tends to repeat it self after every 24 hours, it is possible to consider the time for each day, whether continuous or discrete, as being a member of an ensemble of time series. We thus have the problem of predicting a nonstationary process given an ensemble of same functions.

Considering the load curve divided in to part-day periods of several hours duration. Fig. 2.3 shows a typical day divided into 8 hours periods overlapping by 2 hours. The daily load curves for a particular period form an ensemble, and it is reasonable for this period to define the load on the mth day at the nth instant of time as x_{mn}. an ensemble (with m=5) for the period 1200 to 2000 is shown in Fig. 2.4.

x_{nm} can be written as

$$x_{mn} = \alpha_{mn} + f_1(T_m)\,\beta_{mn} + f_2(L_m)\gamma_{mn} + f_3(W_m)\,\delta_{mn} + \quad \ldots(2.5)$$

where $f_1(T_m), f_2(L_m), f_3(W_m)$ etc are functions of temperature T_m, illumination L_m, and wind velocity W_m. The quantity α_{mn} represents the base load, and the factors $\beta_{mn}, \gamma_{mn}, \delta_{mn}\ldots$ allow for varying importance of the weather parameters with time of day.

The chief advantage of spectral expansion method undoubtedly lies in the fact that no meteorological data are required for its predictions, and consequently the need for expensive instrumentation or the use of possibly inaccurate weather forecasts is saved.

The chief disadvantage of spectral technique lies in its inability to take account of rapid changes which may be caused by the onset of storms or television programmes of national interest or a change in consumers pattern on account of holidays or strikes. These fairly infrequent events, which are normally known in advance, could be accounted for by putting a compensating program into the computer as and when required.

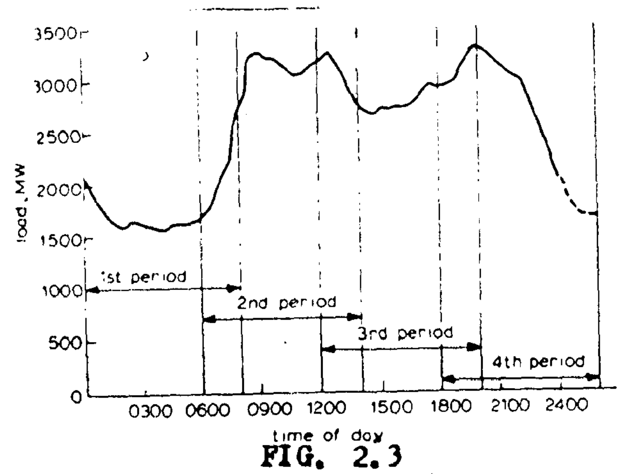

FIG. 2.3

Load Curve Divided into Part-day periods

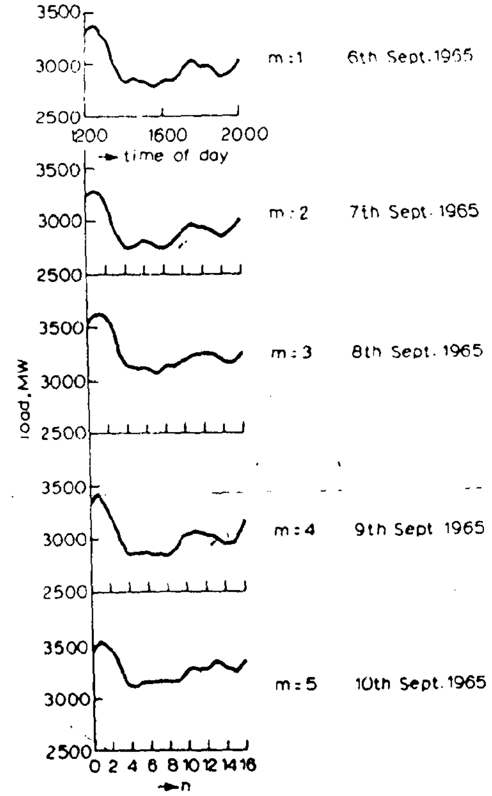

FIG. 2.4

Ensemble of five Functions for the period 1200 to 2000 H.

2.3 Method of Prediction Using Pattern-Recognition Techniques [3,7]

Pattern recognition techniques are generally applied in the study of variables whose total physical principles behind their variation is unknown, but certain kinds of measurements explain their behaviour. Approach to the problem of prediction is based on the fact that daily electrical load patterns in the same geographical area were assumed to have been repeated sometime in the past as a result of similar climatological conditions. This method of prediction utilizes recent load and weather information in addition to weather load relationships. The basic 24-hour load pattern is divided into slots each slot consisting of 2 to 4 hours. This division allows for various weather parameters to be considered for different times of the day. Within each time slot it is assumed that changes in weather pattern do not affect the load significantly. Fig.2.2 shows a standard system of pattern recognition which is adopted here.

Raw Data → Feature Processing → Feature Selection → Decision → Forecast

Fig. 2.2

(i) Feature Processing -

The purpose of features processing is to extract, accumulate and evaluate the relative significance of all the weather variables such as temperature, relative humidity wind velocity etc. in the vicinity of electrical power system. Auto-correlation analysis is performed since it is well-known fact that daily load patterns correlate closely with the previous days climatic condition. The choice for independent weather variables to be selected depends upon the season being analysed. For example humidity is significant in the summer time analysis , and in the same manner, windchill factor is significant in winter time analyses.

(ii) Feature Selection -

In this various means are used to find out the most efficient independent variables that explain similar load patterms on an electrical power system. Two types of studies were performed on weather variebles from feature processing.

(a) All combination Regression

(b) Stepwise linear Reqgression analysis.

In study (a), the multiple correlation coefficient squard factors for all combination of weather variables were determined. Study (b) was performed to obtain total squared error.

(iii) Decision

It incorporates the following functions -

(a) Cluster Analysis - Variables selected through feature selection were used to perform cluster analysis to separate the different dates in to classes with similar climatic parameters. Variation with in a class or cluster represent the unknown nature of load. The optimum number of classes could be one with different cluster as dense and as for as possible. The numbers of classes could also be dependent on available data. Weights can be given to different selected variables to enhance or reduce their relative importance and also to normalize different variables.

(b) Growth Elimination - In order to use load information dating several years back , load growth will be eliminated by the concept of percent spread. Load values will be converted to percent spread values while perserving the shape.

$$\text{Percent spread} = S_t = \frac{L_t - L_{min}}{L_{max} - L_{min}} \times 100 \quad ...(2.6)$$

where,

L_t = load at time t (MW)

L_{min} = Minimum load for that year (MW)

L_{max} = Maximum load for that year (MW)

In performing the conversion each load value will be converted to a value between zero and 100. Zero corresponds to the minimum load for the period of study and 100 corresponds to the maximum load for the same period.

(c) Interpolation - Cluster analysis will identify the best dates for load forecasting of particular day. Depending on the lead time either current weather information (lead time 1-3 hours), or forecasted weather information (lead time up to 24 hours) will be used in the cluster analysis to identify the above dates. It can be proved that if the ratios of minimum to maximum load for two particular days are equal, the corresponding piecewise shapes will only be different by scalar. Percent spread factor will convert all the load to a common base by perserving the shape which will satisfy the above condition.

Interpolation can be repeated 8 times for the three-hour intervals to obtain a base load curve. We will have

$$\frac{F'(t)}{F(t)} = K \pm E$$

where,

$F'(t)$ = Actual load curve at time t

$F(t)$ = Base load curve at time t

K = Constant (Scalar)

E = Error

So, the forecast for time (t+1) will be

$$F''(t+1) = K.F(t+1) \pm E \qquad ...(2.7)$$

where constant K will be changed adaptively (1-3 hours) as new load information is received.

Maximum error of 4 percent was computed by comparing forecasted and actual load curves. This method is suitable for small area power systems due to limitation of geographical area and applicability of weather parameters. In a large power system diversity of loads distort the weather sensitive pattern of load.

2.4 State Estimation Technique [6]

Present day power system engineers have achieved schemes for on-line real time control of complex power systems. A precise short-term forecasting method for estimating the status of systems is required for this purpose.

Before one makes a forecasting model it is necessary to decide the structure of load. It is essential to find a proper modeling of load and some methods of identifying noise characteristics for practical application of state estimation to load forecasting.

The state variables in the load forecasting models are

(1) The system load it-self

(2) The increment of system load

(3) The short term and long term load patterns.

In load forecasting, it is very important to decide how far in future prediction are to be made. The method of forecasting depends upon the forecasting period. **If it** is desired to predict the system load 1 or 2 hours in advance, then the effect of weather fluctuations is not predominant and can be neglected.

State equation can be written as

$$\begin{bmatrix} X_{n+1} \\ \Delta_{n+1} \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} X_n \\ \Delta_n \end{bmatrix} + \begin{bmatrix} \varepsilon_n^1 \\ \varepsilon_n^2 \end{bmatrix} \qquad \ldots(2.8)$$

where Xn is the system load at nth instant, Δn is load increment at nth interval. Observation equation

$$Y_n = [1 \;\; 0] \begin{bmatrix} X_n \\ \Delta_n \end{bmatrix} + n_n \qquad \ldots(2.9$$

where Y_n is an observation value of load at n, n_n, ε^1_n, ε^2_n are the intrinsic system noises. All noises are assumed to occur independently. The most optimal forecast values of states are sequentially given by

$$\begin{bmatrix} X_{n+1} \\ \Delta_{n+1} \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} X_n \\ \Delta_n \end{bmatrix} + \begin{bmatrix} K^1_{n+1} \\ K^2_{n+1} \end{bmatrix} \left[Y_{n+1} - [1 \;\; 0] \begin{bmatrix} 1 & 1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} X_n \\ \Delta_n \end{bmatrix} \right] \qquad \ldots(2.10)$$

Equation (2.10) can be written as

$$X_{n+1} = (1-K^1_{n+1}) \; (X_n + \Delta_n) + K'_{n+1} \; Y_{n+1} \qquad \ldots(2.11)$$

$$\Delta_{n+1} = (1-K^2_{n+1}) \; \Delta_n + K^2_{n+1} \; (Y_{n+1} - X_n) \qquad \ldots(2.12)$$

The above formulation is the same as the exponential smoothing technique for fluctuation with increment. However this forecasting model has excellent properties that of optimal correcting gains, K^1_{n+1} and K^2_{n+1}, sequentially determined by prior information about variances of noise, and that of obtaining the least mean square error of forecasting.

If it is desired to predict the system load 24 hours in a advance then inaddition to load increment, effect of weather variables such as temperature and humidity is taken in to account while modeling the forecasting system. So the structure of system load and observation is written as

$$\begin{bmatrix} X_{n+1} \\ \Delta_{n+1} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & \alpha_n \end{bmatrix} \begin{bmatrix} X_n \\ \Delta_n \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ \beta_n & \gamma_n \end{bmatrix} \begin{bmatrix} T_n \\ H_n \end{bmatrix} + \begin{bmatrix} \varepsilon_n^1 \\ \varepsilon_n^2 \end{bmatrix} \qquad \ldots(2.13)$$

$$Y_{n+1} = [S_{n+1} \quad 1] \begin{bmatrix} X_{n+1} \\ \Delta_{n+1} \end{bmatrix} + n_{n+1} \qquad \ldots(2.14)$$

where X_n is the load at n, 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 ($S_n \simeq S_{n+T}$, $T = 24$ hours). $\alpha_n, \beta_n, \gamma_n$ and S_n can be calculated from data series (Y_o, Y_1, $Y_2 \ldots Y_n$). So the optimal forecasting values of states using the new observed values are sequentially given by

$$X_{n+1} = X_n + K_{n+1}^1 \, [Y_{n+1} - (S_{n+1} X_n + \alpha_n \Delta_n + \beta_n T_n + \gamma_n H_n)] \qquad \ldots(2.15)$$

$$\Delta_{n+1} = \Delta_n + K_{n+1}^2 \, [Y_{n+1} - (S_{n+1} X_n + \alpha_n \Delta_n + \beta_n T_n + \gamma_n H_n)] \qquad \ldots(2.16)$$

where correcting gains K_{n+1}^1 and K_{n+1}^2 are determined using the prior information about noise ε_n^1, ε_n^2, n_{n+1}. Utilising the results of (2.15) and (2.16) the forecasting load Y_{n+T} at n+T is given by

$$Y_{n+T} = S_{n+T} \; X_n + \Delta_{n+T} \qquad \ldots(2.17)$$

In a practical application of load modeling such as the introduced above, there is often no prior information about noise variance. Therefore some identification algorithms

L an nxn matrix of constants called the transition matrix, with the property, $\bar{f}(t) = Lf(t-1)$.

$\bar{R}$ a coulmn vector of 'n' constants called the smoothing vector.

General Model - The observed load X(t) is represented as a linear combination of known functions of time and a noise component, as shown below

$$X(t) = \bar{a}' \quad f(t) + \varepsilon(t) \qquad \ldots(2.18)$$

The coefficients $\bar{a}$ are assumed to be locally constant. The coefficients are gradually changing, but slowly enough so that they can be considered constant over a time span equal to or greater than the maximum lead time. Under this assumption, forecasts can be computed by extrapolating the expression in (2.18). Using the known fitting functions f(t) and estimates $\bar{a}(T)$ of the current values of the coefficients i.e. from

$$X_{\tau} \ (T+\tau) = \bar{a}'(T)\ \bar{f}(t+\tau) \qquad \ldots(2.19)$$

To employ this method, we need (a) an appropriate set of fitting functions and (b) a method for estimating the coefficients from observed values of load. Estimates of the coefficients are revised hourly where as the fitting functions are stationary.

The estimates of the coefficients are computed using weighted least square criterion. A constant β $(0 < \beta < 1)$ is selected and the estimates $\bar{a}(T)$ are computed by minimizing the equation given below

$$\sum_{j=0}^{\alpha} \beta^j \left[X(T-j) - \bar{a}'(T)\,\bar{f}\,(T-J)\right]^2 \qquad \ldots(2.20)$$

The constant β controls the rate at which the past errors are discounted.

After selecting the fitting functions and the smoothing constant, the vector $\bar{h}$ and the transition matrix L are calculated. L and $\bar{h}$ are stored as program constants and forecasts are computed according to the following algorithm.

(A) The estimates of the coefficients are revised according to

$$\bar{a}(T) = L'\bar{a}(T-1) + \bar{h}\,[X(T) - X_1(T)] \qquad \ldots(2.21)$$

(B) New forecasts are then computed from (2.19)

Calculation of L and $\bar{h}$ - It is found that r.m.s value of forecast error is minimum when the smoothing constant is taken as 0.994.

On analysing hourly load data of two years it was found that weekly variations are quite consistent through out the year. So it was decided that the best approach would be to develop a model for the hourly loads over an interval of one week rather than separate 'week day' and 'week end' models. The weekly variations in hourly load are described as a cyclic function of time with a period of one week. It was decided that a Fourier series would be the most appropriate model which meets the requirements for the fitting functions.

The model selected is of the form

$$X(t) = C + \sum_{i=1}^{m} (a_i \sin W_i t + b_i \cos W_i t) \ldots(2.22)$$

$$\sum_{j=o}^{\alpha} \beta^{j} \left[X(T-j) - \bar{a}'(T)\, \bar{f}\, (T-J)\right]^{2} \qquad \ldots(2.20)$$

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that is, a constant C and Fourier series with 'm' frequencies. Since a period of week is assumed, all w's are of the form

$$W = \frac{2\pi}{168} K_i$$

where K_i is a positive integer less than 84.

The fitting functions are expressed by

$$\bar{f}(t) = \begin{bmatrix} \text{Sin } \omega_1 t \\ \text{Cos } \omega_1 t \\ \text{Sin } \omega_2 t \\ \text{Cos } \omega_2 t \\ \vdots \\ \text{Sin } \omega_m t \\ \text{Cos } \omega_m t \end{bmatrix} \qquad \ldots(2.23)$$

The coefficients c, a_i's and b_is constitute the vector $\bar{a}$.

It was found nine frequencies should be introduced for

K = 1,2,3,4,5,6,14, and 28.

The transition matrix L has the property

$$f(t) = L\, f(t-1) \qquad \ldots(2.24)$$

The value of the smoothing vector $\bar{h}$ is given by

$$\bar{h} = [\sum_{j=0}^{\infty} \beta^j f(-j)\, \bar{f}'(-j)\,]^{-1} f(0) \ldots(2.25)$$

Estimates of variance of the forecast errors for various lead times are updated according to

$$S_\tau^2\ (T) = \gamma\, S_\tau^2(T) + (1-\gamma)[X(T) - X_\tau(T)]^2$$

$$\ldots(2.26)$$

The forecast model adapts automatically to seasonal changes and changes in daily fluctuations. The method is also operationally simple. An hourly matrix multiplication and a vector addition are required to update the model. Computer storage requirements are reasonable.

As the weather data has not been taken into account separately, it is reflected by the past data only so whenever there is abrupt change in weather the accuracy of the forecast gets jeoparadised.

2.6 Adaptive Short-term forecasting of hourly loads using weather information

In this methods hourly load forecasts with a lead time of 24-hours are produced based on both historical load data and information from the latest weather forecast. This method combines stochastic load models and adaptive weather load models optimally to yield an adaptive forecasting procedure especially suited for on-line control of power systems. This method is discussed in detail in Chapter -3.

CHAPTER -3

COMPUTER PROGRAMMING
OF
ADAPTIVE SHORT TERM FORECASTING

3.1 Basics of Method

The forecasting model in the method used contains an adaptive weather load model to utilize the weather forecast information and an adaptive stochastic model to utilize the historical load data in making the statistically optimum load forecasts. This adaptive features enables the model to update its own parameters according to its past performance. So the forecasting model is suitable for on-line usage. Simplified flow chart of forecasting procedure is already shown in Fig. 1.1. The procedure is explained under the following sections.

3.1.1 Stochastic load model

The hourly system load is divided in to three components.

$$Z(i,j) = T(i,j) + WC(i,j) + X(i,j) \qquad \ldots(3.1)$$

where,

$Z(i,j)$ = system load measured in hourly MWH at hour j and day i

$T(i,j)$ = Basic component of load at hour j and day i

$WC(i,j)$ = Weekly cycle component (day-of-the-week effect) at hour j and day i

$X(i,j)$ = Residual component containing the effect of weather variation at hour j and day i.

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The nature of these three components is very different. $T(i,j)$ can be considered more or less constant from day to day, $WC(i,j)$ is a slowly changing component signifying the weekly pattern of the hourly loads and $X(i,j)$ is rapidly changing component containing fast hour to hour variations in the load due to numerous random factors such as weather conditions experienced by the load area served by the substation. An autoregressive type of model is chosen for the random component.

$$\underline{X}(i) = A\,\underline{X}\,(i-1) + \underline{W}(i-1) \qquad \ldots(3.2)$$

where,

$$\underline{X}(i) = \begin{bmatrix} X(i,1) \\ X(i,2) \\ \vdots \\ X(i,24) \end{bmatrix}$$

$\underline{X}(i)$ is a (24 X 1) coulmn vector of residual components for the ith day.

A = (24 X 24) matrix of coefficients.

$\underline{W}(i-1)$= (24 X 1) column vector of model error terms.

In this model each element of $\underline{X}(i)$ is linear function of all the elements of $X(i-1)$. An unknown (24X24) covarance matrix Q is defined such that

$$E\,[\underline{W}(i)\,\underline{W}(i)^T] = Q \qquad \ldots(3.3)$$

where $W(i)^T$ denotes the transpose of $W(i)$. An equivalent form of equation (3.3) can be written for the (j,k)th element of Q as

$$Q(j,k) = E[W(i,j)\ W(i,k)] \qquad \ldots(3.4)$$

where $W(i,j)$ is the model error term for hour j of the ith day.

3.1.2 Weather load model

The forecasting procedure required a weather load model in which daily peak load is represented in terms of weather-variables. The model also contains terms corresponding to the basic load and the weekly pattern similar to those used in the stochastic model. The model is of the form.

$$Y(i) = B(i) + S(i) + W(i) + \varepsilon(i) \qquad \ldots(3.5)$$

where,

$Y(i)$ = Peak load on the ith day

$B(i)$ = Basic load component of peak load on i th day

$S(i)$ = Weekly pattern component of the peak load on the ith day

$W(i)$ = Weather-sensitive component of the peak load on the ith day

$\varepsilon(i)$ = Random component of the peak load on the ith day.

Strictly speaking, $B(i)$ and $S(i)$ should be defined as elements of $T(i,j)$ and $WC(i,j)$. However, better estimates can be expected to result if $B(i)$ and $S(i)$ are estimated independely of $T(i,j)$ and $WC(i,j)$ respectively.

The weather-sensitive component $W(i)$ is assumed to be a linear function of suitably transformed values of weather variables such as temperature and humidity observed at the load centre. A general form of the model is given by

$$W(i) = \sum_{j=1}^{k} C_j \; WV_j(i) \qquad \ldots(3.6)$$

where,

k = number of weather variables in the model

$WV_j(i)$=j th weather variable (or a transformed value of of the variable) on the ith day

C_j= unknown jth coefficient of the model.

There will be seven values in the weekly pattern corresponding to each day of the week. Thus

$$S(i) = \sum_{j=1}^{7} S_j P_j(i) \qquad \ldots(3.7)$$

where,

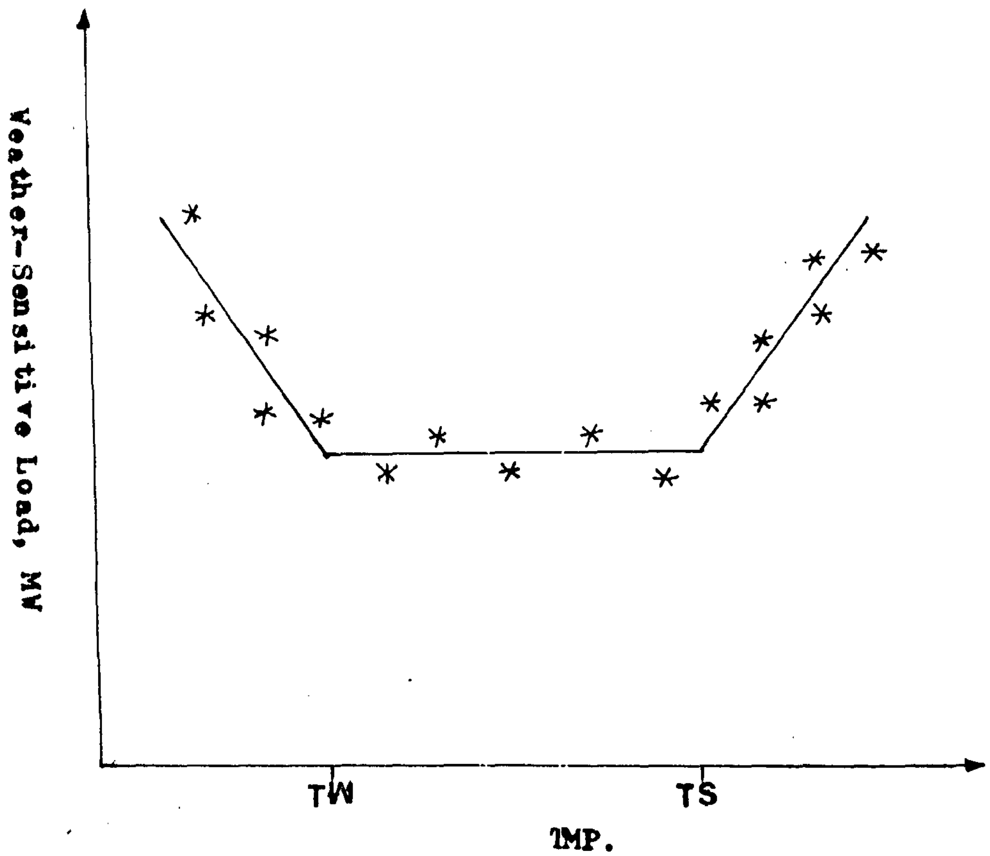
S_j= jth value of weekly pattern (j=1 corresponds to Sunday)

$P_j(i)$ = 1 if the ith day corresponds to the jth day of the week
0 otherwise

The weather variables selected are the average daily temperature and the relative humidity. As shown in Reference [11], it is necessary to make a nonlinear transformation of the temperature variable in order to formulate a linear weather load model of the type shown in equation (3.6). In order to transform the weather variable it is necessary to study the effect of weather variables on the load.

(a) Effect of Temperature

To determine the effect of temperature on the load it is common to plot a scatter diagram of daily peaks versus daily average temperature. The scatter diagram



Daily average temperature

FIG.NO. 3.1

is shown in Fig. 3.1. Using curve fitting techniques, weather variable can be transformed as under.

$$\left.\begin{aligned} WV_1(i) &= TMP(i) - TS \quad && \text{if } TMP(i) - TS \\ &= 0 && \text{if } TW < TMP(i) < TS \\ &= TW - TMP(i) && \text{if } TMP(i) < TW \end{aligned}\right\} \quad \ldots(3.8)$$

where TW and TS are the fixed parameters of the transformation and TMP(i) is the average temperature on the ith day.

(b) <u>Effect of Humidity</u>

For agricultural load it is observed that load requirement is negligible when the relative humidity approaches 100 percent. But as the relative humidity decreases the agricultural load starts increasing. So the relative humidity can be transformed by the following relation.

$$WV_2(i) = 100 - \text{Relative humidity} \qquad \ldots(3.8(b))$$

3.1.3 <u>Initialization Procedures</u>

Initialization procedures involve identification of the unknown parameters of the weather-load model and of the matrices A and Q of the stochastic model. In addition the current values of T(i,j), WC(i,j), X(i,j) of equation (3.1) and B(i) and Si of equations (3.5) and (3.7) are also required.

<u>Indentification of A and Q</u> - The identification of A and Q is based on the residual component $\underline{X}(\cdot)$ of the historical load data. Since the residual component is not directly available, it is necessary to first estimate T(i,j) and WC(i,j) from the given

load data. Each element is obtained by filtering the weekly pattern and the residual component from the load data.

$$T(i,j) = 1/7 \sum_{k=i-6}^{i} Z(k,j) \qquad \begin{matrix} j=1,2,..,24 \\ i=7,8,.., N \end{matrix} \qquad ...(3.9)$$

where N is the number of days for which load data is available.

The weekly pattern component WC(i, j) is obtained by an exponential smoothing filter.

$$WC(i,j) = WC(i-7,j) + \alpha\ [Z(i,j)-T(i,j)-WC(i-7,j)]$$

$$j = 1,2,...,24 \qquad ...(3.10)$$

$$i = 8,9,...,N$$

where α is a filter constant (0.2 to 0.5) and

$$WC(k,j) = Z(k,j) - T(7,j) \quad k=1,2,...7 \qquad ...(3.11)$$

Here using equations (3.9), (3.10) and (3.11), the residual components $\underline{X}(.)$ can be estimated from the given load data. Let these be denoted by $\underline{X}(1)$, $X(2)$...,etc.

Post-multiplying equation (3.2) with $\underline{X}^T(i)$ and taking the expected values gives the following

$$Q = \Gamma_0 - A\Gamma_0\ A^T \qquad ...(3.12)$$

where $\Gamma_0 = E[\underline{X}(i)\ \underline{X}^T(i)] \qquad ...(3.12)$

Similarly post-multiplying equation (3.2) by $\underline{X}^T(i-1)$ and taking the expected values gives

$$A = \Gamma_1\ \Gamma_0^{-1} \qquad ...(3.14)$$

where

$$\Gamma_1 = E\ [\underline{X}(i)\ \underline{X}^T(i-1)] \qquad ...(3.15)$$

Equation (3.12) and (3.14) constitute the identification equations for identifying A and Q. Matrices Γ_o and Γ_1 are estimated from the residual components $\underset{\sim}{X}(.)$ of the historical data as follows

$$\Gamma_o = \frac{1}{N} \sum_{i=1}^{N} \underline{X}^T(i)\, X^T(i) \qquad \text{...(3.16)}$$

$$\Gamma_1 = \frac{1}{N-1} \sum_{i=2}^{N} \underline{X}(i)\, \underline{X}^T(i-1) \qquad \text{...(3.17)}$$

<u>Identification of weather load Model</u> - The unknown parameters of weather-load model are identified by minimizing the exponentially weighted sum of squares of prediction error. So we minimize.

$$E=\sum_{n=1}^{N} [Y(n)-B(n)-\sum_{i=1}^{7} S_iP_i(n)-\sum_{i=1}^{k} C_iWV_i(n)]^2\beta^{N-n} \qquad \text{...(3.18)}$$

B(n) in the above expression is estimated by exponential smoothing scheme,

$$B(n)= B(n-1) +\alpha\, [Y(n-1) - \sum_{i=1}^{7} S_iP_i(n-1) - \sum_{i=1}^{k} C_i\, WV_i(n-1)-B(n-1)] \qquad \text{...(3.19)}$$

where β is a constant between 0 and 1. Constant α is also assumed known. The normal values for α and β are respectively 0.2 and 0.985.

Equation (3.19) can be written as

$$B(n) = \bar{Y}(n-1) - \sum_{i=1}^{k} C_i\, \overline{WV}_i(n-1) - \sum_{i=1}^{7} S_i\bar{P}_i(n-1) \qquad \text{...(3.20)}$$

where,

$$\bar{Y}(n-1) = \alpha Y(n-1) + (1-\alpha)\ \alpha\ Y(n-2) + \cdots$$

$$= \alpha Y(n-1) + (1-\alpha)\ \bar{Y}(n-2) \qquad \ldots(3.21)$$

$$\overline{WV}_i(n-1) = \alpha WV_i(n-1) + (1-\alpha)\alpha WV_i(n-2) + \cdots$$

$$= \alpha WV_i(n-1) + (1-\alpha)\overline{WV}_i(n-2) \qquad \ldots(3.22)$$

$$\bar{P}(n-1) = \alpha P_i(n-1) + (1-\alpha)\alpha P_i(n-2) + \cdots$$

$$= \alpha P_i(n-1) + (1-\alpha)\ \bar{P}_i(n-2) \qquad \ldots(3.23)$$

Hence equation (3.18) becomes

$$E = \sum_{n=1}^{N} [Y(n) - \bar{Y}(n-1) - \sum_{i=1}^{7} S_i(P_i(n) - \bar{P}_i(n-1)) - \sum_{i=1}^{k} C_i(WV_i(n) - \overline{WV}(n-1))]^2 \beta^{N-n} \qquad \ldots(3.24)$$

If the initial values of $\bar{Y}(n)$, $\overline{WV}_i(n)(i=1,2\ldots k)$, $\bar{P}_i(n)(i=1,2,\ldots 7)$ are known, the subsequent values can be estimated using equations (3.21), (3.22) and (3.23) and the unknown parameters Si and Ci can be determined by a least squares method. For computational economy, a recursive estimator is used. Let

$$\Delta Y(n) = Y(n) - \bar{Y}(n-1) \qquad \ldots(3.25)$$

$$a^T = (S_1, S_2 \ldots S_7, C_1, C_2 \ldots, C_k)$$

$$\phi^T(n) = [P_1(n) - \bar{P}_1(n-1), P_2(n) - \bar{P}_2(n-1) \ldots, WV_1(n) - \overline{WV}_1(n-1), WV_2(n) - \overline{WV}_2(n-1), \ldots] \qquad \ldots(3.27)$$

$\hat{a}(N)$ = optimum estimate of the coefficient vector a at the N th iteration. Then a(N) can be written as

$$\hat{a}(N) = \hat{a}(N-1) + P(N)\ \phi(N)[\Delta Y(N) - \phi^T(N)\hat{a}(N-1)] \qquad \ldots(3.28)$$

where P(N) is a newly defined variable.

$$P(N) = 1/\beta(N-1) - \frac{1}{\beta^2}P(N-1)\phi(N)[1+\phi^T(N)\ \frac{1}{\beta}P(N-1)\phi(N)]^{-1}\phi^T(N)\,P(N-1) \qquad \ldots(3.29)$$

To perform the identification process by using equations (3.28) and (3.29), we require initial value of $\overline{Y}(.)$, $\overline{WV}_i(.)$, $\overline{P}_i(.)$, a(.) and P(.). In order to obtain these, the data base is divided in to three parts as shown in Fig. 3.2

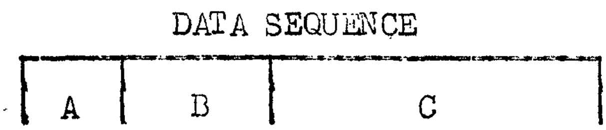


Fig. 3.2 Division of the historical data base in three parts for identification of weather-load model.

Part A is used for determining $\overline{Y}_o$, $\overline{WV}_i0$, $\overline{P}_i0$, the initial values of $\overline{Y}(n)$, $\overline{WV}_i(n)$ and $\overline{P}_i(n)$. The initial values are determined by taking the simple averages

$$\overline{Y}_o = \frac{1}{m}\sum_{n=1}^{m} Y(n) \qquad \ldots(3.30)$$

$$\overline{WV}_i0 = \frac{1}{m}\sum_{n=1}^{m} W_i(n) \qquad i=1,2,\ldots,K \qquad \ldots(3.31)$$

$$\overline{P}_i0 = \frac{1}{m}\sum_{n=1}^{m} P_i(n) \qquad i=1,2,\ldots,7 \qquad \ldots(3.32)$$

where m is the total number of days included in part A. Part B is used for the determination of initial values $\hat{a}(0)$ and P(0). Using equations (3.21),(3.22),(3.23) and (3.27), the values of $\overline{Y}(n)$, $\overline{WV}_i(n)$, $P_i(n)$ and $\phi(n)$ are obtained. Then, $\hat{a}(0)$ and P(0) are estimated from the following equations.

$$P(0) = [\sum_{J\varepsilon PartB} \phi(j)\phi^T_{(j)}]^{-1} \quad ...(3.33)$$

$$a(0) = P(0) [\sum_{j\varepsilon PartB} \phi(j) \Delta Y(j)] \quad ...(3.24)$$

Part C of the data is used for updating P(.) and a(.) recursively and the values are stored for producing peak load forecasts with the current weather load data.

3.1.4 Adaptive Forecasting Procedure

The load forecast for the (i+1)st day, Z(i+1,j), j=1,2...24, is made on the basis of measurements of Z(i,j), j=1,2....24 and the weather forecast $WV_j(i+1)$, j=1,2...k in the following steps.

Update T(i,j) and WC(i,j) - The basic component T(i,j), j=1,2...24 is updated according to equation (3.9) and the weekly pattern component WC(i,j) is updated according to equation (3.10). The residual component $\underline{X}(i)$ is then determined as follows

$$X(i,j) = Z(i,j)-T(i,j) - WC(i,j) \qquad J=1,2....24 \quad ...(3.35)$$

Updata A and Q: - Matrices A and Q are updated by reestimating the conouriance matrics Γ_0 and Γ_1 by the following equations.

$$\overset{i}{\Gamma}_0 = \overset{i-1}{\Gamma}_0 + \frac{1}{i} [\underline{X}(i)\, \underline{X}^T(i) - \overset{i-1}{\Gamma}_0] \quad ...(3.36)$$

$$\overset{i}{\Gamma}_1 = \overset{i-1}{\Gamma}_1 + \frac{1}{i-1} [\underline{X}(i)\, \underline{X}^T(i-1) - \overset{i-1}{\Gamma}_1] \quad ..(3.37)$$

where Γ_o^i and Γ_1^i are the estimates of the covariance matrices Γ_o and Γ_1 obtained by processing the data of the ith day. Equations (3.36) and (3.37) can be easily derived from equation (3.16) and (3.17). The algorithm given above is very efficient since the updating of covariance matrices is based on only the previous estimates and the new product terms $\underline{X}(i)\ \underline{X}^T(i)$ and $\underline{X}(i)\ \underline{X}^T(i-1)$.

The new estimates of A and Q are computed using updated estimates of Γ_o and Γ_1 in equation (3.12) and (3.14).

Forecast Based on stochastic Model

The forecast of the next 24 values of residual component $\underline{X}$ (i+1) is produced by using equation (3.2) and assuming the forecast of model errors $\underline{W}$ (i+1) to be the expected value of $\underline{W}$(i+1) i.e. zero.

$$\underline{X}(i+1) = A\ \underline{X}(i) \qquad \ldots(3.38)$$

The load forecast based on the stochastic model, Zs(i+1,j), is then given by

$$Zs(i+1,j) = T(i,j)+WC(i+1,j)+X(i+1,j)$$
$$j = 1,2,\ldots,24 \qquad \ldots(3.39)$$

In the forecasting equation (3.39), the basic component is assumed to be unchanged from the ith to the (i+1)st day The variance of the forecast Zs(i+1,j) is given by the variance of the J th model error term, i.e. Q(J,J)

$$\sigma_s^2(j) = Q\ (j,j) \qquad \ldots(3.40)$$

Update weather-load Model

The actual peak load for the ith day, $Y(i)$ is determined from the load data

$$Y(i) = \max_{j} \; [Z(i,j)] \qquad \ldots(3.41)$$

By using equations (3.21), (3.22), (3.23), (3.25), (3.28) and (3.29), the parameters of the weather load model $a(i)$ are updated.

Peak load forecast Based on Weather forecast -

The peak load forecast for the (i+1)st day is calculated as follows

$$Y(i+1) = B(i+1)+S(i+1)+\sum_{j=1}^{k} C_j \tilde{WV}_j(i+1) \qquad \ldots(3.42)$$

where $\tilde{WV}_j(i+1)$ is the forecast of the jth variable for the (i+1)st day.

The variance of $Y(i+1)$, σ_y^2 is computed by updating the variance estimate based on the observed peak-load forecast error of the ith day i.e.

$$\sigma_y^2 = \sigma_y^2 + \frac{1}{i} [\{ Y(i) - Y(i)\}^2 - \sigma_y^2] \qquad \ldots(3.43)$$

Composite Load Forecast

The composite load forecast is the optimum combination of the forecast based on stochastic model and the peak load forecast based on weather load model. If the maximum value of $Zs(i+1),j)$, $j=1,2,\ldots 24$ is the same as $Y(i+1)$, then composite forecast is same as given by stochastic model namely, $Zs(i+1,j)$, $j=1,2\ldots24$. However, the weather forecast brings extra information about the future loads and hence, in most cases, $Y(i+1)$ and the maximum of $Zs(i+1,j)$ are different. Two stochastic estimates are combined to obtain a suitable weighted average of the two estimates. The equations for computing a composite load forecast $Z(i+1)$ from $Zs(i+1,j)$ and $Y(i+1)$ are the following.

$$Z(i+1,j) = Z_s(i+1,j) + \frac{[Y(i+1)\ Z_{sp}]Q(J,p)}{Q(p,p) + \sigma_y^2} \qquad \ldots(3.44)$$

where,

$$Z_{sp} = \max_j \ \{ Zs(i+1,j)\} \qquad \ldots(3.45)$$

and p is the hour of the day associated with Z_{sp}. The forecast variance, σ_j^2, is reduced from its original value since extra information in the form of the peak load forecast has been used in the composite forecast.

$$\sigma_j^2 = Q(j,j) - \frac{Q^2(j,p)}{Q(p,p) + \sigma_y^2} \qquad \ldots(3.46)$$

$$j = 1,2.\ldots.24$$

Special holidays modify the daily load pattern in a way that is generally different from the regular pattern of weekends. Special holidays are observed to differ from one holiday to another, although the load pattern of each holiday remains approximately the same from year to year. Where enough data are available, it is possible to determine an average load pattern for each special holiday from historical load data. These average estimates can then be used in the load forecasts for special holidays.

3.2 Flow-Chart

The flow-chart for the developed program has been presented in two sub-sections. Flow chart given in subsection 3.2.1 stands for initialising and identifying the parameters of stochastic load model and weather load model. The values of parameters calculated in this section are passed to adaptive forecasting program.

Flow-chart presented in section 3.2.2 stands for adaptive forecasting program. In this flow-chart, parameters already stored in the previous flowchart are taken out, processed along with current hourly load data, current values of weather variables and forecasted values of weather variables to make hourly -load forecast for the next 24 hours.

3.3 Details of Programming

The flow-charts given in the previous section have been implemented in FORTRAN IV on DEC-2050 computer of R.U.C.C. The software package for short-term load forecasting with lead time of 24 hours consists of two sections.

Section -1 This section is titled, 'Forecasting Incorporating Effect of Temperature' and is given in Appendix-1. It includes the effect of only one weather variable i.e. daily average temperature while making load forecast for the next 24-hours. Two programs have been developed in this section. First program is used to identify and initialise parameters of stochastic model and weather load model as per flow chart.

FLOW CHART FOR INITIALISATION OF STOCHASTIC LOAD MODEL AND WEATHER LOAD MODEL

START

↓

READ HISTORICAL LOAD DATA Z(i,j) AND VALUES OF WEATHER VARIABLES, TMP(i) AND HMDTY(i) FOR THE SAME PERIOD

WHERE $j = 1, 2 \ldots \text{NHOUR}$
$i = 1, 2 \ldots \text{NDAY}$

↓

CALCULATE BASIC LOAD COMPONENTS T(i,j), WEEKLY LOAD COMPONENTS WC(i,j) AND RESIDUAL LOAD COMPONENTS X(i,j) BY PROCESSING THE HISTORICAL DATA USING EQUATIONS, (3.9), (3.10) (3.11) AND (3.1)

↓

CALCULATE AND STORE THE VALUES OF MATRICES $[\Gamma_0]$ AND $[\Gamma_1]$ ESTIMATED FROM RESIDUAL COMPONENTS OF THE HISTORICAL LOAD DATA USING EQUATIONS.

$$[\Gamma_0] = \frac{1}{\text{NDAY}} \sum_{i=1}^{\text{NDAY}} \underline{X}(i)\, \underline{X}^T(i)$$

$$[\Gamma_1] = \frac{1}{\text{NDAY-1}} \sum_{i=2}^{\text{NDAY}} \underline{X}(i)\, \underline{X}^T(i-1)$$

↓

STORE THE VALUES OF FOLLOWING COMPONENTS (FOR USE OF ADAPTIVE FORECASTING): BASIC LOAD COMPONENTS T(i,j) FOR THE LAST SIX DAYS OF AVAILABLE DATA, WEEKLY LOAD COMPONENTS WC(i,j) FOR THE LAST SEVEN DAYS OF AVAILABLE DATA, RESIDUAL COMPONENTS FOR THE LAST DAY OF AVAILABLE DATA.

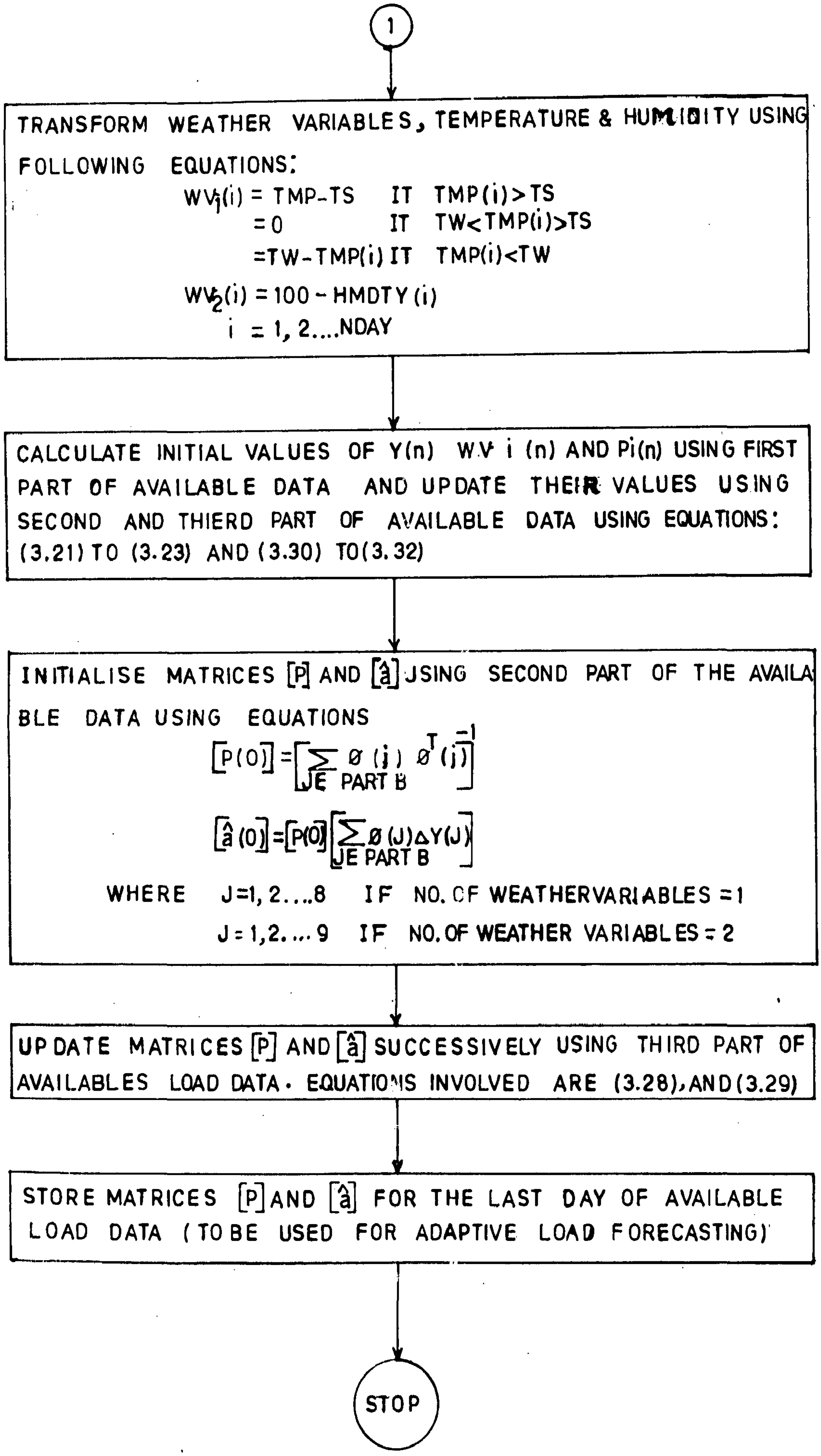
↓

CALCULATE PEAK LOAD, Y(i), FOR EACH DAY OF THE AVAILABLE DATA

WHERE $Y(i) = \max_{j} [Z(i,j)]$; $i = 1, 2 \ldots \text{NDAY}$

↓

①


1
TRANSFORM WEATHER VARIABLES, TEMPERATURE & HUMIDITY USING FOLLOWING EQUATIONS:
$WV_1(i) = TMP-TS$ IT $TMP(i)>TS$
$=0$ IT $TW<TMP(i)>TS$
$=TW-TMP(i)$ IT $TMP(i)<TW$
$WV_2(i) = 100 - HMDTY(i)$
$i = 1, 2 \ldots NDAY$
CALCULATE INITIAL VALUES OF Y(n) WV i (n) AND Pi(n) USING FIRST PART OF AVAILABLE DATA AND UPDATE THEIR VALUES USING SECOND AND THIERD PART OF AVAILABLE DATA USING EQUATIONS: (3.21) TO (3.23) AND (3.30) TO (3.32)
INITIALISE MATRICES [P] AND [$\hat{a}$] USING SECOND PART OF THE AVAILABLE DATA USING EQUATIONS
$[P(0)] = \left[\sum_{J \in PART\ B} \phi(j)\, \phi^T(j)\right]^{-1}$
$[\hat{a}(0)] = [P(0)]\left[\sum_{J \in PART\ B} \phi(J) \Delta Y(J)\right]$
WHERE J=1, 2....8 IF NO. OF WEATHERVARIABLES = 1
J = 1,2.... 9 IF NO. OF WEATHER VARIABLES = 2
UPDATE MATRICES [P] AND [$\hat{a}$] SUCCESSIVELY USING THIRD PART OF AVAILABLES LOAD DATA. EQUATIONS INVOLVED ARE (3.28), AND (3.29)
STORE MATRICES [P] AND [$\hat{a}$] FOR THE LAST DAY OF AVAILABLE LOAD DATA (TO BE USED FOR ADAPTIVE LOAD FORECASTING)
STOP

3.2.2 FLOW CHART FOR ADAPTIVE FORE CASTING:

START

READ STORED VALUES OF BASIC LOAD COMPONENTS $T(i,j)$ WEEKLY LOAD COMPONENTS $WC(i,j)$ AND RESIDUAL LOAD COMPONENTS $X(i,j)$ FROM INTIALISATION PROGRAM

READ STORED MATRICES $[\Gamma_0]$ $[\Gamma_1]$ $[P]$ AND $[\hat{a}]$ FROM INITIALISATION PROGRAM

READ HOURLY LOAD DATA AND VALUES OF WEATHER VARIABLES FOR THE CURRENT DAY AND FORE CASTED VALUES OF WEATHER VARIABLES FOR THE NEXT DAY.

UPDATE BASIC LOAD COMPONENTS $Z(i,j)$, WEEKLY LOAD COMPONENTS $WC(i,j)$ USING CURRENT DAY HOURLY LOAD DATA AND CALCULATE THE VALUES OF RESIDUAL COMPONENTS $X(i,j)$ FOR THE CURRENT DAY USING EQUATIONS (3.9), (3.10) AND (3.35) RESPECTIVELY

UPDATE MATRICES $[\Gamma_0]$ AND $[\Gamma_1]$ AND CALCULATE COEFFICIENT MATRIX $[A]$ AND COVARIANCE MATRIX $[Q]$ USING EQUATIONS.

$$\Gamma_0^{i} = \Gamma_0^{i-1} + \frac{1}{i}\left[\underline{X}(i)\underline{X}^T(i) - \Gamma_0^{i-1}\right]$$

$$\Gamma_1^{i} = \Gamma_1^{i-1} + \frac{1}{i-1}\left[\underline{X}(i)X^T(i-1) - \Gamma_1^{i-1}\right]$$

$$A = \Gamma_1 \Gamma_0^{-1}, \quad Q = \Gamma_0 - A\Gamma_0 A^T$$

CALCULATE THE VALUES OF RESIDUAL COMPONENTS FOR THE NEXT DAY $X(i+1,j)$ USING UPDATE VALUE OF MATRIX $[A]$

$$X(i+1, j) = A\,X(i,j)$$

i STAND FOR CURRENT DAY $j = 1, 2 \ldots NHOUR$

3

3

FORE CAST HOURLY LOAD AND VARIANCE FOR THE NEXT 24 HOURS ON THE BASIS OF STOCHASTIC LOAD MODEL USING EQUATIONS:

$$\hat{Z}_S(i+1,j) = T(i,j) + WC(i+1,j) + X(i+1,j)$$

$$\sigma_S^2(j) = Q(j,j) \; ; \quad j = 1,2.....NHOUR$$

i= CORRESPONDS TO CURRENT DAY

UPDATE MATRICES [P] AND [$\hat{Q}$] USING CURRENT HOURLY LOAD DATA AND VALUES OF WEATHER VARIABLES FROM EQUATIONS (3.28) AND (3.29)

CALCULATE BASIC LOAD COMPONENTS FOR THE NEXT DAY USING EQUATIONS:

$$B(i+1,j) = \bar{Y}(i) - \sum_{l=1}^{k} C_l \, \overline{WV}_l(i) - \sum_{l=1}^{n} S_l \bar{P}_l(i)$$

j = 1,2....NHOUR

k = NO. OF WEATHER VARIABLES CONSIDERED

FORE CAST PEAK LOAD FOR THE NEXT 24 HOURS USING FORE-CASTED VALUES OF WEATHER VARIABLES FROM EQUATION -(3.42)

FORE CAST HOURLY LOAD DATA AND VARIANCE FOR NEXT 24 HOURS BY OPTIMALLY COMBINING THE FORECAST BASED ON STOCHASTIC LOAD MODEL AND WEATHER LOAD MODEL FROM EQUATIONS: (3.44) TO (3.46)

STOP

Second program is used to update the values of parameters provided by the first program, utilising current load data and observed value of weather variable and simultaneously makes forecast for the next 24 hours (as per flow chart).

Section -2 This section bears heading, 'Forecasting incorporating Effect of Temperature and Humidity and is also given in Appendix-1. It includes the effect of two weather variables i.e. daily average temperature and daily relative humidity. Like Section-1 it also consists of two programs. One for initialisation and identification of stochastic and weather load parameters where as the second program updates these parameters and makes forecast for the next 24 hours taking into account the effect of temperature and humidity.

The above mentioned programs use the following subroutines.

MATINV(X,A,L): The function of this subroutine is to calculate the inverse of the matrix [X]. Matrix [A] is the out put of the sub-routine, i.e. $[A] = [X]^{-1}$. L specifies the order of matrix [X]. The distinguishing feature of this subroutine is that the original matrix [X] does not get destroyed.

MATMUL(A,B,C,L1,L2,L3) - The function of this subroutine is to calculate the product of two matrices A and B as and when required by the main program. C is the output matrix. L1 denotes the number of rows in matrix [A]. L2 is equal to the number of coulmns in matrix [A] or number of rows in matrix B. L3 represents the number of coulmns in matrix [B].

ARRAY(MODE, I,J,N,M,S,D) - If MODEL=1, it converts single dimension matrix into double dimension matrix. In this case [S] is input matrix and D is output matrix. N implies no. of rows and M implies no. of coulmns in the output matrix. I and J implies dimensions of input matrix [S].

If MODE=2, it converts double dimension matrix in to single dimension matrix. In this case D is the input matrix and S is the output matrix. This subroutine is used in conjunction with MINV subroutine.

MINV (A,N,D,L,M) - [A] is the matrix whose inverse is required D is the determinant of the matrix. In this subroutine original matrix [A] gets destroyed.

CPU time required by the initialisation program varies from 7 to 8 seconds for processing the data of 92 days. Whereas the CPU time required by the adaptive program varies from 3 to 4 seconds.

CHAPTER - 4

COMPUTATIONS AND RESULTS

The developed programs have been run on actual load data and weather variables records obtained from Ramnagar Substation, Roorkee and Hydrology department of Roorkee University respectively. For this purpose, following data were obtained.

1. Hourly load data for a period of 102 days from 1 Aug. 1987 to 10 Nov. 1987, out of this 92 days data were used for initialising and updating parameters of load models and the rest of data were used for the comparison of results. Hourly load data is given in Appendix - 2.
2. Daily average temperature and relative humidity records are also given in Appendix-2. For the execution of programs, constant α and β were fixed at the following values.

$$\alpha = 0.2, \qquad \beta = 0.985$$

Overall results are divided in the following parts.

Part A In this part results are obtained by incorporating the effect of average temperature only. Results are further subdivided in to two sections. In the first section, load forecasts are made with a lead time of 24 hours and after every 24 hours, the parameters of models have been updated. The above forecasts have also been compared with the actual values of hourly loads observed on the same days.

In second section load projects are made with a lead time of one week, assuming weather forecasts were available.

Part B - In this part results have been obtained by taking into account the effect of average temperature and relative humidity. Here also results have been subdivided into two sections. In the first section, hourly load forecasts are made with a lead time of 24 hours and after every 24 hours the parameters of models have been updated. In the second section load projections are made with a lead time of one week. The above forecasts have also been compared with the actual values of hourly loads observed on the same days.

The computed values of hourly-load forecasts followed by their graphical comparison with the actual hourly loads observed on the same data are presented in a sequence as per the following table.

Thus it will be observed that there is a good agreement in the forecasted and actual values occuring especially in view of the fact that the least count of the observation is 5 units. Sample results are included in Appendix - 3.

Forecasting incorporating effect of	Lead time of forecasts	Forecasted day	Maximum S.D estimated		Maximum S.D actually observed		Comparision graph sheet (Fig.No.)
			S.D.	Hours	S.D.	Hours	
Temperature	24 hours	Nov.2,87	5.44	21	6.52	07	4.1
	24 hours	Nov.3,87	5.76	09	5.52	09	4.2
	24 hours	Nov.7,87	5.45	21	6.05	21	4.3
	24 hours	Nov.8,87	5.47	17	6.28	17	4.4
	4 days	Nov.5,87	5.83	20	6.89	07	4.5
	1 week	Nov8,87	5.89	17	6.65	17	4.6
Temperature and Humidity.	24 hours	Nov.2,87	5.45	21	6.52	07	4.7
	24 hours	Nov.3,87	5.72	18	6.32	19	4.8
	24 hours	Nov.7,87	5.46	16	6.29	10	4.9
	24 hours	Nov.8,87	5.48	13	6.12	17	4.10
	4 days	Nov.5,87	5.81	21	6.81	07	4.11
	1 week	Nov.8,87	5.87	21	6.63	09	4.12

FORECAST FOR NOV. 2, 1987.

INCORPORATING EFFECT OF TEMPERATURE

LEAD TIME = 24 HOURS

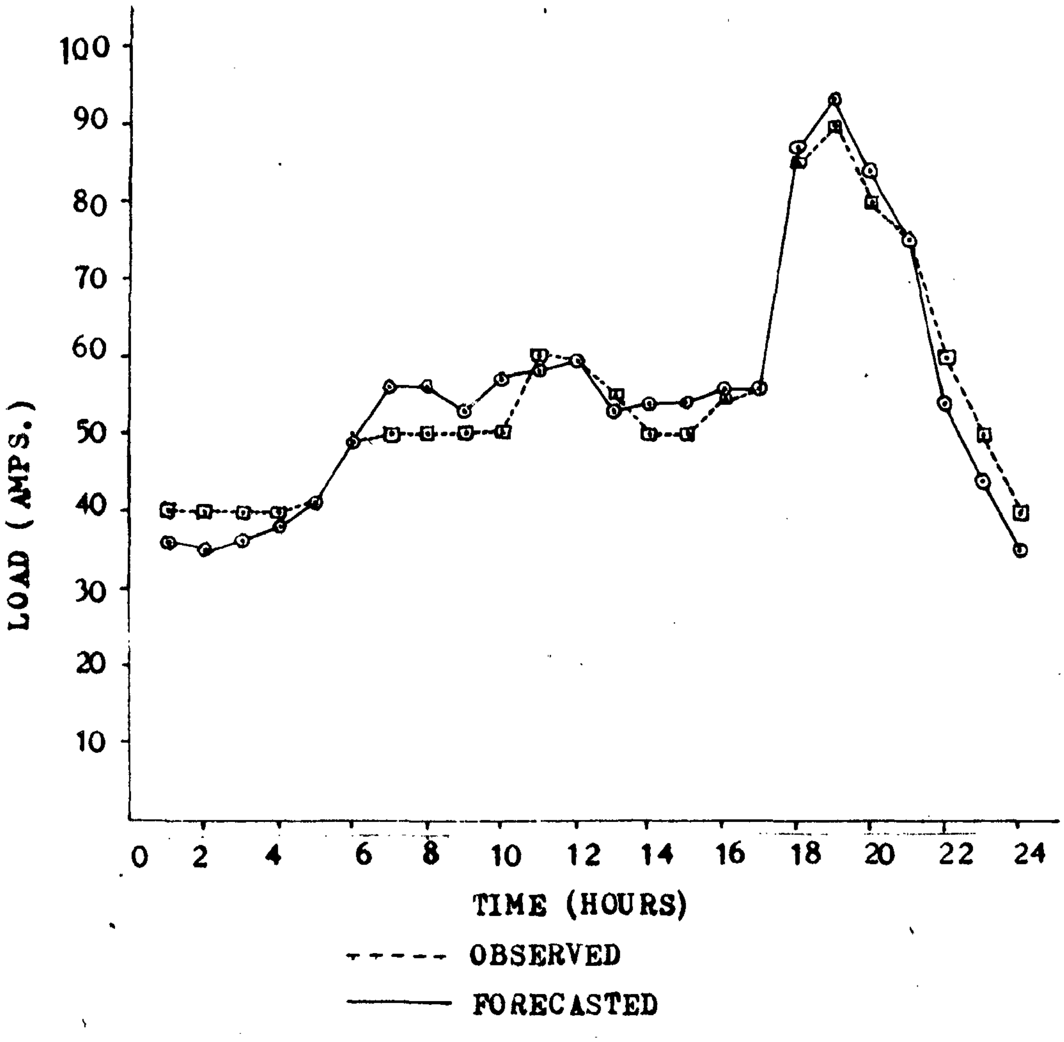


FIG. NO. 4.1

FORECAST FOR NOV. 3, 1987

INCORPORATING EFFECT OF TEMPERATURE

LEAD TIME = 24 HOURS

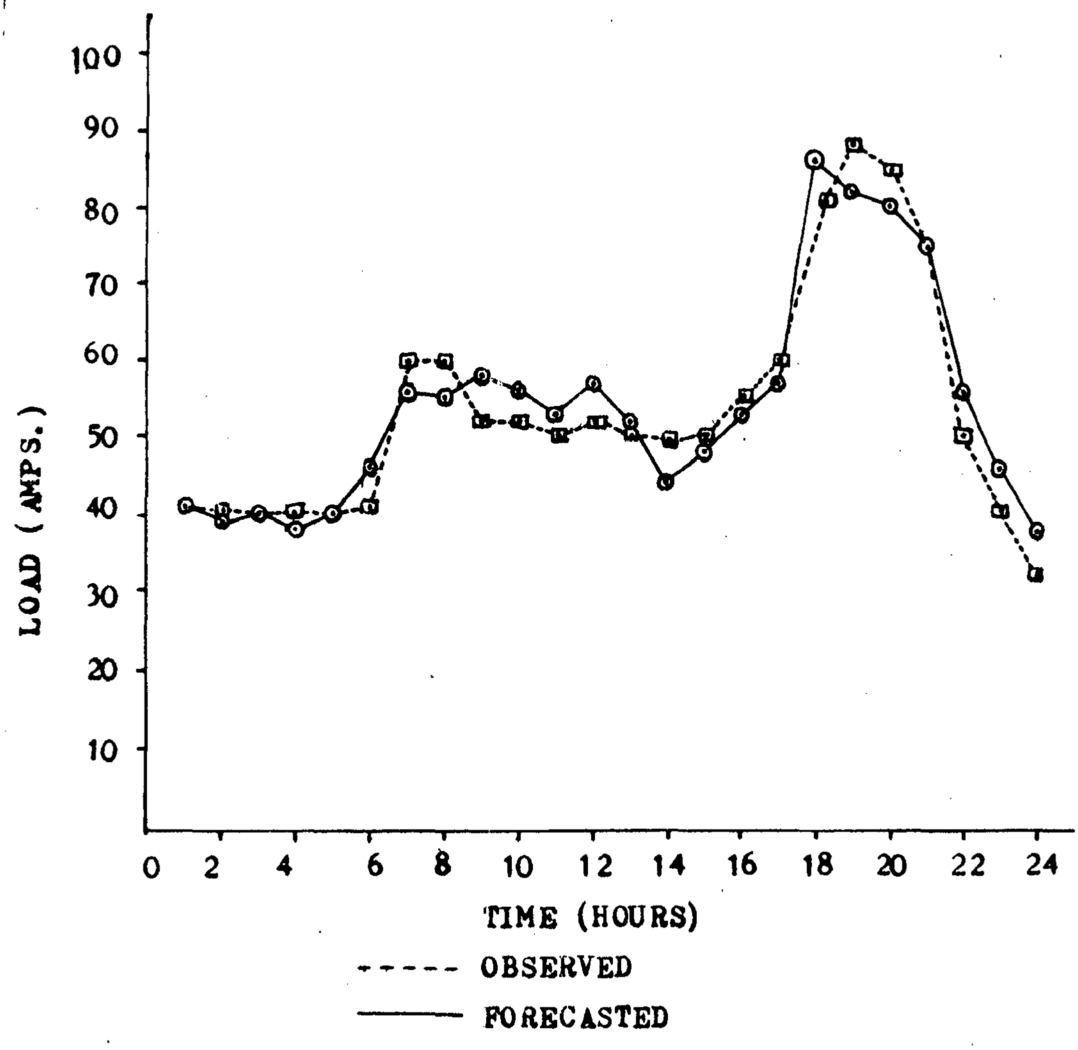


FIG.NO.4.2

FORECAST FOR NOV.7, 1987

INCORPORATING EFFECT OF TEMPERATURE

LEAD TIME = 24 HOURS

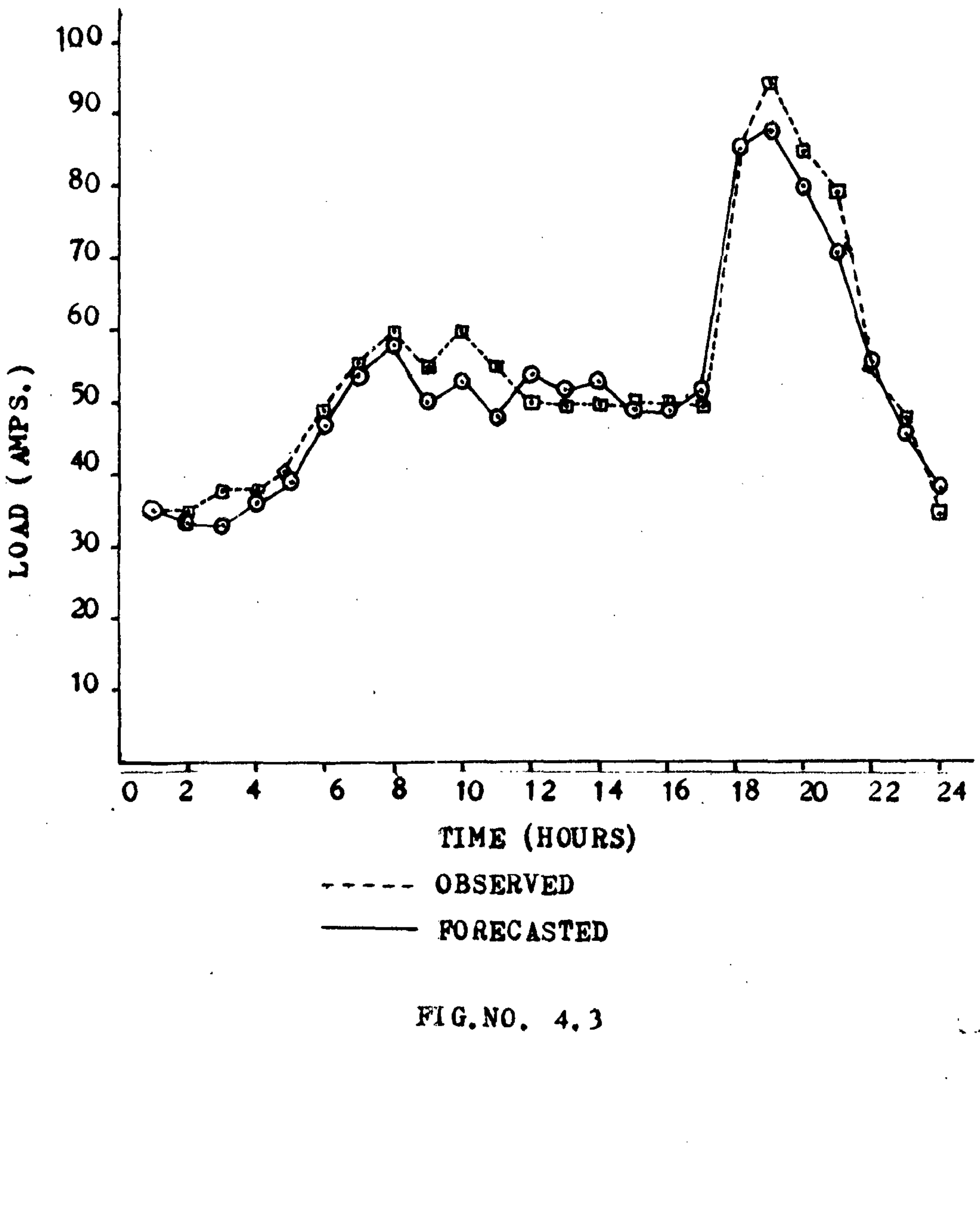
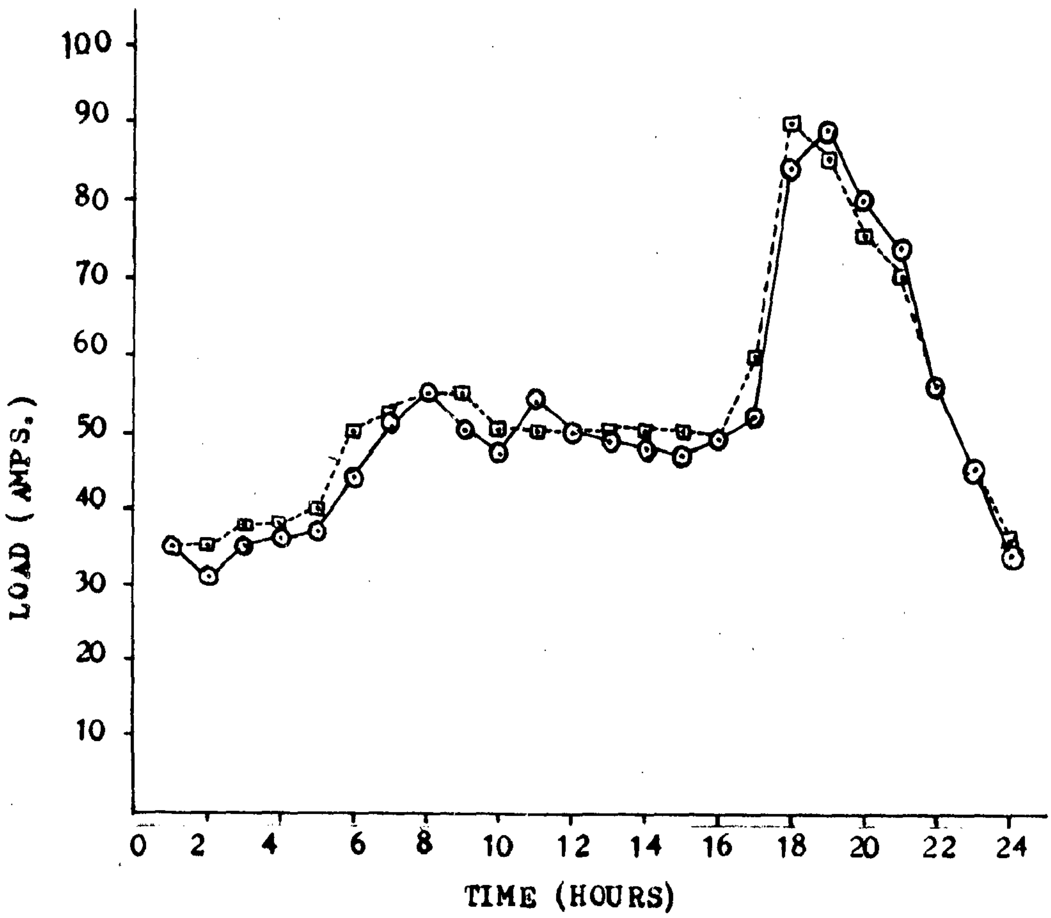


FIG.NO. 4.3

FORECAST FOR NOV.8, 1987

INCORPORATING EFFECT OF TEMPERATURE

LEAD TIME = 24 HOURS



- - - - - OBSERVED

——— FORECASTED

FIG.NO. 4.4

FORECAST FOR NOV. 5, 1987.

INCORPORATING EFFECT OF TEMPERATURE

LEAD TIME = 4 DAYS

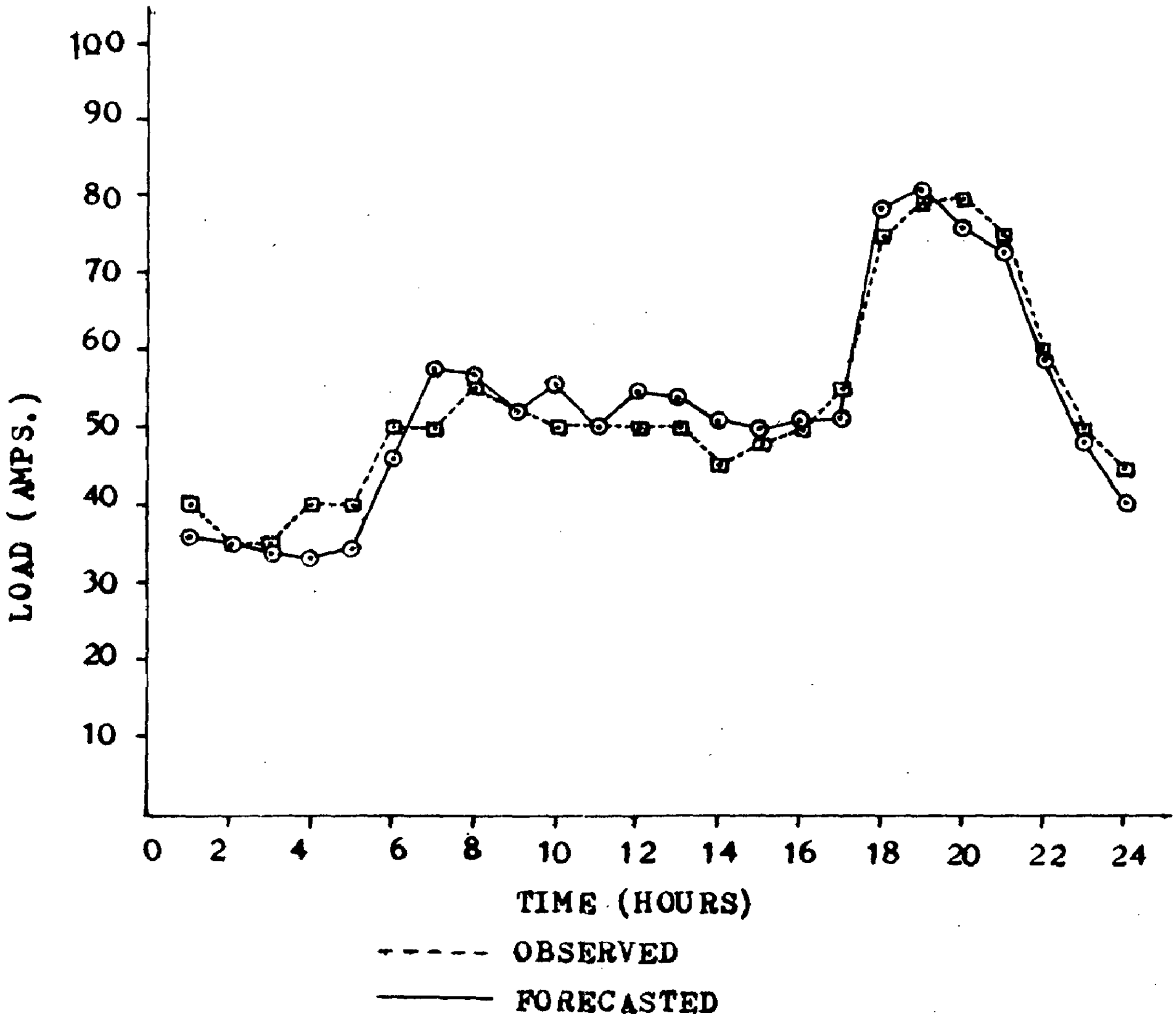


FIG. NO. 4.5

FORECAST FOR NOV. 8, 1987

INCORPORATING EFFECT OF TEMPERATURE

LEAD TIME = 1 WEEK

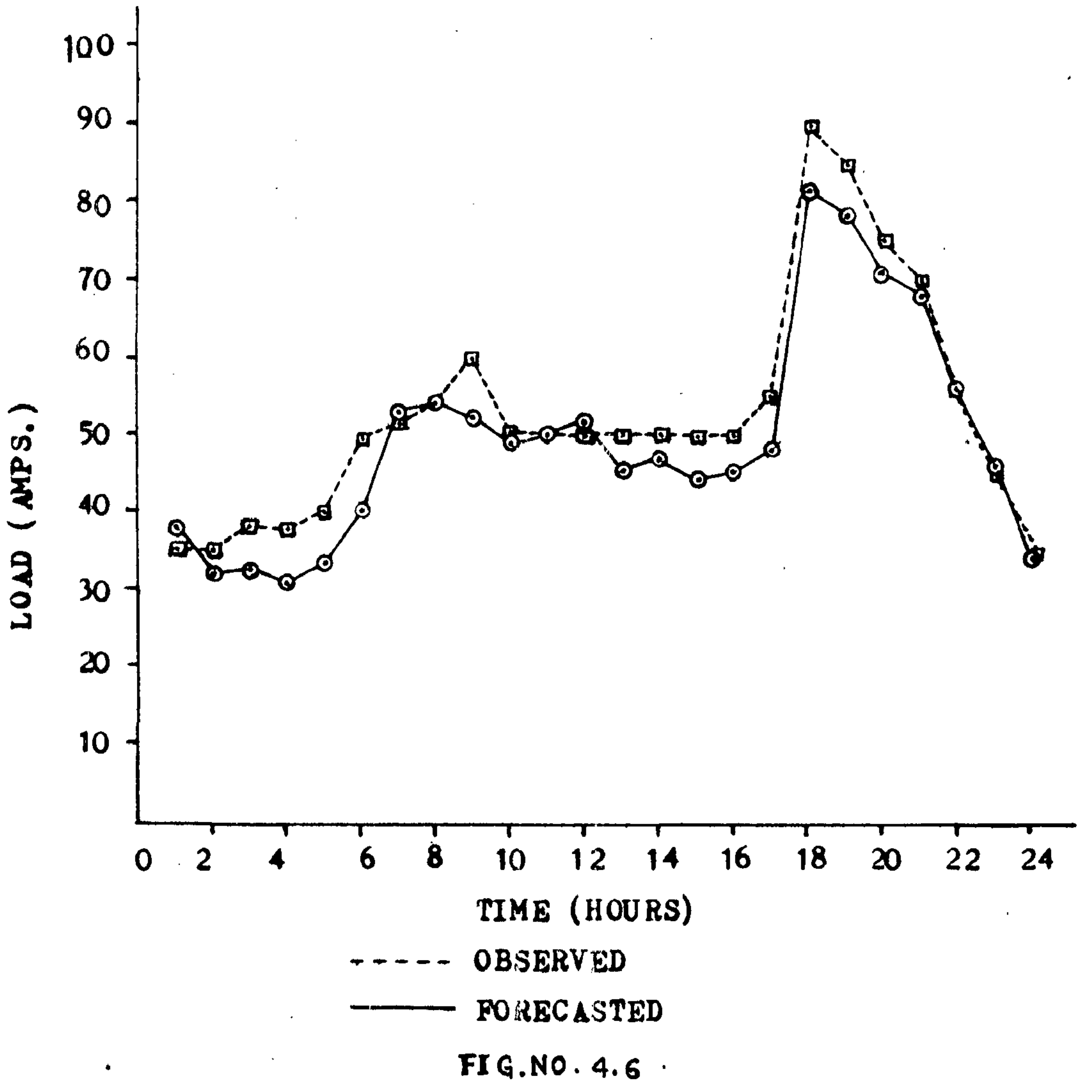


FIG.NO.4.6

FORECAST FOR NOV. 2, 1987.

INCORPORATING EFFECT OF TEMPERATURE AND HUMIDITY

LEAD TIME = 24 HOURS

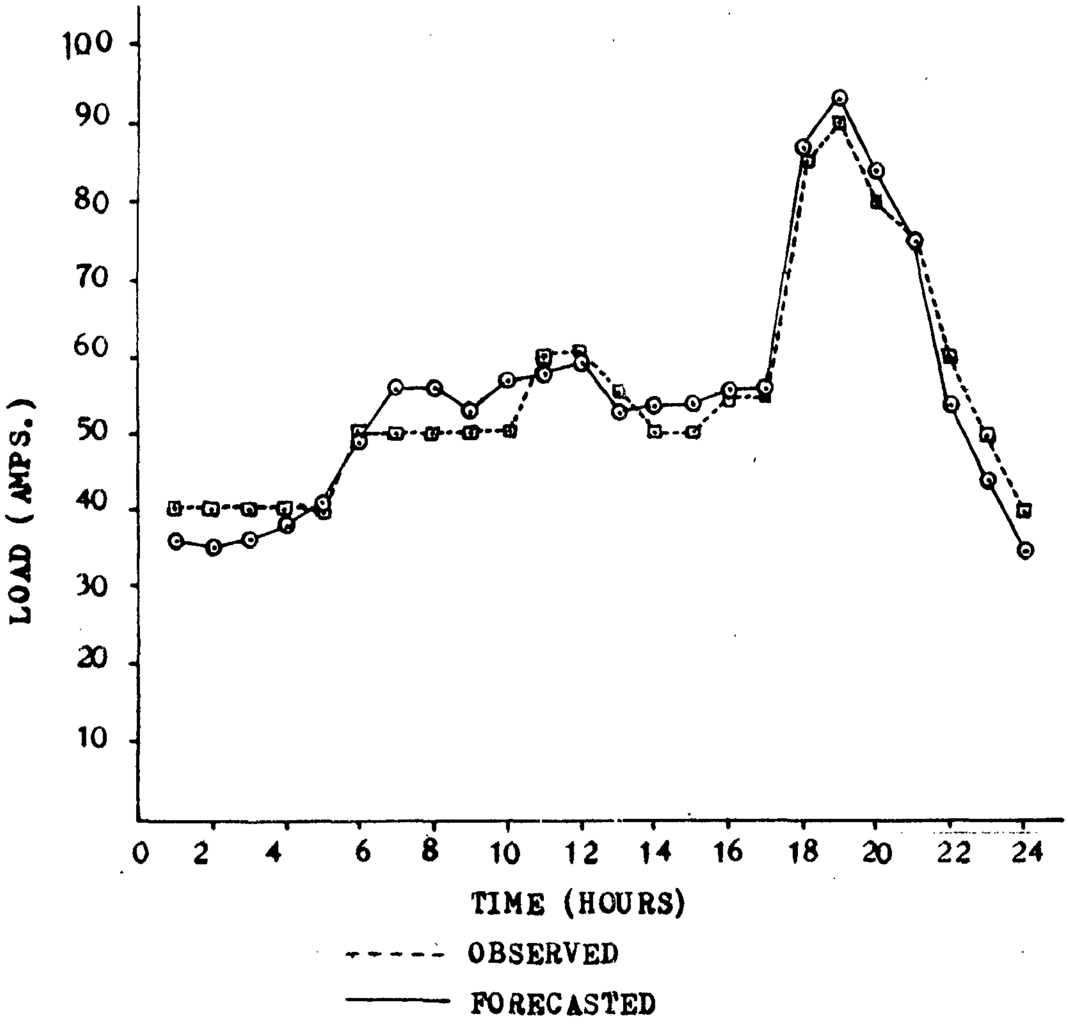


FIG. NO. 4.7

FORECAST FOR NOV.3, 1987.

INCORPORATING EFFECT OF TEMPERATURE AND HUMIDITY

LEAD TIME = 24 HOURS

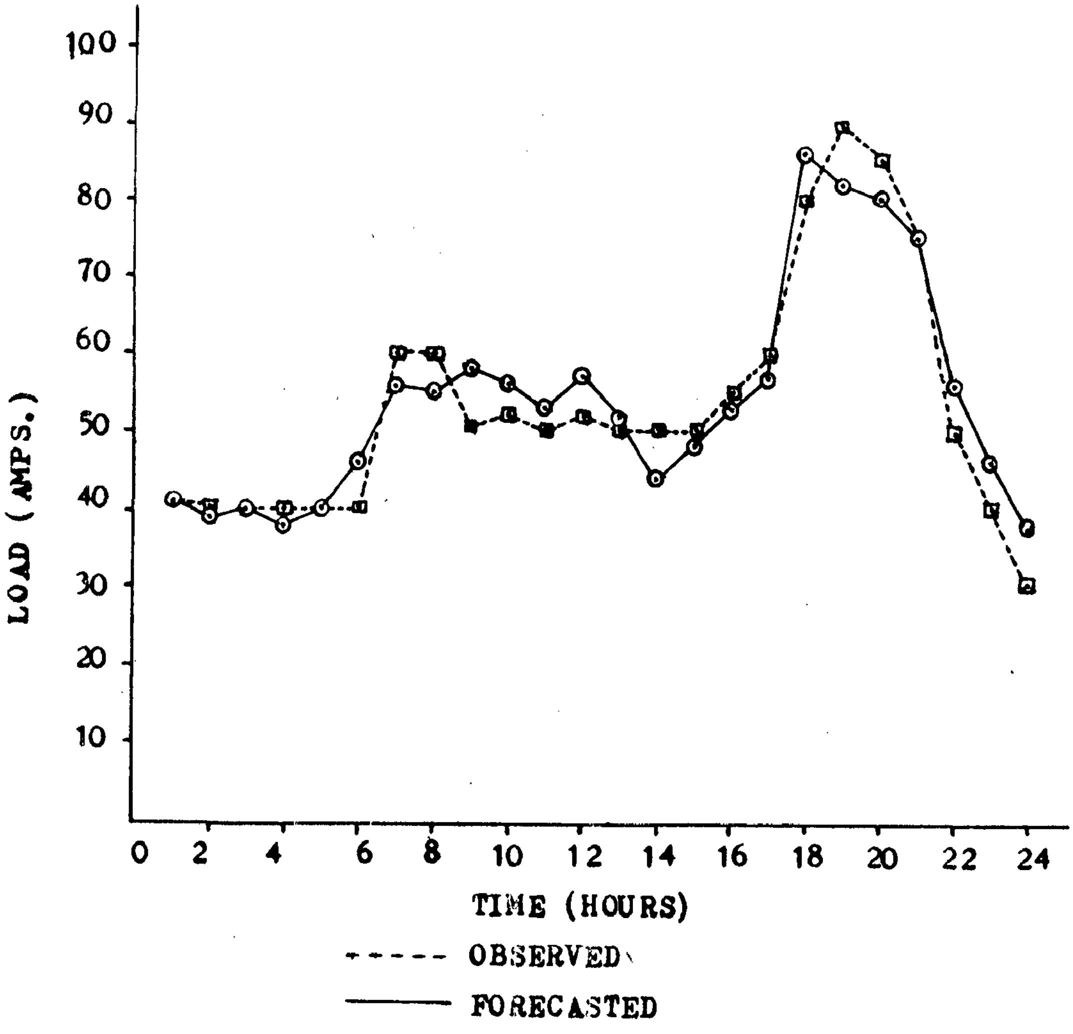


FIG.NO. 4.8

FORECAST FOR NOV. 7, 1987

INCORPORATING EFFECT OF TEMPERATURE AND HUMIDITY

LEAD TIME = 24 HOURS

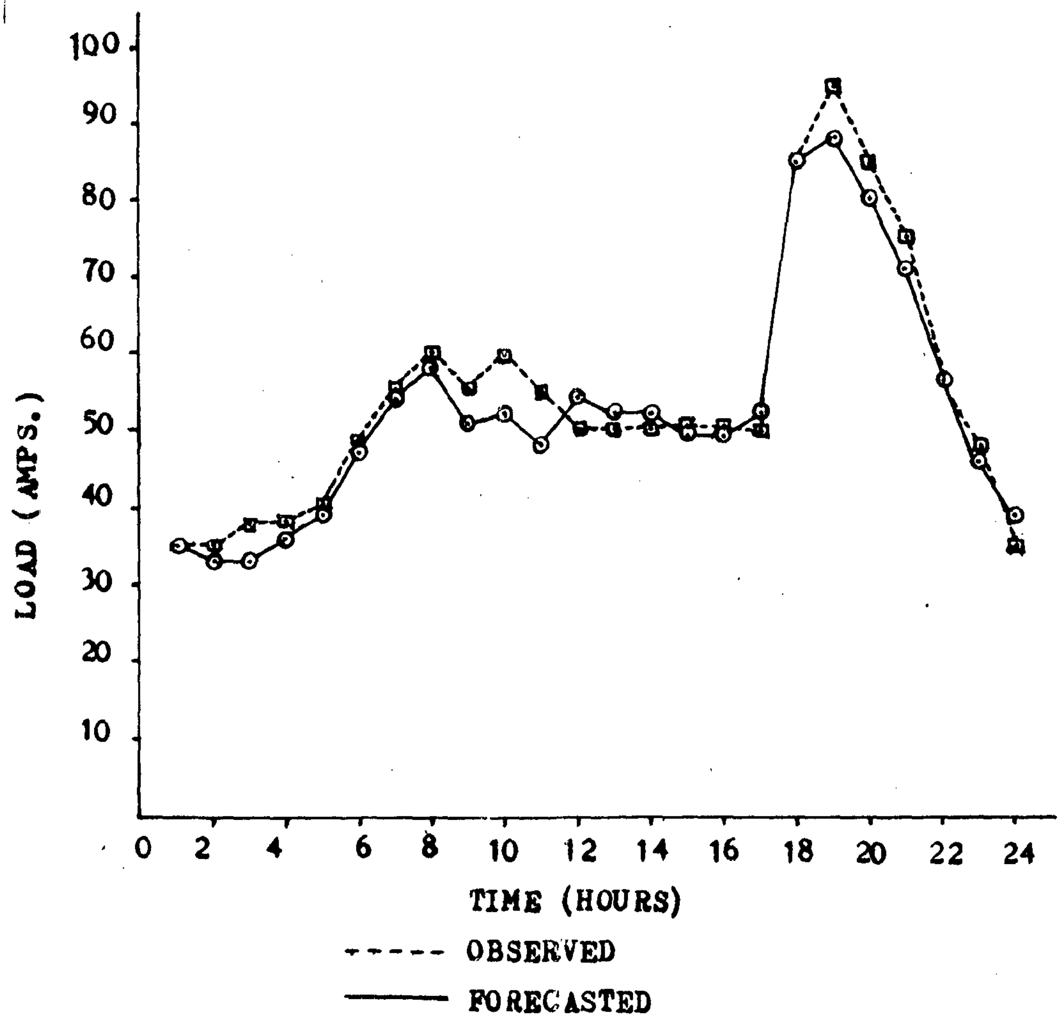


FIG.NO. 4.9

FORECAST FOR NOV. 8, 1987

INCOR PORATING EFFECT OF TEMPERATURE AND HUMIDITY

LEAD TIME = 24 HOURS

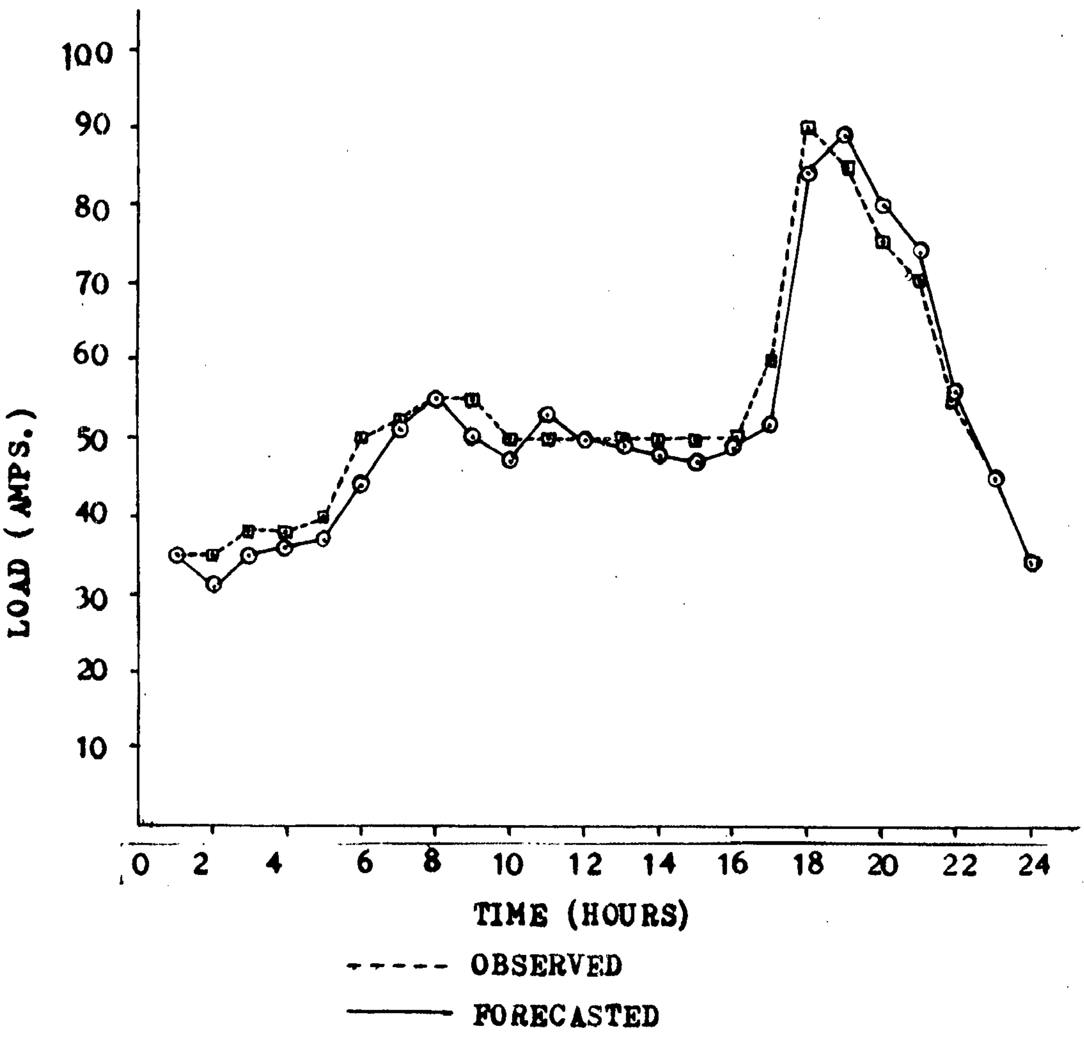


FIG.NO. 4.10

FORECAST FOR NOV. 5, 1987

INCORPORATING EFFECT OF TEMPERATURE AND HUMIDITY

LEAD TIME = 4 DAYS

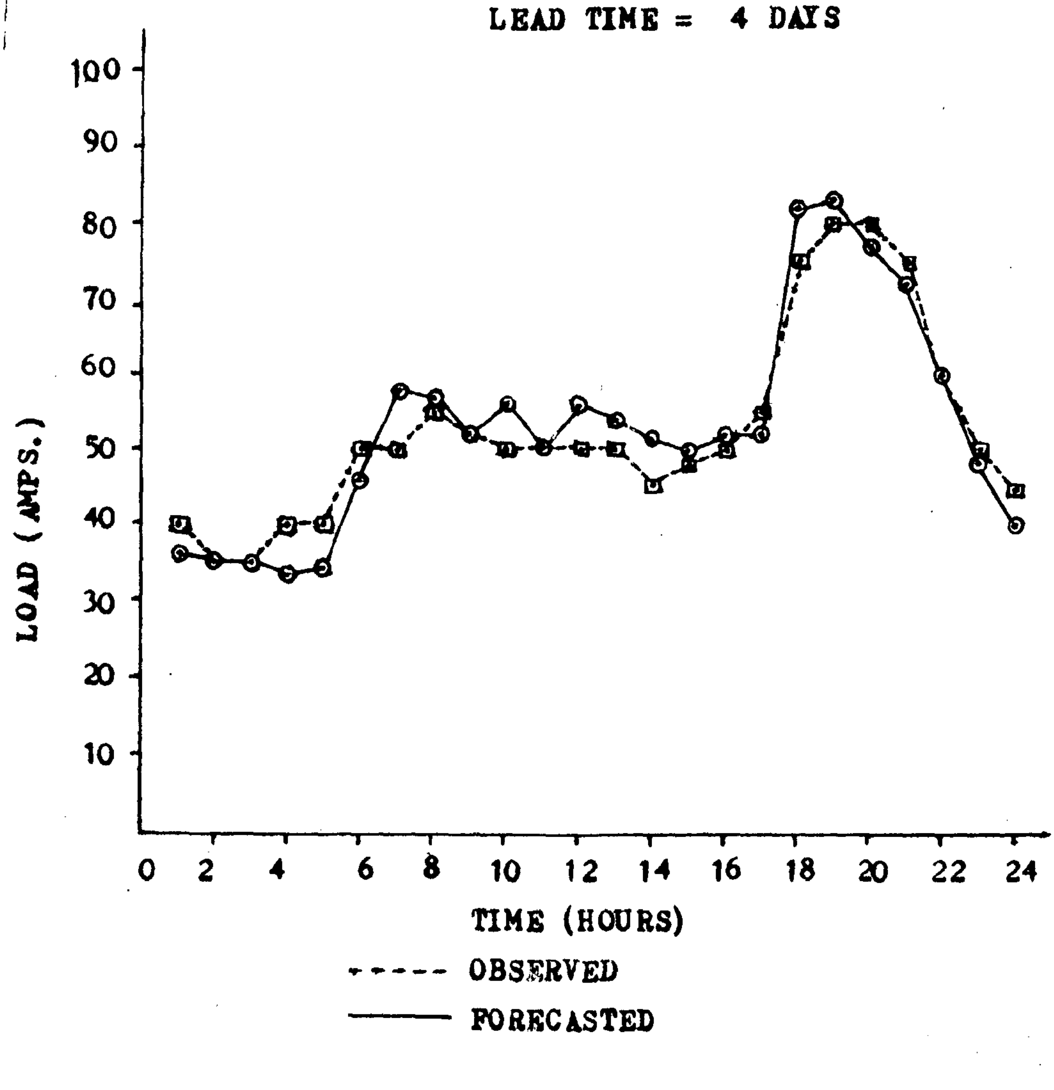


FIG. NO. 4.11

FORECAST FOR NOV.8, 1987

INCORPORATING EFFECT OF TEMPERATURE AND HUMIDITY

LEAD TIME = 1 WEEK

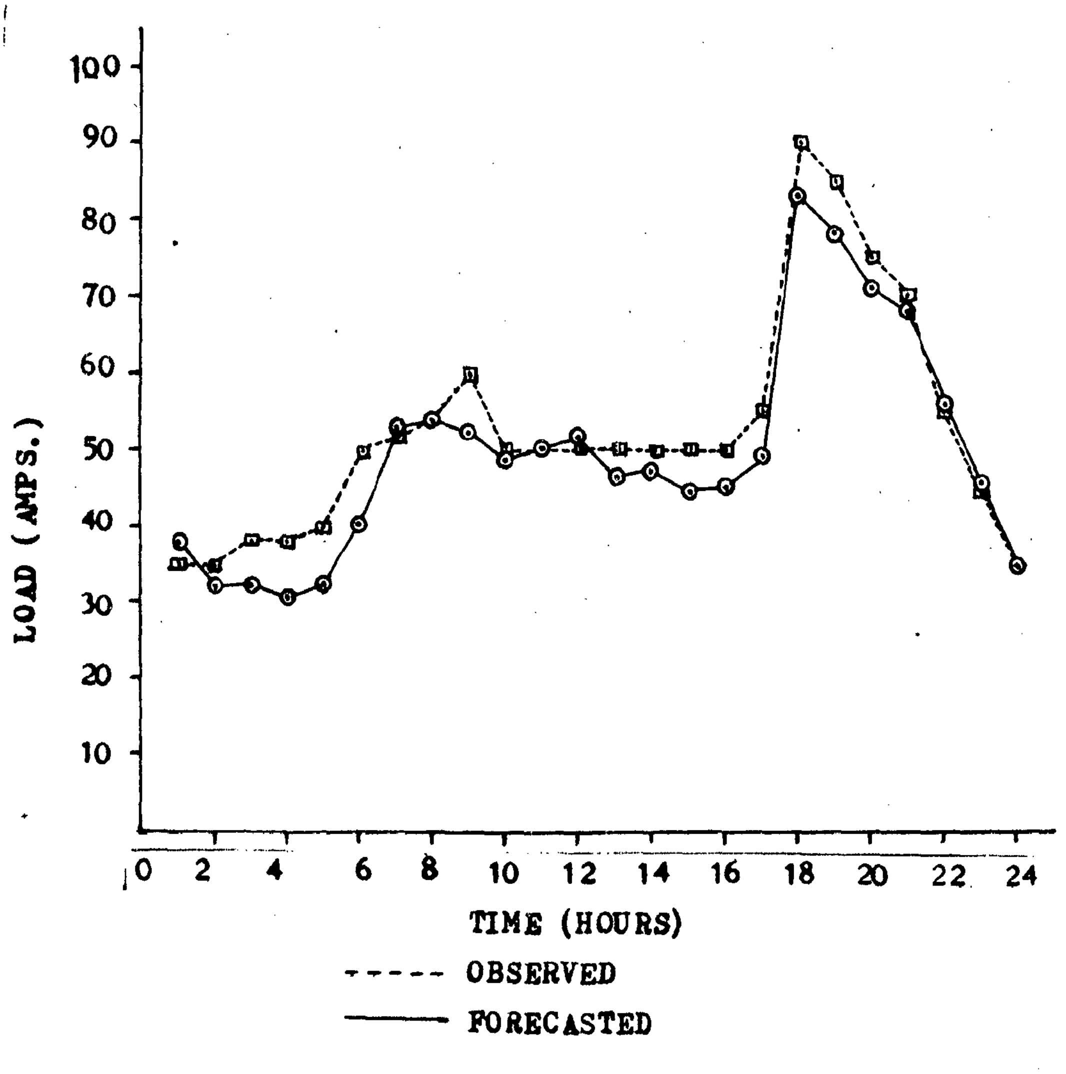


FIG.NO.4.12

CONCLUSIONS

The short-term load forecasting program developed here offers following advantages.

1. The methodology takes both historical load data and weather information in to account in forecasting hourly loads.

2. The forecasting models are adaptive in the sense that the model parameters are automatcally corrected to keep track of the changing load conditions.

3. The methodology can be used effectively as an on-line software package in the utilities control computer system.

4. The methodology produces not only load forecasts but also probable error in each forecast.

5. The methodology has been developed in such a manner that it allows ready adoptation to different power systems.

Forecasts made by this method have been found quite satisfactory even with a lead time of one week when compared with actual values. The maximum standard deviation observed with forecasts in one week advance is 6.89 however when forecasts are made by daily updating the model parameters it has been found that maximum standard-deviation was 6.52 The probable cause for the higher magnitude of standard deviation are -

(1) From the very first observation of load data it appears that the most of values are given as multiple of five (i.e. average step $\simeq$ 5.6 percent of peak load) rather than in decimal points. So it is one of most crucial factors in deciding the magnitude of standard deviation.

(2) As in the methodology used it is required to take the inverse of 8X8 or 9X9 matrix in initialisation operation which is not diagonally dominant with the result large truncation errors are introduced.

The accuracy of adopted methodology can be further improved it instead of daily average values, hourly weather forecasts were used. At the same time α can be assigned different values in different reasons to improve the forecasting accuracy.

In this part of program dealing with historical data could be worked out off-line and only the adaptive part need to be done on-line. Thus this method is well suited for on-line load forecasting.

The present program doesnot have a provision for bad data rejection and special holiday forecasting.

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APPENDIX - 1

```
*****************************************************
C        PROGRAM FOR IDENTIFICATION AND INITIALISATION
C        OF PARAMETERS OF STOCHASTIC LOAD MODEL AND
C        WEATHER LOAD MODEL
*****************************************************
C        IF INTERMEDIATE RESULTS ARE DESIRED THEN REMOVE
C        '*' FROM THE FIRST COULMN OF RESPECTIVE
C        PRINT-STATEMENTS IN THE PROGRAM
C=======================================================
         DIMENSION Z(365,24),T(365,24),WC(365,24),TOW0(24,24),
     1 TOW1(24,24),X(365,24),A(24,24),AT(24,24),
     2 ATO(24,24),TOINV(24,24),Q(24,24),ATOAT(24,24),
     3 TMP(365),WV(365),P(7,365),Y(365),POBAR(7),
     4  YMIN(365),WVMIN(365),PMIN(7,365),DELY(365),
     5  PHAIT(365,8),A0(8),AE(365,8),
     6  AZERO(8),PEE(365,8,8),TAM1(8,8),
     7  PO(8,8),POINV(64),JL(64),JM(64)
C=======================================================
C        Z(N,J)          LOAD IN AMPERS ON N TH DAY
C        AND JTH HOUR
C        TMP(N)          TEMPERATURE ON N TH DAY
C        Y(N)            PEAK LOAD ON N TH DAY
C        NDAY            NUMBER OF DAYS FOR WHICH LOAD
C                        DATA IS AVAILABLE
C        NHOUR           HOURS PER DAY,24
C        N1              LOAD DATA FOR FIRST TO N1 DAY
C                CONSTITUTE THE FIRST PART OF LOAD DATA
C        N2              LOAD DATA FOR N1+1 TO N2 DAY
C                CONSTITUTE THE SECOND PART OF LOAD DATA
C                THIRD PART OF LOAD DATA IS FROM N2+1
C                TO NDAY
C        LDAY            DAY ON THE LAST DATE OF AVAILABLE DATA
C==========================================================
         OPEN(UNIT=1,FILE='LOD1.DAT')
         OPEN(UNIT=4,DEVICE='DSK',FILE='RES1.DAT')
         OPEN(UNIT=7,DEVICE='DSK',FILE='RES2.DAT')
         OPEN(UNIT=9,DEVICE='DSK',FILE='RES3.DAT')
```

```
      OPEN(UNIT=10,DEVICE='DSK',FILE='RES4.DAT')
      READ(1,*) NHOUR,NDAY,N1,N2,ALPHA,BEETA,TS,TW,LDAY
      READ(1,*)((Z(I,J),J=1,NHOUR),I=1,NDAY),(TMP(I),I=1,NDAY)
***********************************************************
C     SECTION 1:  STOCHASTIC LOAD MODEL
C     IDENTIFICATION OF PARAMETERS
************************************************************
C     CALCULATION OF BASIC LOAD COMPONENTS
C=======================================================
      DO10 I=7,NDAY
      DO 10 J=1,NHOUR
      SUM=0.0
      DO5 K=(I-6),I
      SUM=SUM+Z(K,J)
5     CONTINUE
      T(I,J)=SUM/7.
10    CONTINUE
C======================================================
C     CALCULATION OF BASIC LOAD COMPONENTS FOR THE
C     FIRST SIX DAYS OF AVAILABLE DATA
C======================================================
      DO 20 I=1,6
      DO20 J=1,NHOUR
      T(I,J)=T(7,J)
20    CONTINUE
*     PRINT49
 49   FORMAT(T10,'BASIC LOAD COMPONENT')
*     PRINT31,( (T(I,J),J=1,NHOUR),I=1,NDAY)
 31   FORMAT(5X,3(5X,8E13.5/)/)
C======================================================
C     CALCULATION OF WEEKLY LOAD COMPONENTS
C=========================================================
      DO30 K=1,7
      DO 30 J=1,NHOUR
      WC(K,J)=Z(K,J)-T(7,J)
30    CONTINUE
      DO 35 I=8,NDAY
```

```
              DO 35 J=1,NHOUR
              WC(I,J)=WC((I-7),J)+ALPHA*(Z(I,J)-T(I,J)-WC((I-7),J))
       35     CONTINUE
      *       PRINT51
       51     FORMAT(T10,'WEEKLY COMPONENT')
      *       PRINT31,((WC(I,J),J=1,NHOUR),I=1,NDAY)
      C=========================================================
      C       CALCULATION OF RESIDUAL COMPONENTS
      C=========================================================
              DO40 I=1,NDAY
              DO40 J=1,NHOUR
              X(I,J)=Z(I,J)-T(I,J)-WC(I,J)
       40     CONTINUE
      *       PRINT71
       71     FORMAT(T10,'RESIDUAL COMPONENT')
      *       PRINT31,((X(I,J),J=1,NHOUR),I=1,NDAY)
              WRITE(4,*) ((Z(I,J),J=1,NHOUR),I=(NDAY-5),NDAY)
              WRITE(4,*) ((WC(I,J),J=1,NHOUR),I=(NDAY-6),NDAY)
              WRITE(4,*) (X(NDAY,J),J=1,NHOUR)
              F=FLOAT(NDAY)
              DO50 J=1,NHOUR
              DO50 K=1,NHOUR
              TOW0(J,K)=0.0
              DO60 I=1,NDAY
              TOW0(J,K)=TOW0(J,K)+X(I,J)*X(I,K)
       60     CONTINUE
              TOW0(J,K)=TOW0(J,K)/F
       50     CONTINUE
      *       PRINT33
       33     FORMAT(20X,'TOW0')
      *       PRINT31,((TOW0(J,K),K=1,NHOUR),J=1,NHOUR)
              DO70 J=1,NHOUR
              DO 70 K=1,NHOUR
              TOW1(J,K)=0.0
              DO 65 I=2,NDAY
              TOW1(J,K)=TOW1(J,K)+X(I,J)*X((I-1),K)
       65     CONTINUE
```

```
              TOW1(J,K)=TOW1(J,K)/(F-1.0)
       70     CONTINUE
*             PRINT69
       69     FORMAT(T15,'TOW1')
*             PRINT31,((TOW1(J,K),K=1,NHOUR),J=1,NHOUR)
              WRITE(7,*) ((TOW0(I,J),J=1,NHOUR),I=1,NHOUR)
              WRITE(7,*) ((TOW1(I,J),J=1,NHOUR),I=1,NHOUR)
              NH=NHOUR
              CALL MATINV(TOW0,TOINV,NH)
              CALL MATMUL(TOW1,TOINV,A,NH,NH,NH)
*             PRINT6
        6     FORMAT(/T10,'A'/)
*             PRINT300,((A(I,J),J=1,NHOUR),I=1,NHOUR)
       300    FORMAT(5X,4(5X,6E15.7/))
              DO80 I=1,NHOUR
              DO80 J=1,NHOUR
              AT(I,J)=A(J,I)
       80     CONTINUE
              CALL MATMUL(A,TOW0,ATO,NH,NH,NH)
              CALL MATMUL(ATO,AT,ATOAT,NH,NH,NH)
              DO90 J=1,NHOUR
              DO90 K=1,NHOUR
              Q(J,K)=TOW0(J,K)-ATOAT(J,K)
       90     CONTINUE
*             PRINT 7
        7     FORMAT(/T10,'Q'/)
*             PRINT300,((Q(J,K),K=1,NHOUR),J=1,NHOUR)
*******************************************************
CC            SECTION 2:  WEATHER LOAD MODEL
CC            INITIALISATION OF PARAMETERS
******************************************************
C             CALCULATION OF DAILY PEAK LOAD
C====================================================
              DO 4 I=1,NDAY
              Y(I)=0.0
              DO4 J=1,NHOUR
              IF(Z(I,J).GT.Y(I)) Y(I)=Z(I,J)
```

```
 4      CONTINUE
C============================================================
C       NON-LINEAR TRANSFORMATION OF THE WEATHER VARIABLE
C==============================================================
        DO 8 I=1,NDAY
        IF(TMP(I).GE.TS) WV(I)=TMP(I)-TS
        IF(TMP(I).GT.TW.AND.TMP(I).LT.TS) WV(I)=0.0
        IF(TMP(I).LE.TW) WV(I)=TW-TMP(I)
 8      CONTINUE
*       PRINT296
 296    FORMAT(38X,'WV(I)'/)
*       PRINT308,(WV(I),I=1,NDAY)
 308    FORMAT(30X,2E13.5/)
C=======================================================
C       CALCULATION OF P(J,I)
C======================================================
        MDAY=NDAY/7
        KDAY=NDAY-(MDAY*7)
        IF(LDAY.GT.KDAY) GO TO 12
        LDAY=LDAY+7
 12     IDAY=LDAY-KDAY
        IDD=IDAY+1
        DO16 K=1,NDAY
        IDAY=IDAY+1
        IF(IDAY.GT.7) IDAY=IDAY-7
        DO16 J=1,7
        IF(J.EQ.IDAY) GO TO 24
        P(J,K)=0.0
        GO TO 16
 24     P(J,K)=1.0
 16     CONTINUE
*       PRINT 184
 184    FORMAT(/T20,'P(J,K)'/)
*       PRINT 188,((P(J,K),J=1,7),K=1,NDAY)
 188    FORMAT(T5,7F5.1)
C===========================================================
C       CALCULATOIN OF INITIAL VALUES,YOBAR,WVOBAR,POBAR(K)
```

```
              DO52 I=1,7
              PMIN(I,(N-1))=ALPHA*P(I,(N-1))+(1.0-ALPHA)*PMIN(I,(N-2))
        52    CONTINUE
        48    CONTINUE
      *       PRINT248,(YMIN(N),N=N1,NDAY)
        248   FORMAT(/15X,'YMIN',5X,E15.7)
      *       PRINT249,(WVMIN(N),N=N1,NDAY)
        249   FORMAT(/15X,'WVMIN',5X,E15.7)
      *       PRINT270
        270   FORMAT(/30X,'PMIN(I,J)'/)
      *       PRINT274,((PMIN(I,J),I=1,7),J=N1,NDAY)
        274   FORMAT(5X,7E12.5)
              WRITE(9,*) YMIN(NDAY),WVMIN(NDAY),(PMIN(J,NDAY),J=1,7)
              WRITE(9,*) (P(J,NDAY),J=1,7)
      C=================================================================
      C       CALCULATION OF DELTA Y(N)
      C=================================================================
              DO56 N=N11DAY,NDAY
              DELY(N)=Y(N)-YMIN(N-1)
        56    CONTINUE
      *       PRINT280
        280   FORMAT(30X,'DELY(N)'/)
      *       PRINT284,(DELY(N),N=N11DAY,NDAY)
        284   FORMAT(25X,2E13.5/)
      C=============================================================
      CC      MATRIX PHAI AND ITS TRANSPOSE
      C=============================================================
              NC=8
              DO72 N=N11DAY,NDAY
              DO72 I=1,NC
              IF(I.GT.7) GO TO 76
              PHAIT(N,I)=P(I,N)-PMIN(I,(N-1))
              GO TO 72
        76    PHAIT(N,I)=WV(N)-WVMIN(N-1)
        72    CONTINUE
      *       PRINT212
        212   FORMAT(25X,'PHAIT(N,I)'/)
```

```
 4      CONTINUE
C===========================================================
C       NON-LINEAR TRANSFORMATION OF THE WEATHER VARIABLE
C============================================================
        DO 8 I=1,NDAY
        IF(TMP(I).GE.TS) WV(I)=TMP(I)-TS
        IF(TMP(I).GT.TW.AND.TMP(I).LT.TS) WV(I)=0.0
        IF(TMP(I).LE.TW) WV(I)=TW-TMP(I)
 8      CONTINUE
*       PRINT296
 296    FORMAT(38X,'WV(I)'/)
*       PRINT308,(WV(I),I=1,NDAY)
 308    FORMAT(30X,2E13.5/)
C=====================================================
C       CALCULATION OF P(J,I)
C====================================================
        MDAY=NDAY/7
        KDAY=NDAY-(MDAY*7)
        IF(LDAY.GT.KDAY) GO TO 12
        LDAY=LDAY+7
 12     IDAY=LDAY-KDAY
        IDD=IDAY+1
        DO16 K=1,NDAY
        IDAY=IDAY+1
        IF(IDAY.GT.7) IDAY=IDAY-7
        DO16 J=1,7
        IF(J.EQ.IDAY) GO TO 24
        P(J,K)=0.0
        GO TO 16
 24     P(J,K)=1.0
 16     CONTINUE
*       PRINT 184
 184    FORMAT(/T20,'P(J,K)'/)
*       PRINT 188,((P(J,K),J=1,7),K=1,NDAY)
 188    FORMAT(T5,7F5.1)
C==========================================================
C       CALCULATOIN OF INITIAL VALUES,YOBAR,WVOBAR,POBAR(K)
```

```
C==========================================================
        YOBAR=0.0
        WVOBAR=0.0
        DO28 N=1,N1
        YOBAR=YOBAR+Y(N)
        WVOBAR=WVOBAR+WV(N)
28      CONTINUE
        G=FLOAT(N1)
        YOBAR=YOBAR/G
        WVOBAR=WVOBAR/G
        DO32 K=1,7
        POBAR(K)=0.0
        DO36 N=1,N1
        POBAR(K)=POBAR(K)+P(K,N)
 36     CONTINUE
        POBAR(K)=POBAR(K)/G
 32     CONTINUE
*       PRINT228,WVOBAR,YOBAR
 228    FORMAT(/15X,2F12.6)
*       PRINT252
 252    FORMAT(30X,'POBAR(K)'/)
*       PRINT256,(POBAR(K),K=1,7)
 256    FORMAT(27X,E15.7)
C=======================================================
C       CALCULATION OF MEAN VALUES
C       FOR THE SUCCESSIVE DAYS
C========================================================
        YMIN(N1)=YOBAR
        WVMIN(N1)=WVOBAR
        DO44 I=1,7
        PMIN(I,N1)=POBAR(I)
 44     CONTINUE
        N1DAY=NDAY+1
        N11DAY=N1+1
        DO48 N=(N1+2),N1DAY
        YMIN(N-1)=ALPHA*Y(N-1)+(1.0-ALPHA)*YMIN(N-2)
        WVMIN(N-1)=ALPHA*WV(N-1)+(1.0-ALPHA)*WVMIN(N-2)
```

```
              DO52 I=1,7
              PMIN(I,(N-1))=ALPHA*P(I,(N-1))+(1.0-ALPHA)*PMIN(I,(N-2))
      52      CONTINUE
      48      CONTINUE
     *        PRINT248,(YMIN(N),N=N1,NDAY)
      248     FORMAT(/15X,'YMIN',5X,E15.7)
     *        PRINT249,(WVMIN(N),N=N1,NDAY)
      249     FORMAT(/15X,'WVMIN',5X,E15.7)
     *        PRINT270
      270     FORMAT(/30X,'PMIN(I,J)'/)
     *        PRINT274,((PMIN(I,J),I=1,7),J=N1,NDAY)
      274     FORMAT(5X,7E12.5)
              WRITE(9,*) YMIN(NDAY),WVMIN(NDAY),(PMIN(J,NDAY),J=1,7)
              WRITE(9,*) (P(J,NDAY),J=1,7)
     C===========================================================
     C        CALCULATION OF DELTA Y(N)
     C==========================================================
              DO56 N=N11DAY,NDAY
              DELY(N)=Y(N)-YMIN(N-1)
      56      CONTINUE
     *        PRINT280
      280     FORMAT(30X,'DELY(N)'/)
     *        PRINT284,(DELY(N),N=N11DAY,NDAY)
      284     FORMAT(25X,2E13.5/)
     C=======================================================
     CC       MATRIX PHAI AND ITS TRANSPOSE
     C========================================================
              NC=8
              DO72 N=N11DAY,NDAY
              DO72 I=1,NC
              IF(I.GT.7) GO TO 76
              PHAIT(N,I)=P(I,N)-PMIN(I,(N-1))
              GO TO 72
      76      PHAIT(N,I)=WV(N)-WVMIN(N-1)
      72      CONTINUE
     *        PRINT212
      212     FORMAT(25X,'PHAIT(N,I)'/)
```

```
*         PRINT216,((PHAIT(N,I),I=1,NC),N=N11DAY,NDAY)
 216      FORMAT(5X,8F12.6/)
C===========================================================
CC        CALCULATION OF P0
C============================================================
          DO82 J=1,NC
          DO82 K=1,NC
          P0(J,K)=0.0
          DO84 N=N11DAY,N2
          P0(J,K)=P0(J,K)+PHAIT(N,J)*PHAIT(N,K)
  84      CONTINUE
 82       CONTINUE
          CALL ARRAY(2,NC,NC,NC,NC,P0INV,P0)
          CALL MINV(P0INV,NC,C,JL,JM)
*         PRINT288
 288      FORMAT(25X,'DETERMINANT'/)
*         PRINT292,C
 292      FORMAT(35X,E13.5/)
          CALL ARRAY(1,NC,NC,NC,NC,P0INV,P0)
*         PRINT240
 240      FORMAT(30X,'P0(I,J)'/)
*         PRINT244,((P0(I,J),J=1,NC),I=1,NC)
 244      FORMAT(5X,8(E15.7))
C===========================================================
CC        CALCULATION OF A(0)
C===========================================================
          DO89 J=1,NC
          A0(J)=0.0
          DO88 N=N11DAY,N2
          A0(J)=A0(J)+PHAIT(N,J)*DELY(N)
 88       CONTINUE
 89       CONTINUE
*         PRINT264
 264      FORMAT(/30X,'A0(J)'/)
*         PRINT260,(A0(J),J=1,NC)
 260      FORMAT(25X,E14.6)
 151      CONTINUE
```

```
            DO91 I=1,NC
            AZERO(I)=0.0
            DO91 J=1,NC
            AZERO(I)=AZERO(I)+PO(I,J)*AO(J)
  91        CONTINUE
*           PRINT232
  232       FORMAT(30X,'AZERO(J)'/)
*           PRINT236,(AZERO(J),J=1,NC)
  236       FORMAT(25X,E15.7)
C=====================================================
CC          CALCULATION OF PEE FOR SUCCESSIVE DAYS
C======================================================
            DO92 I=1,NC
            DO92 J=1,NC
            PEE(N2,I,J)=PO(I,J)
  92        CONTINUE
            N21DAY=N2+1
            DO152 N=N21DAY,NDAY
            SUM4=0.0
            DO124 I=1,NC
            SUM3=0.0
            DO128 J=1,NC
            SUM3=SUM3+PHAIT(N,J)*PEE((N-1),J,I)
  128       CONTINUE
            SUM4=SUM4+SUM3*PHAIT(N,I)
  124       CONTINUE
            SUM4=1.0+SUM4/BEETA
            SUM4=1.0/SUM4
            DO132 I=1,NC
            SUM5=0.0
            DO136 J=1,NC
            SUM5=SUM5+PEE((N-1),I,J)*PHAIT(N,J)
  136       CONTINUE
            DO140 J=1,NC
            TAM1(I,J)=SUM5*PHAIT(N,J)
  140       CONTINUE
  132       CONTINUE
```

```
              DO148 I=1,NC
              DO148 K=1,NC
              PEE(N,I,K)=0.0
              DO144 J=1,NC
              PEE(N,I,K)=PEE(N,I,K)+TAM1(I,J)*PEE((N-1),J,K)
       144    CONTINUE
              PEE(N,I,K)=PEE(N,I,K)/(BEETA**2)
              PEE(N,I,K)=PEE((N-1),I,K)/BEETA-PEE(N,I,K)*SUM4
       148    CONTINUE
       152    CONTINUE
      *       PRINT204
       204    FORMAT(T20,'PEE(N,I,K)'/)
      *       PRINT208,(((PEE(N,I,K),K=1,NC),I=1,NC),N=N2,NDAY)
       208    FORMAT(5X,8(5X,8E14.5/)//)
      C===========================================================
      CC      CALCULATION OF AE FOR SUCCESSIVE DAYS
      C===========================================================
              DO156 J=1,NC
              AE(N2,J)=AZERO(J)
       156    CONTINUE
              DO176 N=N21DAY,NDAY
              SUM7=0.0
              DO164 J=1,NC
              SUM7=SUM7+PHAIT(N,J)*AE((N-1),J)
       164    CONTINUE
              SUM7=DELY(N)-SUM7
              DO168 I=1,NC
              AE(N,I)=0.0
              DO172 J=1,NC
              AE(N,I)=AE(N,I)+PEE(N,I,J)*PHAIT(N,J)
       172    CONTINUE
              AE(N,I)=AE(N,I)*SUM7+AE((N-1),I)
       168    CONTINUE
       176    CONTINUE
              WRITE(10,*) ((PEE(NDAY,I,J),J=1,NC),I=1,NC)
              WRITE(10,*) (AE(NDAY,J),J=1,NC)
      *       PRINT180
```

```
 180    FORMAT(15X/T15,'AE'/)
*       PRINT185,((AE(I,J),J=1,NC),I=N2,NDAY)
 185    FORMAT(5X,8E13.5/)
        STOP
        END
************************************************************************
C*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*
```

FORECASTING INCORPORATING EFFECT OF TEMPERATURE

```
*****************************************************
CC      PROGRAM FOR ADAPTIVE FORECASTING
*****************************************************
        DIMENSION Z(8,24),WC(8,24),TMP(3),WV(3),Y(2),
     1  X(3,24),TOW0(24,24),TOW1(24,24),T(24),P(7,2),
     2  A(24,24),AT(24,24),TOINV(24,24),ATO(24,24),
     3  DELY(2),TAM1(8,8),PEE(2,8,8),AE(2,8),B(3),
     4  ATOAT(24,24),Q(24,24),ZS(24),SVAR(24),YMIN(2),
     5  WVMIN(2),PMIN(7,2),PHAIT(2,8),CVAR(24),ZC(24)
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
        OPEN(UNIT=3,DEVICE='DSK',FILE='INP1.DAT')
        OPEN(UNIT=4,DEVICE='DSK',FILE='RES1.DAT')
        OPEN(UNIT=5,DEVICE='DSK',FILE='INP2.DAT')
        OPEN(UNIT=6,DEVICE='DSK',FILE='INTL.DAT')
        OPEN(UNIT=7,DEVICE='DSK',FILE='RES2.DAT')
        OPEN(UNIT=9,DEVICE='DSK',FILE='RES3.DAT')
        OPEN(UNIT=10,DEVICE='DSK',FILE='RES4.DAT')
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
        READ(3,*) NH,ALPHA,BEETA,TS,TW
        READ(4,*)((Z(I,J),J=1,NH),I=2,7)
        READ(4,*) ((WC(I,J),J=1,NH),I=1,7)
        READ(4,*) (X(1,J),J=1,NH)
        READ(5,*) (Z(8,J),J=1,NH),TMP(2),TMP(3)
        READ(6,*) NCOUNT,MCOUNT,YOLD,WVAR
        READ(7,*) ((TOW0(I,J),J=1,NH),I=1,NH),
     1  ((TOW1(I,J),J=1,NH),I=1,NH)
        READ(9,*) YMIN(1),WVMIN(1),(PMIN(J,1),J=1,7)
        READ(9,*) (P(J,1),J=1,7)
        READ(10,*) ((PEE(1,I,J),J=1,8),I=1,8),(AE(1,J),J=1,8)
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C       UPDATE BASIC ,WEEKLY PATTERN COMPONENT AND
C       CALCULATE RESIDUAL COMPONENT
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
        DO13 J=1,NH
        T(J)=0.0
        DO15 I=2,8
        T(J)=T(J)+Z(I,J)
```

```
 15      CONTINUE
         T(J)=T(J)/7.0
         WC(8,J)=WC(1,J)+ALPHA*(Z(8,J)-T(J)-WC(1,J))
         X(2,J)=Z(8,J)-T(J)-WC(8,J)
 13      CONTINUE
*        PRINT 14
 14      FORMAT(10X,'BASIC LOAD COMPONENT'/)
*        PRINT16,(T(J),J=1,NH)
 16      FORMAT(5X,8F12.6)
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C        CALCULATION OF PEAK LOAD
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
         Y(2)=0.0
         DO49 J=1,NH
         IF(Z(8,J).GT.Y(2)) Y(2)=Z(8,J)
 49      CONTINUE
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C        WEATHER VARIABLE TRANSFORMATION
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
         DO46 I=2,3
         IF(TMP(I).GE.TS) WV(I)=TMP(I)-TS
         IF(TMP(I).LT.TS.AND.TMP(I).GT.TW) WV(I)=0.0
         IF(TMP(I).LE.TW) WV(I)=TW-TMP(I)
 46      CONTINUE
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C        CALCULATION OF P(J,K)
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
         DO53 J=1,7
         M=J+1
         IF(J.EQ.7) M=1
         P(M,2)=P(J,1)
 53      CONTINUE
*        PRINT 211,(P(M,2),M=1,7)
 211     FORMAT(5X,'P(M,2)',5X,7F3.1)
         COUNT=FLOAT(NCOUNT)
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C        UPDATE 'A' AND 'Q' MATRICES
```

```
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
          DO17 J=1,NH
          DO17 K=1,NH
          TOWO(J,K)=TOWO(J,K)+(X(2,J)*X(2,K)-TOWO(J,K))/COUNT
          TOW1(J,K)=TOW1(J,K)+(X(2,J)*X(1,K)-TOW1(J,K))/
     2    (COUNT-1.0)
   17     CONTINUE
          CALL MATINV(TOWO,TOINV,NH)
          CALL MATMUL(TOW1,TOINV,A,NH,NH,NH)
          DO21 I=1,NH
          DO21 J=1,NH
          AT(I,J)=A(J,I)
   21     CONTINUE
          CALL MATMUL(A,TOWO,ATO,NH,NH,NH)
          CALL MATMUL(ATO,AT,ATOAT,NH,NH,NH)
          DO23 J=1,NH
          DO23 K=1,NH
          Q(J,K)=TOWO(J,K)-ATOAT(J,K)
   23     CONTINUE
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
CC        FORECAST BASED ON STOCHASTIC MODEL
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
          DO27 I=1,NH
          X(3,I)=0.0
          DO29 J=1,NH
          X(3,I)=X(3,I)+A(I,J)*X(2,J)
    29    CONTINUE
          ZS(I)=T(I)+WC(2,I)+X(3,I)
   27     CONTINUE
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C         HOUR CORRESPONDING TO PEAK LOAD
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
          ZSP=0.0
          DO35 J=1,NH
          IF(ZS(J).GT.ZSP) ZSP=ZS(J)
   35     CONTINUE
          DO36 J=1,NH
```

```
            IF(ZS(J).EQ.ZSP) KP=J
   36       CONTINUE
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C           STOCHASTIC VARIANCE
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
            DO37 J=1,NH
            SVAR(J)=Q(J,J)
   37       CONTINUE
            REWIND 4
            WRITE(4,*) ((Z(I,J),J=1,NH),I=3,8)
            WRITE(4,*) ((WC(I,J),J=1,NH),I=2,8)
            WRITE(4,*) (X(2,J),J=1,NH)
            REWIND 7
            WRITE(7,*) ((TOW0(I,J),J=1,NH),I=1,NH),
          4 ((TOW1(I,J),J=1,NH),I=1,NH)
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C           UPDATE WEATHER LOAD MODEL
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
            YMIN(2)=ALPHA*Y(2)+(1.0-ALPHA)*YMIN(1)
            WVMIN(2)=ALPHA*WV(2)+(1.0-ALPHA)*WVMIN(1)
            DO51 J=1,7
            PMIN(J,2)=ALPHA*P(J,2)+(1.0-ALPHA)*PMIN(J,1)
   51       CONTINUE
*           PRINT212,YMIN(1),YMIN(2),WVMIN(1),WVMIN(2)
*           PRINT212,((PMIN(J,I),J=1,7),I=1,2)
   212      FORMAT(5X,4F12.4/)
            REWIND 9
            WRITE(9,*) YMIN(2),WVMIN(2),(PMIN(J,2),J=1,7)
            WRITE(9,*) (P(J,2),J=1,7)
            DO57 J=1,8
            IF(J.GT.7) GO TO 59
            PHAIT(2,J)=P(J,2)-PMIN(J,1)
            GO TO 57
   59       PHAIT(2,J)=WV(2)-WVMIN(1)
   57       CONTINUE
*           PRINT213,(PHAIT(2,J),J=1,8)
   213      FORMAT(5X,'PHAIT',8E12.5/)
```

```
          DELY(2)=Y(2)-YMIN(1)
          SUM4=0.0
          DO61 I=1,8
          SUM3=0.0
          DO63 J=1,8
          SUM3=SUM3+PHAIT(2,J)*PEE(1,J,I)
 63       CONTINUE
          SUM4=SUM4+SUM3*PHAIT(2,I)
 61       CONTINUE
          SUM4=1.0+SUM4/BEETA
          SUM4=1.0/SUM4
          DO65 I=1,8
          SUM5=0.0
          DO67 J=1,8
          SUM5=SUM5+PEE(1,I,J)*PHAIT(2,J)
 67       CONTINUE
          DO69 K=1,8
          TAM1(I,K)=SUM5*PHAIT(2,K)
 69       CONTINUE
 65       CONTINUE
*         PRINT217,((TAM1(I,J),J=1,8),I=1,8)
 217      FORMAT(5X,'TAM1',3X,8E13.5)
          DO71 I=1,8
          DO71 K=1,8
          PEE(2,I,K)=0.0
          DO73 J=1,8
          PEE(2,I,K)=PEE(2,I,K)+TAM1(I,J)*PEE(1,J,K)
 73       CONTINUE
*         PRINT218,PEE(2,I,K)
 218      FORMAT(5X,'PEE',3X,E13.5)
          PEE(2,I,K)=PEE(2,I,K)/(BEETA**2)
          PEE(2,I,K)=PEE(1,I,K)/BEETA-PEE(2,I,K)*SUM4
 71       CONTINUE
          SUM7=0.0
          DO75 J=1,8
          SUM7=SUM7+PHAIT(2,J)*AE(1,J)
 75       CONTINUE
```

```
            SUM7=DELY(2)-SUM7
            DO77 I=1,8
            AE(2,I)=0.0
            DO79 J=1,8
            AE(2,I)=AE(2,I)+PEE(2,I,J)*PHAIT(2,J)
 79         CONTINUE
            AE(2,I)=AE(2,I)*SUM7+AE(1,I)
 77         CONTINUE
*           PRINT72,(AE(2,I),I=1,8)
 72         FORMAT(5X,'AE',3X,8F12.6/)
*           PRINT74,((PEE(2,I,J),J=1,8),I=1,8)
 74         FORMAT(5X,'PEE',3X,8E13.5/)
            REWIND 10
            WRITE(10,*) ((PEE(2,I,J),J=1,8),I=1,8),(AE(2,J),J=1,8)
            SUM2=0.0
            DO70 J=1,7
            SUM2=SUM2+AE(2,J)*PMIN(J,2)
 70         CONTINUE
            B(3)=YMIN(2)-AE(2,8)*WVMIN(2)-SUM2
            SUM=0.0
            DO83 J=1,7
            SUM=SUM+AE(2,J)*P(J,2)
 83         CONTINUE
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C           PEAK LOAD FORECAST BASED ON WEATHER MODEL
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
            YW=B(3)+SUM+AE(2,8)*WV(3)
            IF(MCOUNT.EQ.0) GO TO 89
            SQ=Y(2)-YOLD
            WVAR=WVAR+(SQ**2-WVAR)/FLOAT(MCOUNT)
 89         MCOUNT=MCOUNT+1
            YOLD=YW
            NCOUNT=NCOUNT+1
            REWIND 6
            WRITE(6,*) NCOUNT,MCOUNT,YOLD,WVAR
*           PRINT80,WVAR
 80         FORMAT(10X,'WVAR',F12.5/)
```

```
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
CC        COMPOSITE  FORECAST AND VARIANCE
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
          SUB=YW-ZSP
          DENOM=Q(KP,KP)+WVAR
          DO91 J=1,NH
          ZC(J)=ZS(J)+SUB*Q(J,KP)/DENOM
          CVAR(J)=Q(J,J)-Q(J,KP)**2/DENOM
   91     CONTINUE
          REWIND 5
CC        WRITE (5,*) (ZC(J),J=1,NH)
          PRINT31
   31     FORMAT(1H1///10X,'LOAD FORECAST BASED ON STOCHASTIC MODEL'
     1    ,10X,'VARIANCE'/)
          PRINT33,(ZS(J),SVAR(J),J=1,NH)
   33     FORMAT(20X,F10.5,28X,F10.5/)
          PRINT85,YW
   85     FORMAT(///20X,'PEAK LOAD BASED ON WEATHER MODEL=',F10.5)
          PRINT93
   93     FORMAT(1H1///25X,'COMPOSITE LOAD FORECAST',10X,'VARIANCE
          1'/)
          PRINT95,(ZC(J),CVAR(J),J=1,NH)
   95     FORMAT(30X,F10.5,17X,F10.5/)
          STOP
          END
C=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*
```

```
*******************************************************
C         PROGRAM FOR IDENTIFICATION AND INITIALISATION
C         OF PARAMETERS OF STOCHASTIC LOAD MODEL AND
C         WEATHER LOAD MODEL
*******************************************************
C         IF INTERMEDIATE RESULTS ARE DESIRED THEN REMOVE
C         '*' FROM THE FIRST COULMN OF RESPECTIVE
C         PRINT STATEMENTS IN THE PROGRAM
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
          DIMENSION Z(365.24),T(365,24),WC(365,24),TOWO(24,24),
       1 TOW1(24,24),X(365.24),A(24,24),AT(24,24),
       2 ATO(24.24).TOINV(24.24).Q(24,24),ATOAT(24,24),
       3 TMP(365).WV(2,365).P(7,365),Y(365),POBAR(7),
       4  YMIN(365).WVMIN(2.365).PMIN(7,365).DELY(365),
       5  PHAIT(365.9),A0(9),AE(365,9),
       6  AZERO(9).PEE(365.9.9),TAM1(9.9),HMDTY(365),
       7  PO(9,9).POINV(81).JL(81),JM(81),WVOBAR(2)
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::
C         Z(N.J)           LOAD IN AMPERS ON N TH DAY
C         AND JTH HOUR
C         HMDTY(N)         HUMIDITY ON N TH DAY
C         TMP(N)           TEMPERATURE ON N TH DAY
C         Y(N)             PEAK LOAD ON N TH DAY
C         NDAY             NUMBER OF DAYS FOR WHICH LOAD
C                          DATA IS AVAILABLE
C         NHOUR            HOURS PER DAY,24
C         N1               LOAD DATA FOR FIRST TO N1 DAY
C                 CONSTITUTE THE FIRST PART OF LOAD DATA
C         N2               LOAD DATA FOR N1+1 TO N2 DAY
C                 CONSTITUTE THE SECOND PART OF LOAD DATA
C                 THIRD PART OF LOAD DATA IS FROM N2+1
C                 TO NDAY
C         LDAY             DAY ON THE LAST DATE OF AVAILABLE DATA
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
          OPEN(UNIT=1,FILE='LOD1.DAT')
          OPEN(UNIT=4,DEVICE='DSK',FILE='RES1.DAT')
          OPEN(UNIT=7,DEVICE='DSK',FILE='RES2.DAT')
```

```
          OPEN(UNIT=9,DEVICE='DSK',FILE='RES3.DAT')
          OPEN(UNIT=10,DEVICE='DSK',FILE='RES4.DAT')
          READ(1,*) NHOUR,NDAY,N1,N2,ALPHA,BEETA,TS,TW,LDAY
          READ(1,*)((Z(I,J),J=1,NHOUR),I=1,NDAY),(TMP(I),I=1,NDAY)
          READ(1,*) (HMDTY(I),I=1,NDAY)
**************************************************************
C         SECTION 1:  STOCHASTIC LOAD MODEL
C         IDENTIFICATION OF PARAMETERS
****************************************************************
C         CALCULATION OF BASIC LOAD COMPONENTS
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
          DO10 I=7,NDAY
          DO 10 J=1,NHOUR
          SUM=0.0
          DO5 K=(I-6),I
          SUM=SUM+Z(K,J)
5         CONTINUE
          T(I,J)=SUM/7.
10        CONTINUE
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C         CALCULATION OF BASIC LOAD COMPONENTS FOR THE
C         FIRST SIX DAYS OF AVAILABLE DATA
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
          DO 20 I=1,6
          DO20 J=1,NHOUR
          T(I,J)=T(7,J)
20        CONTINUE
*         PRINT49
 49       FORMAT(T10,'BASIC LOAD COMPONENT')
*         PRINT31,( (T(I,J),J=1,NHOUR),I=1,NDAY)
 31       FORMAT(5X,3(5X,8F13.5/)/)
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C         CALCULATION OF WEEKLY LOAD COMPONENTS
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
          DO30 K=1,7
          DO 30 J=1,NHOUR
          WC(K,J)=Z(K,J)-T(7,J)
```

```
30      CONTINUE
        DO 35 I=8,NDAY
        DO 35 J=1,NHOUR
        WC(I,J)=WC((I-7),J)+ALPHA*(Z(I,J)-T(I,J)-WC((I-7),J))
 35     CONTINUE
*       PRINT51
 51     FORMAT(T10,'WEEKLY COMPONENT')
*       PRINT31,((WC(I,J),J=1,NHOUR),I=1,NDAY)
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C       CALCULATION OF RESIDUAL COMPONENTS
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
        DO40 I=1,NDAY
        DO40 J=1,NHOUR
        X(I,J)=Z(I,J)-T(I,J)-WC(I,J)
 40     CONTINUE
*       PRINT71
 71     FORMAT(T10,'RESIDUAL COMPONENT')
*       PRINT31,((X(I,J),J=1,NHOUR),I=1,NDAY)
        WRITE(4,*) ((Z(I,J),J=1,NHOUR),I=(NDAY-5),NDAY)
        WRITE(4,*) ((WC(I,J),J=1,NHOUR),I=(NDAY-6),NDAY)
        WRITE(4,*) (X(NDAY,J),J=1,NHOUR)
        F=FLOAT(NDAY)
        DO50 J=1,NHOUR
        DO50 K=1,NHOUR
        TOWO(J,K)=0.0
        DO60 I=1,NDAY
        TOWO(J,K)=TOWO(J,K)+X(I,J)*X(I,K)
 60     CONTINUE
        TOWO(J,K)=TOWO(J,K)/F
 50     CONTINUE
*       PRINT33
 33     FORMAT(20X,'TOWO')
*       PRINT31,((TOWO(J,K),K=1,NHOUR),J=1,NHOUR)
        DO70 J=1,NHOUR
        DO 70 K=1,NHOUR
        TOW1(J,K)=0.0
        DO 65 I=2,NDAY
```

```
          TOW1(J,K)=TOW1(J,K)+X(I,J)*X((I-1),K)
   65     CONTINUE
          TOW1(J,K)=TOW1(J,K)/(F-1.0)
   70     CONTINUE
*         PRINT69
   69     FORMAT(T15,'TOW1')
*         PRINT31,((TOW1(J,K),K=1,NHOUR),J=1,NHOUR)
          WRITE(7,*) ((TOW0(I,J),J=1,NHOUR),I=1,NHOUR)
          WRITE(7,*) ((TOW1(I,J),J=1,NHOUR),I=1,NHOUR)
          NH=NHOUR
          CALL MATINV(TOW0,TOINV,NH)
          CALL MATMUL(TOW1,TOINV,A,NH,NH,NH)
*         PRINT6
    6     FORMAT(/T10,'A'/)
*         PRINT300,((A(I,J),J=1,NHOUR),I=1,NHOUR)
  300     FORMAT(5X,4(5X,6E15.7/))
          DO80 I=1,NHOUR
          DO80 J=1,NHOUR
          AT(I,J)=A(J,I)
   80     CONTINUE
          CALL MATMUL(A,TOW0,ATO,NH,NH,NH)
          CALL MATMUL(ATO,AT,ATOAT,NH,NH,NH)
          DO90 J=1,NHOUR
          DO90 K=1,NHOUR
          Q(J,K)=TOW0(J,K)-ATOAT(J,K)
   90     CONTINUE
*         PRINT7
    7     FORMAT(/T10,'Q'/)
*         PRINT300,((Q(J,K),K=1,NHOUR),J=1,NHOUR)
*********************************************************
CC        SECTION 2:  WEATHER LOAD MODEL
CC        INITIALISATION OF PARAMETERS
*********************************************************
C         CALCULATION OF DAILY PEAK LOAD
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::
          DO4 I=1,NDAY
          Y(I)=0.0
```

```
           DO4 J=1,NHOUR
           IF(Z(I,J).GT.Y(I)) Y(I)=Z(I,J)
   4       CONTINUE
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C          NON-LINEAR TRANSFORMATION OF THE WEATHER VARIABLE
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
           DO8 I=1,NDAY
           IF(TMP(I).GE.TS) WV(1,I)=TMP(I)-TS
           IF(TMP(I).GT.TW.AND.TMP(I).LT.TS) WV(1,I)=0.0
           IF(TMP(I).LE.TW) WV(1,I)=TW-TMP(I)
           WV(2,I)=100.0-HMDTY(I)
   8       CONTINUE
*          PRINT296
  296      FORMAT(38X,'WV(J,I)'/)
*          PRINT308,(( WV(J, I),I=1,NDAY),J=1,2)
  308      FORMAT(30X,2E13.5/)
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C          CALCULATION OF P(J,I)
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
           MDAY=NDAY/7
           KDAY=NDAY-(MDAY*7)
           IF(LDAY.GT.KDAY) GO TO 12
           LDAY=LDAY+7
  12       IDAY=LDAY-KDAY
           IDD=IDAY+1
           DO16 K=1,NDAY
           IDAY=IDAY+1
           IF(IDAY.GT.7) IDAY=IDAY-7
           DO16 J=1,7
           IF(J.EQ.IDAY) GO TO 24
           P(J,K)=0.0
           GO TO 16
  24       P(J,K)=1.0
  16       CONTINUE
*          PRINT 184
  184      FORMAT(/T20,'P(J,K)'/)
*          PRINT 188,((P(J,K),J=1,7),K=1,NDAY)
```

```
 188    FORMAT(T5,7F5.1)
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C       CALCULATOIN OF INITIAL VALUES,YOBAR,WVOBAR(K)
C       AND POBAR(K)
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
        YOBAR=0.0
        DO28 N=1,N1
        YOBAR=YOBAR+Y(N)
28      CONTINUE
        G=FLOAT(N1)
        YOBAR=YOBAR/G
        DO32 K=1,7
        POBAR(K)=0.0
        DO36 N=1,N1
        POBAR(K)=POBAR(K)+P(K,N)
 36     CONTINUE
        POBAR(K)=POBAR(K)/G
 32     CONTINUE
        DO34 K=1,2
        WVOBAR(K)=0.0
        DO39 N=1,N1
        WVOBAR(K)=WVOBAR(K)+WV(K,N)
 39     CONTINUE
        WVOBAR(K)=WVOBAR(K)/G
 34     CONTINUE
*       PRINT228,YOBAR
 228    FORMAT(/15X,2F12.6)
*       PRINT252
 252    FORMAT(30X,'POBAR(K)'/)
*       PRINT256,(POBAR(K),K=1,7)
 256    FORMAT(27X,E15.7)
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C       CALCULATION OF MEAN VALUES
C       FOR THE SUCCESSTVE DAYS
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
        YMIN(N1)=YOBAR
        DO45 K=1,2
```

```
          WVMIN(K,N1)=WV0BAR(K)
 45       CONTINUE
          DO44 I=1,7
          PMIN(I,N1)=P0BAR(I)
 44       CONTINUE
          N1DAY=NDAY+1
          N11DAY=N1+1
          DO48 N=(N1+2),N1DAY
          YMIN(N-1)=ALPHA*Y(N-1)+(1.0-ALPHA)*YMIN(N-2)
          DO53 K=1,2
          WVMIN(K,(N-1))=ALPHA*WV(K,(N-1))+(1.0-ALPHA)*
          1WVMIN(K,(N-2))
 53       CONTINUE
          DO52 I=1,7
          PMIN(I,(N-1))=ALPHA*P(I,(N-1))+(1.0-ALPHA)*PMIN(I,(N-2))
 52       CONTINUE
 48       CONTINUE
*         PRINT248,(YMIN(N),N=N1,NDAY)
 248      FORMAT(/15X,'YMIN',5X,E15.7)
*         PRINT249,((WVMIN(K,N),K=1,2),N=N1,NDAY)
 249      FORMAT(/15X,'WVMIN',5X,2E15.7)
*         PRINT270
 270      FORMAT(/30X,'PMIN(I,J)'/)
*         PRINT274,((PMIN(I,J),I=1,7),J=N1,NDAY)
 274      FORMAT(5X,7E12.5)
          WRITE(9,*) YMIN(NDAY),(WVMIN(K,NDAY),K=1,2),
     1    (PMIN(J,NDAY),J=1,7)
          WRITE(9,*) (P(J,NDAY),J=1,7)
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C         CALCULATION OF DELTA Y(N)
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
          DO56 N=N11DAY,NDAY
          DELY(N)=Y(N)-YMIN(N-1)
 56       CONTINUE
*         PRINT280
 280      FORMAT(30X,'DELY(N)'/)
*         PRINT284,(DELY(N),N=N11DAY,NDAY)
```

```
 284      FORMAT(25X,2E13.5/)
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
CC        MATRIX PHAI AND ITS TRANSPOSE
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
          DO72 N=N11DAY,NDAY
          DO72 I=1,9
          IF(I.GT.7) GO TO 76
          PHAIT(N,I)=P(I,N)-PMIN(I,(N-1))
          GO TO 72
 76       JD=I-7
          PHAIT(N,I)=WV(JD,N)-WVMIN(JD,(N-1))
 72       CONTINUE
*         PRINT212
 212      FORMAT(25X,'PHAIT(N,I)'/)
*         PRINT216,((PHAIT(N,I),I=1,9),N=N11DAY,NDAY)
 216      FORMAT(5X,9F12.6/)
CC        CALCULATION OF PO
          NC=9
          DO82 J=1,NC
          DO82 K=1,NC
          PO(J,K)=0.0
          DO84 N=N11DAY,N2
          PO(J,K)=PO(J,K)+PHAIT(N,J)*PHAIT(N,K)
  84      CONTINUE
 82       CONTINUE
          CALL ARRAY(2,NC,NC,NC,NC,POINV,PO)
          CALL MINV(POINV,NC,C,JL,JM)
*         PRINT288
 288      FORMAT(25X,'DETERMINANT'/)
*         PRINT292,C
 292      FORMAT(35X,E13.5/)
          CALL ARRAY(1,NC,NC,NC,NC,POINV,PO)
*         PRINT240
 240      FORMAT(30X,'PO(I,J)'/)
*         PRINT244,((PO(I,J),J=1,NC),I=1,NC)
 244      FORMAT(5X,9(E12.5))
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
```

```
      CALCULATION OF A(O)
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
      DO89 J=1,NC
      AO(J)=0.0
      DO88 N=N11DAY,N2
      AO(J)=AO(J)+PHATT(N,J)*DELY(N)
8     CONTINUE
9     CONTINUE
      PRINT264
54    FORMAT(/30X,'AO(J)'/)
      PRINT260,(AO(J),J=1,NC)
50    FORMAT(25X,E14.6)
51    CONTINUE
      DO91 I=1,NC
      AZERO(I)=0.0
      DO91 J=1,NC
      AZERO(I)=AZERO(I)+PO(I,J)*AO(J)
1     CONTINUE
      PRINT232
32    FORMAT(30X,'AZERO(J)'/)
      PRINT236,(AZERO(J),J=1,NC)
36    FORMAT(25X,E15.7)
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
      CALCULATION OF PEE MATRIX FOR SUCCESSIVE DAYS
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
      DO92 I=1,NC
      DO92 J=1,NC
      PEE(N2,I,J)=PO(I,J)
      CONTINUE
      N21DAY=N2+1
      DO152 N=N21DAY,NDAY
      SUM4=0.0
      DO124 I=1,NC
      SUM3=0.0
      DO128 J=1,NC
      SUM3=SUM3+PHAIT(N,J)*PEE((N-1),J,I)
8     CONTINUE
```

```
            SUM4=SUM4+SUM3*PHAIT(N,I)
     124    CONTINUE
            SUM4=1.0+SUM4/BEETA
            SUM4=1.0/SUM4
            DO132 I=1,NC
            SUM5=0.0
            DO136 J=1,NC
            SUM5=SUM5+PEE((N-1)/     *PHAIT(N,J)
     136    CONTINUE
            DO140 J=1,NC
            TAM1(I,J)=SUM5*P
     140    CONTINUE
     132    CONTINUE
            DO148 I=1,NC
            DO148 K=1,NC
            PEE(N,I,K)=0.0
            DO144 J=1,NC
            PEE(N,I,K)=PEE(N,I,K)+TAM1(I,J)*PEE((N-1),J,K)
     144    CONTINUE
            PEE(N,I,K)=PEE(N,I,K)/(BEETA**2)
            PEE(N,I,K)=PEE((N-1),I,K)/BEETA-PEE(N,I,K)*SUM4
     148    CONTINUE
     152    CONTINUE
*           PRINT204
     204    FORMAT(T20,'PEE(N,I,K)'/)
*           PRINT208,(((PEE(N,I,K),K=1,NC),I=1,NC),N=N2,NDAY)
     208    FORMAT(5X,9(5X,9E12.5/)//)
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
CC          CALCULATION OF AE MATRIX FOR SUCCESSIVE DAYS
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
            DO156 J=1,NC
            AE(N2,J)=AZERO(J)
     156    CONTINUE
            DO176 N=N21DAY,NDAY
            SUM7=0.0
            DO164 J=1,NC
            SUM7=SUM7+PHAIT(N,J)*AE((N-1),J)
```

```
 164    CONTINUE
        SUM7=DELY(N)-SUM7
        DO168 I=1,NC
        AE(N,I)=0.0
        DO172 J=1,NC
        AE(N,I)=AE(N,I)+PEE(N,I,J)*PHAIT(N,J)
 172    CONTINUE
        AE(N,I)=AE(N,I)*SUM7+AE((N-1),I)
 168    CONTINUE
 176    CONTINUE
        WRITE(10,*) ((PEE(NDAY,I,J),J=1,NC),I=1,NC)
        WRITE(10,*) (AE(NDAY,J),J=1,NC)
*       PRINT180
 180    FORMAT(15X/T15,'AE'/)
*       PRINT185,((AE(I,J),J=1,NC),I=N2,NDAY)
 185    FORMAT(5X,9E12.5/)
        STOP
        END
C.............................................................
C.............................................................
        SUBROUTINE MATINV(X,A,L)
C       THIS SUBROUTINE CALCULATES THE INVERSE
C       OF MATRIX,X.
C       ORIGNAL MATRIX,X IS NOT DESTROYED
        DIMENSION X(24,24),A(24,24),B(24,48)
        DO5000 J=1,L
        DO5000 K=1,L
        B(J,K)=X(J,K)
 5000   CONTINUE
        N1=2*L
        N2=L+1
        DO101 M=1,L
        DO201 N=N2,N1
        B(M,N)=0.0
 201    MN=M+L
 101    B(M,MN)=1.0
        DO450 J=1,L
```

```
               IF(B(J,J).EQ.0) GO TO 102
               DO450 M=1,L
               IF(M.EQ.J) GO TO 450
               C=B(M,J)
               C=C/B(J,J)
               DO105  N=1,N1
     105       B(M,N)=B(M,N)-B(J,N)*C
     450       CONTINUE
               DO106 J=1,L
               R=1./B(J,J)
               DO106 N=N2,N1
     106       B(J,N)=B(J,N)*R
               DO1001 J=1,L
               DO1001 K=1,L
     1001      A(J,K)=B(J,K+L)
     102       RETURN
               END
   C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
   C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
               SUBROUTINE MATMUL(R,S,U,L1,L2,L3)
   C           THIS SUBROUTINE CALCULATES THE MULTIPLICATION
   C           OF TWO MATRICES.R AND S.
   C           U IS THE RESULTANT MATRIX
   C           L1 IS THE NUMBER OF ROWS IN MATRIX R
   C           L2 IS THE NUMBER OF COULMNS IN MATRIX R
   C           OR NUMBER OF ROWS IN MATRI S.
   C           L3 IS THE NUMBER OF COULMNS IN MATRIX S
               DIMENSION R(24,24),S(24,24),U(24,24)
               DO13 I=1,L1
               DO13 J=1,L3
               U(I,J)=0.0
               DO19 K=1,L2
               U(I,J)=U(I,J)+R(I,K)*S(K,J)
     19        CONTINUE
     13        CONTINUE
               RETURN
               END
```

```
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
      SUBROUTINE ARRAY (MODE,I,J,N,M,S,D)
      DIMENSION S(81) ,D(81)
      NI=N-I
C        TEST TYPE OF CONVERSION
      IF(MODE-1) 100, 100, 120
C        CONVERT FROM SINGLE TO DOUBLE DIMENSION
  100 IJ=I*J+1
      NM=N*J+1
      DO 110 K=1,J
      NM=NM-NI
      DO 110 L=1,I
      IJ=IJ-1
      NM=NM-1
  110 D(NM)=S(IJ)
      GO TO 140
C        CONVERT FROM DOUBLE TO SINGLE DIMENSION
  120 IJ=0
      NM=0
      DO 130 K=1,J
      DO 125 L=1,I
      IJ=IJ+1
      NM=NM+1
  125 S(IJ)=D(NM)
  130 NM=NM+NI
  140 RETURN
      END
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
      SUBROUTINE MINV(A,N,D,L,M)
      DIMENSION A(81),L(81),M(81)
C...............................................................
C        IF A DOUBLE PRECISION VERSION OF THIS ROUTINE
C       IS DESIRED,THE C IN COULMN 1 SHOULD BE REMOVED
C       FROM THE DOUBLE PRECISION STATEMENT WHICH FOLLOWS
C       DOUBLE PRECISION A,D,BIGA,HOLD
```

```
C          THE C MUST ALSO BE REMOVED FROM DOUBLE PRECISION
C           STATEMENTS APPEARING IN OTHER ROUTINES USED IN
C           CONJUCTION WITH THIS ROUTINE.
C           THE DOUBLE PRECISION VERSION OF THIS SUBROUTINE
C           MUST ALSO CONTAIN DOUBLE PRECISION FORTRAN
C           FUNCTIONS.  ABS IN STATEMENT
C           10 MUST BE CHANGED TO DABS.
C           ...........................................................
C           SEARCH FOR LARGEST ELEMENT
         D=1.0
         NK=-N
         DO 80 K=1,N
         NK=NK+N
         L(K)=K
         M(K)=K
         KK=NK+K
         BIGA=A(KK)
         DO 20 J=K,N
         IZ=N*(J-1)
         DO 20 I=K,N
         IJ=IZ+I
 10        IF(ABS(BIGA)- ABS(A(IJ))) 15,20,20
    15 BIGA=A(IJ)
         L(K)=I
           M(K)=J
    20 CONTINUE
C           INTERCHANGE ROWS
         J=L(K)
         IF(J-K) 35,35,25
    25 KI=K-N
         DO 30 I=1,N
         KI=KI+N
         HOLD=-A(KI)
         JI=KI-K+J
           A(KI)=A(JI)
    30 A(JI) =HOLD
C           INTERCHANGE COLUMNS
```

```
      35 I=M(K)
         IF(I-K) 45,45,38
      38 JP=N*(I-1)
         DO 40 J=1,N
         JK=NK+J
         JI=JP+J
         HOLD=-A(JK)
         A(JK)=A(JI)
      40 A(JI) =HOLD
C           DIVIDE COLUMN BY MINUS PIVOT (VALUE OF PIVOT ELEMENT IS
C           CONTAINED IN BIGA)
      45 IF(BIGA) 48,46,48
      46 D=0.0
         RETURN
      48 DO 55 I=1,N
         IF(I-K) 50,55,50
      50 IK=NK+I
         A(IK)=A(IK)/(-BIGA)
      55 CONTINUE
C           REDUCE MATRIX
         DO 65 I=1,N
         IK=NK+I
         HOLD=A(IK)
         IJ=I-N
         DO 65 J=1,N
         IJ=IJ+N
         IF(I-K) 60,65,60
      60 IF(J-K) 62,65,62
      62 KJ=IJ-I+K
         A(IJ)=HOLD*A(KJ)+A(IJ)
      65 CONTINUE
C           DIVIDE ROW BY PIVOT
         KJ=K-N
         DO 75 J=1,N
         KJ=KJ+N
         IF(J-K) 70,75,70
      70 A(KJ)=A(KJ)/BIGA
```

```
   75 CONTINUE
C        PRODUCT OF PIVOTS
      D=D*BIGA
C        REPLACE PIVOT BY RECIPROCAL
      A(KK)=1.0/BIGA
   80 CONTINUE
C        FINAL ROW AND COLUMN INTERCHANGE
      K=N
  100 K=(K-1)
      IF(K) 150,150,105
  105 I=L(K)
      IF(I-K) 120.120,108
  108 JQ=N*(K-1)
      JR=N*(I-1)
      DO 110 J=1,N
      JK=JQ+J
      HOLD=A(JK)
      JI=JR+J
      A(JK)=-A(JI)
  110 A(JI) =HOLD
  120 J=M(K)
      IF(J-K) 100.100,125
  125 KI=K-N
      DO 130 I=1,N
      KI=KI+N
      HOLD=A(KI)
      JI=KI-K+J
      A(KI)=-A(JI)
  130 A(JI) =HOLD
      GO TO 100
  150 RETURN
      END
```

```
****************************************************
CC      PROGRAM FOR ADAPTIVE FORECASTING
****************************************************
        DIMENSION Z(8,24),WC(8,24),TMP(3),WV(2,3),Y(2),
     1  X(3,24),TOW0(24,24),TOW1(24,24),T(24),P(7,2),
     2  A(24,24),AT(24,24),TOINV(24,24),ATO(24,24),HMDTY(3),
     3  DELY(2),TAM1(9,9),PEE(2,9,9),AE(2,9),B(3),
     4  ATOAT(24,24),Q(24,24),ZS(24),SVAR(24),YMIN(2),
     5  WVMIN(2,2),PMIN(7,2),PHAIT(2,9),CVAR(24),ZC(24)
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
        OPEN(UNIT=3,DEVICE='DSK',FILE='INP1.DAT')
        OPEN(UNIT=4,DEVICE='DSK',FILE='RES1.DAT')
        OPEN(UNIT=5,DEVICE='DSK',FILE='INP2.DAT')
        OPEN(UNIT=6,DEVICE='DSK',FILE='INTL.DAT')
        OPEN(UNIT=7,DEVICE='DSK',FILE='RES2.DAT')
        OPEN(UNIT=9,DEVICE='DSK',FILE='RES3.DAT')
        OPEN(UNIT=10,DEVICE='DSK',FILE='RES4.DAT')
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
        READ(3,*) NH,ALPHA,BEETA,TS,TW
        READ(4,*)((Z(I,J),J=1,NH),I=2,7)
        READ(4,*) ((WC(I,J),J=1,NH),I=1,7)
        READ(4,*) (X(1,J),J=1,NH)
        READ(5,*)(Z(8,J),J=1,NH),TMP(2),TMP(3),HMDTY(2),HMDTY(3)
        READ(6,*) NCOUNT,MCOUNT,YOLD,WVAR
        READ(7,*) ((TOW0(I,J),J=1,NH),I=1,NH),
     1  ((TOW1(I,J),J=1,NH),I=1,NH)
        READ(9,*) YMIN(1),(WVMIN(K,1),K=1,2),(PMIN(J,1),J=1,7)
        READ(9,*) (P(J,1),J=1,7)
        READ(10,*) ((PEE(1,I,J),J=1,9),I=1,9),(AE(1,J),J=1,9)
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C       UPDATE BASIC , WEEKLY PATTERN COMPONENT AND
C       CALCULATE RESIDUAL COMPONENT
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
        DO13 J=1,NH
        T(J)=0.0
        DO15 I=2,8
        T(J)=T(J)+Z(I,J)
```

```
15      CONTINUE
        T(J)=T(J)/7.0
        WC(8,J)=WC(1,J)+ALPHA*(Z(8,J)-T(J)-WC(1,J))
        X(2,J)=Z(8,J)-T(J)-WC(8,J)
13      CONTINUE
*       PRINT 14
14      FORMAT(10X,'BASIC LOAD COMPONENT'/)
*       PRINT16,(T(J),J=1,NH)
16      FORMAT(5X,8F12.6)
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C       CALCULATION OF PEAK LOAD
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
        Y(2)=0.0
        DO49 J=1,NH
        IF(Z(8,J).GT.Y(2)) Y(2)=Z(8,J)
49      CONTINUE
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C       WEATHER VARIABLE TRANSFORMATION
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
        DO46 I=2,3
        IF(TMP(I).GE.TS) WV(1,I)=TMP(I)-TS
        IF(TMP(I).LT.TS.AND.TMP(I).GT.TW) WV(1,I)=0.0
        IF(TMP(I).LE.TW) WV(1,I)=TW-TMP(I)
46      CONTINUE
        WV(2,2)=100.0-HMDTY(2)
        WV(2,3)=100.0-HMDTY(3)
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C       CALCULATION OF P(J,K)
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
        DO53 J=1,7
        M=J+1
        IF(J.EQ.7) M=1
        P(M,2)=P(J,1)
53      CONTINUE
*       PRINT 211,(P(M,2),M=1,7)
211     FORMAT(5X,'P(M,2)',5X,7F3.1)
        COUNT=FLOAT(NCOUNT)
```

```
   15     CONTINUE
          T(J)=T(J)/7.0
          WC(8,J)=WC(1,J)+ALPHA*(Z(8,J)-T(J)-WC(1,J))
          X(2,J)=Z(8,J)-T(J)-WC(8,J)
   13     CONTINUE
*         PRINT 14
   14     FORMAT(10X,'BASIC LOAD COMPONENT'/)
*         PRINT16,(T(J),J=1,NH)
   16     FORMAT(5X,8F12.6)
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C         CALCULATION OF PEAK LOAD
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
          Y(2)=0.0
          DO49 J=1,NH
          IF(Z(8,J).GT.Y(2)) Y(2)=Z(8,J)
   49     CONTINUE
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C         WEATHER VARIABLE TRANSFORMATION
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
          DO46 I=2,3
          IF(TMP(I).GE.TS) WV(1,I)=TMP(I)-TS
          IF(TMP(I).LT.TS.AND.TMP(I).GT.TW) WV(1,I)=0.0
          IF(TMP(I).LE.TW) WV(1,I)=TW-TMP(I)
   46     CONTINUE
          WV(2,2)=100.0-HMDTY(2)
          WV(2,3)=100.0-HMDTY(3)
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C         CALCULATION OF P(J,K)
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
          DO53 J=1,7
          M=J+1
          IF(J.EQ.7) M=1
          P(M,2)=P(J,1)
   53     CONTINUE
*         PRINT 211,(P(M,2),M=1,7)
  211     FORMAT(5X,'P(M,2)',5X,7F3.1)
          COUNT=FLOAT(NCOUNT)
```

```
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C         UPDATE 'A' AND 'Q' MATRIX
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
          DO17 J=1,NH
          DO17 K=1,NH
          TOW0(J,K)=TOW0(J,K)+(X(2,J)*X(2,K)-TOW0(J,K))/COUNT
          TOW1(J,K)=TOW1(J,K)+(X(2,J)*X(1,K)-TOW1(J,K))/
     2    (COUNT-1.0)
 17       CONTINUE
          CALL MATINV(TOW0,TOINV,NH)
          CALL MATMUL(TOW1,TOINV,A,NH,NH,NH)
          DO21 I=1,NH
          DO21 J=1,NH
          AT(I,J)=A(J,I)
 21       CONTINUE
          CALL MATMUL(A,TOW0,ATO,NH,NH,NH)
          CALL MATMUL(ATO,AT,ATOAT,NH,NH,NH)
          DO23 J=1,NH
          DO23 K=1,NH
          Q(J,K)=TOW0(J,K)-ATOAT(J,K)
 23       CONTINUE
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
CC        FORECAST BASED ON STOCHASTIC MODEL
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
          DO27 I=1,NH
          X(3,I)=0.0
          DO29 J=1,NH
          X(3,I)=X(3,I)+A(I,J)*X(2,J)
 29       CONTINUE
          ZS(I)=T(I)+WC(2,I)+X(3,I)
 27       CONTINUE
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C         HOUR CORRESPONDING TO PEAK LOAD
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
          ZSP=0.0
          DO35 J=1,NH
          IF(ZS(J).GT.ZSP) ZSP=ZS(J)
```

```
 35     CONTINUE
        DO36 J=1,NH
        IF(ZS(J).EQ.ZSP) KP=J
 36     CONTINUE
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C       STOCHASTIC VARIANCE
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
        DO37 J=1,NH
        SVAR(J)=Q(J,J)
 37     CONTINUE
        REWIND 4
        WRITE(4,*) ((Z(I,J),J=1,NH),I=3,8)
        WRITE(4,*) ((WC(I,J),J=1,NH),I=2,8)
        WRITE(4,*) (X(2,J),J=1,NH)
        REWIND 7
        WRITE(7,*) ((TOWO(I,J),J=1,NH),I=1,NH),
     4  ((TOW1(I,J),J=1,NH),I=1,NH)
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::
C       UPDATE WEATHER LOAD MODEL
C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::
        YMIN(2)=ALPHA*Y(2)+(1.0-ALPHA)*YMIN(1)
        DO 50 K=1,2
        WVMIN(K,2)=ALPHA*WV(K,2)+(1.0-ALPHA)*WVMIN(K,1)
 50     CONTINUE
        DO51 J=1,7
        PMIN(J,2)=ALPHA*P(J,2)+(1.0-ALPHA)*PMIN(J,1)
 51     CONTINUE
*       PRINT212,YMIN(1),YMIN(2),((WVMIN(K,J),K=1,2),J=1,2)
*       PRINT212,((PMIN(J,I),J=1,7),I=1,2)
 212    FORMAT(5X,4F12.4/)
        REWIND 9
        WRITE(9,*) YMIN(2),(WVMIN(K,2),K=1,2),(PMIN(J,2),J=1,7)
        WRITE(9,*) (P(J,2),J=1,7)
        NC=9
        DO57 J=1,NC
        IF(J.GT.7) GO TO 59
        PHAIT(2,J)=P(J,2)-PMIN(J,1)
```

```
             GO TO 57
      59     JD=J-7
             PHAIT(2,J)=WV(JD,2)-WVMIN(JD,1)
       57    CONTINUE
      *      PRINT213,(PHAIT(2,J),J=1,NC)
       213   FORMAT(5X,'PHAIT',9E12.5/)
             DELY(2)=Y(2)-YMIN(1)
             SUM4=0.0
             DO61 I=1,NC
             SUM3=0.0
             DO63 J=1,NC
             SUM3=SUM3+PHAIT(2,J)*PEE(1,J,I)
       63    CONTINUE
             SUM4=SUM4+SUM3*PHAIT(2,I)
       61    CONTINUE
             SUM4=1.0+SUM4/BEETA
             SUM4=1.0/SUM4
             DO65 I=1,NC
             SUM5=0.0
             DO67 J=1,NC
             SUM5=SUM5+PEE(1,I,J)*PHAIT(2,J)
       67    CONTINUE
      *      PRINT216,SUM5
             DO69 K=1,NC
             TAM1(I,K)=SUM5*PHAIT(2,K)
       69    CONTINUE
       65    CONTINUE
      *      PRINT217,((TAM1(I,J),J=1,NC),I=1,NC)
       217   FORMAT(5X,'TAM1',3X,9E13.5)
             DO71 I=1,NC
             DO71 K=1,NC
             PEE(2,I,K)=0.0
             DO73 J=1,NC
             PEE(2,I,K)=PEE(2,I,K)+TAM1(I,J)*PEE(1,J,K)
       73    CONTINUE
      *      PRINT218,PEE(2,I,K)
       218   FORMAT(5X,'PEE',3X,E13.5)
```

```
              PEE(2,I,K)=PEE(2,I,K)/(BEETA**2)
              PEE(2,I,K)=PEE(1,I,K)/BEETA-PEE(2,I,K)*SUM4
    71        CONTINUE
              SUM7=0.0
              DO75 J=1,NC
              SUM7=SUM7+PHAIT(2,J)*AE(1,J)
    75        CONTINUE
              SUM7=DELY(2)-SUM7
              DO77 I=1,NC
              AE(2,I)=0.0
              DO79 J=1,NC
              AE(2,I)=AE(2,I)+PEE(2,I,J)*PHAIT(2,J)
    79        CONTINUE
              AE(2,I)=AE(2,I)*SUM7+AE(1,I)
    77        CONTINUE
  *           PRINT72,(AE(2,I),I=1,NC)
    72        FORMAT(5X,'AE',3X,9F12.6/)
  *           PRINT74,((PEE(2,I,J),J=1,NC),I=1,NC)
    74        FORMAT(5X,'PEE',3X,9E13.5/)
              REWIND 10
              WRITE(10,*)((PEE(2,I,J),J=1,NC),I=1,NC),(AE(2,J),J=1,NC)
              SUM2=0.0
              DO70 J=1,NC
              SUM2=SUM2+AE(2,J)*PMIN(J,2)
    70        CONTINUE
              B(3)=YMIN(2)-AE(2,8)*WVMIN(1,2)-AE(2,9)*WVMIN(2,2)-SUM2
              SUM=0.0
              DO83 J=1,7
              SUM=SUM+AE(2,J)*P(J,2)
    83        CONTINUE
  *           PRINT 84,AE(2,8),WV(1,3),AE(2,9),WV(2,3)
    84        FORMAT(/3X,'AE(2,8)=',F10.6,3X,'WV(1,3)=',F10.6,3X,
         1    'AE(2,9)=',F10.6,3X,'WV(2,3)=',F10.6/)
  C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
  C           PEAK LOAD FORECAST BASED ON WEATHER MODEL
  C:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
              YW=B(3)+SUM+AE(2,8)*WV(1,3)+AE(2,9)*WV(2,3)
```

```
      IF(MCOUNT.EQ.0) GO TO 89
      SQ=Y(2)-YOLD
      WVAR=WVAR+(SQ**2-WVAR)/FLOAT(MCOUNT)
 89   MCOUNT=MCOUNT+1
      YOLD=YW
      NCOUNT=NCOUNT+1
      REWIND 6
      WRITE(6,*) NCOUNT,MCOUNT,YOLD,WVAR
*     PRINT80,WVAR
 80   FORMAT(10X,'WVAR',F12.5/)
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
CC    COMPOSITE  FORECAST AND VARIANCE
C::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
      SUB=YW-ZSP
      DENOM=Q(KP,KP)+WVAR
      DO91 J=1,NH
      ZC(J)=ZS(J)+SUB*Q(J,KP)/DENOM
      CVAR(J)=Q(J,J)-Q(J,KP)**2/DENOM
 91   CONTINUE
      REWIND 5
C     WRITE (5,*) (ZC(J),J=1,NH)
      PRINT31
 31   FORMAT(1H1///10X,'LOAD FORECAST BASED ON STOCHASTIC MODEL'
     1 ,10X,'VARIANCE'/)
      PRINT33,(ZS(J),SVAR(J),J=1,NH)
 33   FORMAT(20X,F10.5,28X,F10.5/)
      PRINT85,YW
 85   FORMAT(///20X,'PEAK LOAD BASED ON WEATHER MODEL=',F10.5)
      PRINT93
 93   FORMAT(1H1///25X,'COMPOSITE LOAD FORECAST',10X,'VARIANCE
      1'/)
      PRINT95,(ZC(J),CVAR(J),J=1,NH)
 95   FORMAT(30X,F10.5,17X,F10.5/)
      STOP
      END
C=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*=*
```

--*-*-*-*-*-*-*-*=*-*-*-*-*-*-*-*-*-*

*   *

*   APPENDIX - 2   *

*   *

--*-*-*-*-*-*-*-*=*-*-*-*-*-*-*-*-*-*

LOAD (AMPS.) OBSERVED AT RAMNAGAR SUBSTATION
FROM 1AUGUST,87. TO 10NOVEMBER,87. ON 33KV
FEEDER SUPPLYING POWER TO ROORKEE TOWN

45.0	40.0	40.0	40.0	45.0	50.0	55.0	55.0
60.0	70.0	70.0	75.0	70.0	70.0	70.0	65.0
60.0	65.0	75.0	80.0	80.0	70.0	60.0	50.0
45.0	40.0	38.0	38.0	40.0	42.0	45.0	50.0
60.0	60.0	70.0	65.0	60.0	60.0	60.0	55.0
55.0	60.0	75.0	80.0	80.0	70.0	50.0	50.0
45.0	40.0	45.0	45.0	50.0	50.0	50.0	52.0
60.0	65.0	70.0	70.0	75.0	75.0	70.0	75.0
75.0	50.0	50.0	65.0	75.0	70.0	50.0	45.0
50.0	50.0	50.0	50.0	48.0	50.0	50.0	52.0
60.0	75.0	75.0	80.0	70.0	75.0	75.0	75.0
70.0	65.0	75.0	85.0	75.0	60.0	50.0	50.0
50.0	45.0	45.0	48.0	50.0	50.0	50.0	45.0
50.0	50.0	50.0	60.0	75.0	50.0	50.0	50.0
50.0	55.0	65.0	90.0	80.0	75.0	60.0	70.0
50.0	55.0	50.0	40.0	40.0	50.0	50.0	50.0
65.0	75.0	80.0	80.0	80.0	70.0	70.0	75.0
75.0	70.0	75.0	90.0	85.0	75.0	60.0	60.0
50.0	50.0	45.0	45.0	50.0	50.0	50.0	50.0
60.0	65.0	60.0	75.0	70.0	70.0	70.0	70.0
60.0	55.0	80.0	100.0	90.0	65.0	60.0	55.0
40.0	40.0	50.0	50.0	45.0	50.0	55.0	50.0
45.0	65.0	60.0	75.0	70.0	60.0	65.0	65.0
65.0	65.0	85.0	90.0	95.0	60.0	50.0	40.0
40.0	45.0	45.0	45.0	50.0	50.0	50.0	60.0
60.0	55.0	65.0	65.0	65.0	65.0	50.0	55.0
55.0	65.0	75.0	90.0	85.0	70.0	50.0	50.0
45.0	45.0	48.0	50.0	50.0	52.0	52.0	52.0
55.0	65.0	78.0	78.0	80.0	75.0	70.0	65.0
75.0	70.0	80.0	100.0	85.0	75.0	55.0	50.0
50.0	50.0	50.0	50.0	50.0	55.0	55.0	65.0
60.0	70.0	70.0	80.0	80.0	75.0	75.0	75.0
80.0	75.0	85.0	95.0	90.0	65.0	60.0	50.0
48.0	45.0	40.0	42.0	42.0	45.0	50.0	50.0
55.0	60.0	75.0	70.0	70.0	70.0	70.0	75.0
70.0	60.0	70.0	90.0	85.0	70.0	55.0	50.0
40.0	40.0	38.0	35.0	30.0	28.0	23.0	40.0
45.0	50.0	50.0	50.0	50.0	50.0	56.0	55.0
60.0	60.0	60.0	90.0	75.0	50.0	40.0	40.0
40.0	38.0	36.0	30.0	32.0	35.0	40.0	45.0
60.0	60.0	65.0	65.0	60.0	55.0	60.0	60.0
60.0	60.0	60.0	90.0	80.0	65.0	50.0	45.0
40.0	40.0	45.0	45.0	48.0	50.0	50.0	50.0
50.0	55.0	55.0	60.0	60.0	55.0	50.0	50.0
55.0	60.0	70.0	90.0	90.0	70.0	55.0	50.0
45.0	45.0	48.0	48.0	50.0	50.0	50.0	50.0
60.0	60.0	65.0	65.0	60.0	60.0	65.0	60.0
60.0	65.0	75.0	85.0	80.0	70.0	55.0	45.0

45.0 , 40.0 , 40.0 , 50.0 , 50.0 , 50.0 , 50.0 , 50.0 ,
55.0 , 60.0 , 70.0 , 60.0 , 60.0 , 60.0 , 60.0 , 50.0 ,
60.0 , 60.0 , 80.0 , 95.0 , 90.0 , 80.0 , 60.0 , 50.0 ,

35.0 , 35.0 , 40.0 , 50.0 , 55.0 , 55.0 , 55.0 , 55.0 ,
60.0 , 60.0 , 65.0 , 70.0 , 60.0 , 60.0 , 60.0 , 65.0 ,
65.0 , 70.0 , 75.0 , 100.0 , 90.0 , 80.0 , 60.0 , 55.0 ,

50.0 , 50.0 , 55.0 , 55.0 , 60.0 , 60.0 , 55.0 , 55.0 ,
55.0 , 60.0 , 60.0 , 65.0 , 65.0 , 65.0 , 60.0 , 60.0 ,
55.0 , 50.0 , 80.0 , 98.0 , 95.0 , 55.0 , 50.0 , 50.0 ,

45.0 , 45.0 , 50.0 , 50.0 , 55.0 , 55.0 , 50.0 , 55.0 ,
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65.0 , 62.0 , 95.0 , 100.0 , 75.0 , 75.0 , 60.0 , 50.0 ,

40.0 , 35.0 , 50.0 , 50.0 , 50.0 , 50.0 , 50.0 , 50.0 ,
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65.0 , 60.0 , 90.0 , 75.0 , 90.0 , 75.0 , 60.0 , 50.0 ,

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60.0 , 65.0 , 75.0 , 95.0 , 90.0 , 80.0 , 65.0 , 50.0 ,

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70.0 , 80.0 , 90.0 , 95.0 , 90.0 , 75.0 , 60.0 , 50.0 ,

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70.0 , 60.0 , 80.0 , 95.0 , 90.0 , 75.0 , 50.0 , 45.0 ,

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70.0 , 60.0 , 80.0 , 95.0 , 90.0 , 75.0 , 50.0 , 45.0 ,
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65.0 ,	95.0 ,	95.0 ,	95.0 ,	75.0 ,	50.0 ,	40.0 ,	35.0 ,
35.0 ,	35.0 ,	35.0 ,	38.0 ,	40.0 ,	50.0 ,	50.0 ,	52.0 ,
50.0 ,	60.0 ,	60.0 ,	60.0 ,	60.0 ,	60.0 ,	65.0 ,	65.0 ,
70.0 ,	80.0 ,	100.0 ,	90.0 ,	80.0 ,	60.0 ,	50.0 ,	40.0 ,
35.0 ,	35.0 ,	35.0 ,	38.0 ,	38.0 ,	48.0 ,	50.0 ,	50.0 ,
50.0 ,	50.0 ,	60.0 ,	60.0 ,	60.0 ,	60.0 ,	60.0 ,	60.0 ,
60.0 ,	75.0 ,	95.0 ,	90.0 ,	80.0 ,	60.0 ,	50.0 ,	40.0 ,
45.0 ,	45.0 ,	40.0 ,	40.0 ,	50.0 ,	50.0 ,	55.0 ,	55.0 ,
50.0 ,	50.0 ,	50.0 ,	65.0 ,	60.0 ,	60.0 ,	60.0 ,	60.0 ,
65.0 ,	70.0 ,	90.0 ,	90.0 ,	75.0 ,	60.0 ,	50.0 ,	40.0 ,
40.0 ,	35.0 ,	35.0 ,	35.0 ,	45.0 ,	50.0 ,	50.0 ,	50.0 ,
60.0 ,	60.0 ,	50.0 ,	50.0 ,	50.0 ,	50.0 ,	50.0 ,	50.0 ,
55.0 ,	70.0 ,	90.0 ,	80.0 ,	75.0 ,	65.0 ,	55.0 ,	40.0 ,
35.0 ,	35.0 ,	40.0 ,	40.0 ,	50.0 ,	50.0 ,	60.0 ,	50.0 ,
30.0 ,	45.0 ,	60.0 ,	60.0 ,	55.0 ,	55.0 ,	50.0 ,	50.0 ,
55.0 ,	75.0 ,	90.0 ,	85.0 ,	75.0 ,	60.0 ,	50.0 ,	45.0 ,

50.0 , 40.0 , 36.0 , 30.0 , 40.0 , 40.0 , 50.0 , 50.0 ,
50.0 , 55.0 , 55.0 , 50.0 , 50.0 , 40.0 , 45.0 , 50.0 ,
50.0 , 75.0 , 55.0 , 80.0 , 70.0 , 65.0 , 50.0 , 50.0 ,

40.0 , 40.0 , 36.0 , 30.0 , 30.0 , 50.0 , 50.0 , 55.0 ,
50.0 , 50.0 , 52.0 , 55.0 , 50.0 , 50.0 , 45.0 , 50.0 ,
70.0 , 75.0 , 90.0 , 85.0 , 75.0 , 65.0 , 60.0 , 50.0 ,

50.0 , 50.0 , 45.0 , 45.0 , 45.0 , 50.0 , 50.0 , 55.0 ,
50.0 , 50.0 , 45.0 , 45.0 , 45.0 , 40.0 , 42.0 , 40.0 ,
50.0 , 60.0 , 80.0 , 75.0 , 75.0 , 60.0 , 60.0 , 50.0 ,

50.0 , 50.0 , 40.0 , 40.0 , 40.0 , 40.0 , 50.0 , 55.0 ,
50.0 , 50.0 , 45.0 , 45.0 , 40.0 , 30.0 , 25.0 , 25.0 ,
50.0 , 65.0 , 75.0 , 75.0 , 75.0 , 55.0 , 35.0 , 30.0 ,

28.0 , 30.0 , 30.0 , 30.0 , 35.0 , 35.0 , 45.0 , 45.0 ,
45.0 , 45.0 , 45.0 , 45.0 , 45.0 , 40.0 , 30.0 , 35.0 ,
50.0 , 70.0 , 70.0 , 70.0 , 60.0 , 50.0 , 45.0 , 40.0 ,

40.0 , 40.0 , 40.0 , 40.0 , 45.0 , 45.0 , 45.0 , 50.0 ,
45.0 , 45.0 , 48.0 , 50.0 , 45.0 , 45.0 , 50.0 , 50.0 ,
50.0 , 65.0 , 70.0 , 70.0 , 60.0 , 45.0 , 35.0 , 20.0 ,

25.0 , 25.0 , 20.0 , 20.0 , 30.0 , 35.0 , 50.0 , 50.0 ,
50.0 , 50.0 , 55.0 , 80.0 , 50.0 , 50.0 , 50.0 , 50.0 ,
50.0 , 80.0 , 90.0 , 80.0 , 70.0 , 50.0 , 40.0 , 25.0 ,

35.0 , 35.0 , 38.0 , 38.0 , 38.0 , 45.0 , 50.0 , 50.0 ,
55.0 , 50.0 , 50.0 , 50.0 , 50.0 , 50.0 , 50.0 , 50.0 ,
60.0 , 80.0 , 85.0 , 70.0 , 65.0 , 50.0 , 38.0 , 30.0 ,

35.0 , 35.0 , 38.0 , 38.0 , 40.0 , 45.0 , 50.0 , 55.0 ,
60.0 , 50.0 , 50.0 , 50.0 , 50.0 , 50.0 , 50.0 , 50.0 ,
55.0 , 70.0 , 70.0 , 70.0 , 70.0 , 50.0 , 45.0 , 35.0 ,

30.0 , 30.0 , 35.0 , 35.0 , 35.0 , 50.0 , 70.0 , 60.0 ,
50.0 , 60.0 , 50.0 , 60.0 , 60.0 , 50.0 , 50.0 , 50.0 ,
50.0 , 75.0 , 75.0 , 75.0 , 70.0 , 60.0 , 50.0 , 40.0 ,

40.0 , 40.0 , 35.0 , 35.0 , 40.0 , 50.0 , 60.0 , 60.0 ,
60.0 , 50.0 , 50.0 , 55.0 , 50.0 , 50.0 , 50.0 , 50.0 ,
55.0 , 80.0 , 100.0 , 90.0 , 80.0 , 60.0 , 40.0 , 35.0 ,

40.0 , 40.0 , 35.0 , 35.0 , 40.0 , 50.0 , 50.0 , 60.0 ,
55.0 , 60.0 , 50.0 , 55.0 , 50.0 , 55.0 , 50.0 , 50.0 ,
50.0 , 95.0 , 90.0 , 80.0 , 80.0 , 60.0 , 50.0 , 40.0 ,

40.0 , 30.0 , 30.0 , 28.0 , 30.0 , 35.0 , 50.0 , 50.0 ,
50.0 , 50.0 , 55.0 , 55.0 , 50.0 , 50.0 , 45.0 , 50.0 ,
50.0 , 80.0 , 80.0 , 75.0 , 70.0 , 60.0 , 50.0 , 40.0 ,

40.0 , 40.0 , 40.0 , 40.0 , 40.0 , 50.0 , 63.0 , 50.0 ,
50.0 , 50.0 , 60.0 , 60.0 , 55.0 , 50.0 , 50.0 , 55.0 ,
55.0 , 85.0 , 90.0 , 80.0 , 75.0 , 60.0 , 50.0 , 40.0 ,

40.0 , 40.0 , 40.0 , 40.0 , 40.0 , 40.0 , 60.0 , 60.0 ,
50.0 , 52.0 , 50.0 , 52.0 , 50.0 , 50.0 , 50.0 , 55.0 ,
60.0 , 80.0 , 90.0 , 85.0 , 75.0 , 50.0 , 40.0 , 30.0 ,

35.0 , 30.0 , 32.0 , 35.0 , 35.0 , 55.0 , 55.0 , 55.0 ,
56.0 , 52.0 , 52.0 , 50.0 , 50.0 , 50.0 , 50.0 , 50.0 ,
60.0 , 90.0 , 90.0 , 90.0 , 80.0 , 50.0 , 40.0 , 40.0 ,

40.0	35.0	35.0	40.0	40.0	50.0	50.0	55.0
52.0	50.0	50.0	50.0	50.0	45.0	48.0	50.0
55.0	75.0	80.0	80.0	75.0	60.0	50.0	45.0
38.0	30.0	30.0	35.0	40.0	50.0	55.0	65.0
60.0	60.0	50.0	50.0	50.0	55.0	50.0	50.0
50.0	80.0	85.0	80.0	75.0	60.0	45.0	35.0
35.0	35.0	38.0	38.0	40.0	48.0	55.0	60.0
55.0	60.0	55.0	50.0	50.0	50.0	50.0	50.0
50.0	85.0	95.0	85.0	75.0	55.0	48.0	35.0
35.0	35.0	38.0	38.0	40.0	50.0	52.0	55.0
59.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
55.0	90.0	85.0	75.0	70.0	55.0	45.0	35.0
30.0	30.0	35.0	35.0	38.0	50.0	50.0	55.0
55.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
60.0	80.0	95.0	95.0	85.0	55.0	50.0	50.0
40.0	35.0	30.0	30.0	35.0	50.0	60.0	65.0
50.0	50.0	50.0	60.0	50.0	50.0	50.0	50.0
50.0	80.0	90.0	85.0	75.0	50.0	40.0	40.0

DAILY AVERAGE TEMPERATURE RECORDED AT
HYDROLOGY DEPARTMENT,UNIVERSITY OF ROORKEE
FROM 1AUGUST,87. TO 10NOVEMBER,87.

33.25	33.00	32.10	31.00	30.00	30.60	31.00	32.00
33.35	33.25	32.50	33.10	27.10	33.00	29.35	30.15
30.10	33.10	26.00	32.25	30.10	31.25	28.75	28.25
31.50	32.00	28.85	27.80	26.25	30.60	28.65	29.35
31.00	31.60	30.50	28.85	29.25	30.50	28.20	29.20
29.75	27.70	29.50	29.75	29.80	30.25	29.95	30.90
31.75	31.00	30.35	30.75	30.25	29.90	29.95	29.85
29.80	29.00	28.90	29.10	28.50	27.90	28.40	28.50
27.50	27.25	27.35	27.30	28.10	28.35	27.70	28.[illegible]0
28.40	28.20	27.40	26.55	26.75	26.70	27.80	25.50
20.50	21.45	22.30	22.55	23.35	23.95	24.05	23.75
27.35	24.50	26.00	25.20	23.50	21.25	21.80	22.00
21.75	20.85	20.10	21.50	22.25	22.55		

DAILY RELATIVE HUMIDITY RECORDED AT
HYDROLOGY DEPARTMENT,UNIVERSITY OF ROORKEE
FROM 1AUGUST,87. TO 10NOVEMBER,87.

65.00	67.00	64.00	74.00	70.00	64.00	67.00	73.00
72.00	65.00	67.00	64.00	74.00	70.00	64.00	67.00
73.00	72.00	69.00	75.00	65.00	87.00	85.00	72.00
55.00	91.00	82.00	95.00	82.00	82.00	77.00	82.00
85.00	79.00	86.00	83.00	81.00	93.00	91.00	81.00
85.00	76.00	79.00	81.00	75.00	71.00	78.00	73.00
85.00	76.00	75.00	71.00	73.00	62.00	70.00	50.00
76.00	73.00	66.00	51.00	63.00	65.00	73.00	72.00
52.00	53.00	64.00	64.00	56.00	63.00	66.00	70.00
63.00	67.00	56.00	62.00	52.00	75.00	67.00	81.00
77.00	71.00	49.00	64.00	69.00	67.00	71.00	70.00
72.00	75.00	68.00	62.00	71.00	60.00	61.00	64.00
53.00	67.00	70.00	62.00	64.00	69.00		

APPENDIX-3

LOAD FORECAST FOR NOV.2,1987.

INCORPORATING EFFECT OF TEMERATURE

LEAD TIME = 24 HOURS

STOCHASTIC MODEL FORECAST	VARIANCE	COMPOSITE LOAD FORECAST	VARIANCE
35.58047	11.75080	35.64714	11.74755
35.55842	11.30281	35.11317	11.15779
35.97369	9.67181	35.74727	9.63431
38.74831	9.23400	38.30494	9.09021
41.11955	9.42730	40.72059	9.31087
50.28537	9.23137	49.52908	8.81296
56.80984	9.90273	56.51877	9.84076
56.18791	7.60052	55.95837	7.56198
52.64802	14.55344	52.32492	14.47708
57.40342	15.37038	56.91782	15.19789
58.96393	21.84258	58.33269	21.55110
59.83277	24.53753	58.81046	23.77302
53.65423	14.73419	53.39414	14.68471
55.39155	25.79219	54.77410	25.51331
55.14290	19.60849	54.28445	19.06942
56.47277	21.61483	55.77385	21.25750
57.06711	20.46026	56.41126	20.14562
87.81229	26.79156	86.62767	25.76500
96.97104	33.38753	92.90589	21.29901
85.96086	31.17362	83.49074	26.71033
75.80860	31.07944	74.39875	29.62544
53.88451	22.06274	53.67560	22.03082
43.80680	14.77484	43.64203	14.75498
35.18908	16.10780	35.17769	16.10771

PEAK LOAD FORECAST BASED ON WEATHER LOAD MODEL = 85.74341

APPENDIX-3

LOAD FORECAST FOR NOV.2,1987.
INCORPORATING EFFECT OF TEMERATURE
LEAD TIME = 24 HOURS

STOCHASTIC MODEL FORECAST	VARIANCE	COMPOSITE LOAD FORECAST	VARIANCE
35.58047	11.75080	35.64714	11.74755
35.55842	11.30281	35.11317	11.15779
35.97369	9.67181	35.74727	9.63431
38.74831	9.23400	38.30494	9.09021
41.11955	9.42730	40.72059	9.31087
50.28537	9.23137	49.52908	8.81296
56.80984	9.90273	56.51877	9.84076
56.18791	7.60052	55.95837	7.56198
52.64802	14.55344	52.32492	14.47708
57.40342	15.37038	56.91782	15.19789
58.96393	21.84258	58.33269	21.55110
59.83277	24.53753	58.81046	23.77302
53.65423	14.73419	53.39414	14.68471
55.39155	25.79219	54.77410	25.51331
55.14290	19.60849	54.28445	19.06942
56.47277	21.61483	55.77385	21.25750
57.06711	20.46026	56.41126	20.14562
87.81229	26.79156	86.62767	25.76500
96.97104	33.38753	92.90589	21.29901
85.96086	31.17362	83.49074	26.71033
75.80860	31.07944	74.39875	29.62544
53.88451	22.06274	53.67560	22.03082
43.80680	14.77484	43.64203	14.75498
35.18908	16.10780	35.17769	16.10771

PEAK LOAD FORECAST BASED ON WEATHER LOAD MODEL = 85.74341

APPENDIX-3

LOAD FORECAST FOR NOV.8,1987.
INCORPORATING EFFECT OF TEMERATURE
LEAD TIME = 1 WEEK

STOCHASTIC MODEL FORECAST	VARIANCE	COMPOSITE LOAD FORECAST	VARIANCE
38.09843	10.45588	38.19225	10.38194
32.11634	10.46504	32.28756	10.21873
32.02110	9.00662	32.03035	9.00590
30.04130	8.58199	29.93548	8.48792
32.70704	8.86735	32.58941	8.75110
40.01230	8.64343	40.00938	8.64336
52.56910	9.36676	52.52585	9.35104
53.89843	7.21517	53.87573	7.21084
51.96153	13.50227	52.15696	13.18140
48.47491	13.87326	48.77850	13.09895
49.13355	21.12627	49.64807	18.90230
51.24337	23.90858	51.80264	21.28089
45.30100	14.55949	45.47681	14.29981
46.55671	24.91983	46.66912	24.81369
43.35238	19.04880	43.67102	18.19585
45.00019	21.36379	45.30045	20.60638
47.73059	20.11817	48.35538	16.83868
79.29706	26.13197	80.98432	2.21568
76.86715	31.36696	77.50095	27.99218
70.17398	29.72483	70.70805	27.32854
67.49090	30.73060	67.66405	30.47872
55.96167	21.36624	56.07414	21.25998
45.92212	14.09879	45.93226	14.09792
34.47274	15.33168	34.49542	15.32736

PEAK LOAD FORECAST BASED ON WEATHER LOAD MODEL = 81.14063

APPENDIX-3

LOAD FORECAST FOR NOV.2,1987.
INCORPORATING EFFECT OF TEMPERATURE AND HUMIDITY
LEAD TIME = 24 HOURS

STOCHASTIC MODEL FORECAST	VARIANCE	COMPOSITE LOAD FORECAST	VARIANCE
35.74101	11.78330	35.81097	11.77954
35.57708	11.30193	35.15880	11.16772
35.89503	9.67326	35.67881	9.63740
38.71941	9.18967	38.30231	9.05622
41.09866	9.39107	40.72359	9.28315
50.14407	9.22262	49.42705	8.82824
56.51855	10.02229	56.23106	9.95890
56.03846	7.63240	55.81541	7.59424
53.21648	14.31842	52.87455	14.22873
57.05699	15.54117	56.58376	15.36939
58.72188	21.91650	58.11707	21.63590
59.66159	24.57889	58.69172	23.85733
53.55248	14.74889	53.30298	14.70114
55.00433	25.98280	54.40592	25.70811
55.04967	19.62041	54.23768	19.11465
56.32219	21.64722	55.65745	21.30827
56.84657	20.48778	56.22034	20.18696
87.65183	26.80778	86.52862	25.84002
96.67952	33.50584	92.84122	22.20477
86.05322	31.16454	83.73261	27.03363
75.89475	31.08994	74.57248	29.74877
54.01022	22.00983	53.81783	21.98143
43.81393	14.77034	43.65878	14.75187
35.45101	16.19595	35.45215	16.19595

PEAK LOAD FORECAST BASED ON WEATHER LOAD MODEL = 85.29960

APPENDIX-3

LOAD FORECAST FOR NOV.8,1987.
INCORPORATING EFFECT OF TEMPERATURE AND HUMIDITY
LEAD TIME = 1 WEEK

STOCHASTIC MODEL FORECAST	VARIANCE	COMPOSITE LOAD FORECAST	VARIANCE
38.01353	10.45090	38.21633	10.37756
32.04951	10.45509	32.42370	10.20540
32.01506	9.00604	32.03271	9.00549
30.02983	8.58396	29.79247	8.48349
32.73195	8.87145	32.46776	8.74699
40.04193	8.64390	40.03825	8.64387
52.58879	9.36115	52.50318	9.34808
53.93337	7.21502	53.88295	7.21049
51.84630	13.49025	52.27328	13.16514
48.22092	13.87738	48.89560	13.06569
48.91124	21.12627	50.05393	18.79787
51.15303	23.93290	52.39973	21.16129
45.21427	14.56994	45.61038	14.29016
46.61071	24.91834	46.85888	24.80852
43.24993	19.04254	43.95498	18.15612
44.83516	21.35678	45.49908	20.57077
47.53774	20.12046	48.92589	16.68428
78.91781	26.20560	82.67042	1.09439
76.75441	31.41256	78.16785	27.85005
70.08097	29.74227	71.26952	27.22319
67.46298	30.73400	67.84517	30.47353
56.04992	21.37103	56.30500	21.25501
45.98029	14.09792	46.00586	14.09676
34.46171	15.33175	34.51378	15.32691

PEAK LOAD FORECAST BASED ON WEATHER LOAD MODEL = 82.83396