ELECTRICAL LOAD FORECASTING

MODELING AND MODEL CONSTRUCTION

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Modeling and Model Construction

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Electrical Load Forecasting

To my parents, I was in need of them during my operation
To my wife, Laila, with love and respect
To my kids, Rasha, Shady, Samia, Hadeer,
and Ahmad, I love you all
To everyone who has the same liver problem,
please do not lose hope in God
(S. A. Soliman)

To my parents, who raised me
To my wife, Noureyah, with great love and respect
To my sons, Eng.Bader and Eng.Khalied,
for their encouragement
To my beloved family and friends
(A. M. Al-Kandari)

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In the market and the community of electric power system engineers, there is a shortage of books focusing on short-term electric load forecasting. Many papers have been published in the literature, but no book is available that contains all these publications. The idea of writing this book came to my mind two or three years ago, but the time was too limited to write such a big book. In the spring of 2009, I was diagnosed with liver cancer, and I have had to treat it locally through chemical therapy until a suitable donor is available and I can have a liver transplant. The president of Misr University for Science and Technology, Professor Mohammad Rafat, and my brothers, Professor Mostafa Kamel, vice president for academic affairs, and Professor Kamal Al-Bedawy, dean of engineering, asked me to stay at home to eliminate physical stress. As such, I had a lot of time to write such a book, especially because there are many publications in the area of short-term load forecasting. Indeed, my appreciation goes to them and chancellor of Misr University, Mr. Khalied Al-Tokhay.

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A.M. Al-Kandari

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Introduction

Economic development, throughout the world, depends directly on the availability of electric energy, especially because most industries depend almost entirely on its use. The availability of a source of continuous, cheap, and reliable energy is of foremost economic importance.

Electrical load forecasting is an important tool used to ensure that the energy supplied by utilities meets the load plus the energy lost in the system. To this end, a staff of trained personnel is needed to carry out this specialized function. Load forecasting is always defined as basically the science or art of predicting the future load on a given system, for a specified period of time ahead. These predictions may be just for a fraction of an hour ahead for operation purposes, or as much as 20 years into the future for planning purposes.

Load forecasting can be categorized into three subject areas—namely,

1. Long-range forecasting, which is used to predict loads as distant as 50 years ahead so that expansion planning can be facilitated.
2. Medium-range forecasting, which is used to predict weekly, monthly, and yearly peak loads up to 10 years ahead so that efficient operational planning can be carried out.
3. Short-range forecasting, which is used to predict loads up to a week ahead so that daily running and dispatching costs can be minimized.

In the preceding three categories, an accurate load model is required to mathematically represent the relationship between the load and influential variables such as time, weather, economic factors, etc. The precise relationship between the load and these variables is usually determined by their role in the load model. After the mathematical model is constructed, the model parameters are determined through the use of estimation techniques.

Extrapolating the mathematical relationship to the required lead time ahead and giving the corresponding values of influential variables to be available or predictable, forecasts can be made. Because factors such as weather and economic indices are increasingly difficult to predict accurately for longer lead times ahead, the greater the lead time, the less accurate the prediction is likely to be.

The final accuracy of any forecast thus depends on the load model employed, the accuracy of predicted variables, and the parameters assigned by the relevant estimation technique. Because different methods of estimation will result in different values of estimated parameters, it follows that the resulting forecasts will differ in prediction accuracy.

Over the past 50 years, the parameter estimation algorithms used in load forecasting have been limited to those based on the least error squares minimization criterion, even though estimation theory indicates that algorithms based on the least absolute value criteria are viable alternatives. Furthermore, the artificial neural network (ANN) had showed success in estimating the load for the next hour. However, the ANN used by a utility is not necessarily suitable for another utility and should be retrained to be suitable for that utility.

It is well known that the electric load is a dynamic one and does not have a precise value from one hour to another. In this book, fuzzy systems theory is implemented to estimate the load model parameters, which are assumed to be fuzzy parameters having a certain middle and spread. Different membership functions, for load parameters, are used—namely, triangular membership and trapezoidal membership functions. The problem of load forecasting in this book is restricted to short-term load forecasting and is formulated as a linear estimation problem in the parameters to be estimated. In this book, the parameters in the first part are assumed to be crisp parameters, whereas in the rest of the book these parameters are assumed to be fuzzy parameters. The objective is to minimize the spread of the available data points, taking into consideration the type of membership of the fuzzy parameters, subject to satisfying constraints on each measurement point, to ensure that the original membership is included in the estimated membership.

Outline of the Book

In this book, different techniques used in the past two decades are implemented to estimate the load model parameters, including fuzzy parameters with certain middle and certain spread. The book contains nine chapters:

Chapter 1, "Mathematical Background and State of the Art." This chapter introduces mathematical background to help the reader understand the problems formulated in this book. In this chapter, the reader will study matrices and their applications in estimation theory and see that the use of matrix notation simplifies complex mathematical expressions. The simplifying matrix notation may not reduce the amount of work required to solve mathematical equations, but it usually makes the equations much easier to handle and manipulate. This chapter explains the vectors and the formulation of quadratic forms, and, as we shall see, that most objective functions to be minimized (least errors square criteria) are quadratic in nature. This chapter also explains some optimization techniques and introduces the concept of a state space model, which is commonly used in dynamic state estimation. The reader will also review different techniques that, developed for the short term, give the state of the art of the various algorithms used during the past decades for short-term load forecasting. A brief discussion for each algorithm is presented in this chapter. Advantages and disadvantages of each algorithm are discussed. Reviewing the most recent publications in the area of short-term load forecasting indicates that most of the available algorithms treat the parameters of the proposed load model as crisp parameters, which is not the case in reality.

Chapter 2, "Static State Estimation." This chapter presents the theory involved in different approaches that use parameter estimation algorithms. In the first part of the chapter, the crisp parameter estimation algorithms are presented; they include the least error squares (LES) algorithm and the least absolute value (LAV) algorithm. The second part of the chapter presents an introduction to fuzzy set theory and systems, followed by a discussion of fuzzy linear regression algorithms. Different cases for the fuzzy parameters are discussed in this part. The first case is for the fuzzy linear regression of the linear models having fuzzy parameters with nonfuzzy outputs, the second case is for the linear regression of fuzzy parameters with fuzzy output, and the third case is for fuzzy parameters formulated with fuzzy output of left and right type (LR-type).

Chapter 3, "Load Modeling for Short-Term Forecasting." This chapter proposes different load models used in short-term load forecasting for 24 hours.

- Three models are proposed in this chapter—namely, models A, B, and C. Model A is a multiple linear regression model of the temperature deviation, base load, and either wind-chill factor for winter load or temperature humidity factor for summer load. The parameters of load A are assumed to be crisp parameters in this chapter. The term *crisp parameters* mean clearly defined parameter values without ambiguity.
- Load model B is a harmonic decomposition model that expresses the load at any instant, t, as a harmonic series. In this model, the weekly cycle is accounted for through use of a daily load model, the parameters of which are estimated seven times weekly. Again, the parameters of this model are assumed to be crisp.
- Load model C is a hybrid load model that expresses the load as the sum of a time-varying base load and a weather-dependent component. This model is developed with the aim of eliminating the disadvantages of the other two models by combining their modeling approaches. After finding the parameter values, one uses them to determine the electric load from which these parameter values are extracted, and this value is called the estimated load. Then the parameter values are used to predict the electric load for a randomly chosen day in the future, and it is called the predicted load for that chosen day.

Chapter 4, "Fuzzy Regression Systems and Fuzzy Linear Models." The objective of this chapter is to introduce principal concepts and mathematical notions of fuzzy set theory, a theory of classes of objects with non sharp boundaries.

- We first review fuzzy sets as a generalization of classical crisp sets by extending the range of the membership function (or characteristic function) from [0, 1] to all real numbers in the interval [0, 1].
- A number of notions of fuzzy sets, such as representation support, α-cuts, convexity, and fuzzy numbers, are then introduced. The resolution principle, which can be used to expand a fuzzy set in terms of its α-cuts, is discussed.
- This chapter introduces fuzzy mathematical programming and fuzzy multiple-objective decision making. We first introduce the required knowledge of fuzzy set theory and fuzzy mathematics in this chapter.
- Fuzzy linear regression also is introduced in this chapter; the first part is to estimate the fuzzy regression coefficients when the set of measurements available is crisp, whereas in the second part the fuzzy regression coefficients are estimated when the available set of measurements is a fuzzy set with a certain middle and spread.
- Some simple examples for fuzzy linear regression are introduced in this chapter.

- The models proposed in Chapter 3 for crisp parameters are used in this chapter. Fuzzy model A employs a multiple fuzzy linear regression model. The membership function for the model parameters is developed, where triangular membership functions are assumed for each parameter of the load model. Two constraints are imposed on each load measurement to ensure that the original membership is included in the estimated membership.
- Fuzzy model B, which is a harmonic model, also is proposed in this chapter. This model involves fuzzy parameters having a certain median and certain spread.
- Finally, a hybrid fuzzy model C, which is the combination of the multiple linear regression model A and harmonic model B, is presented in this chapter.

Chapter 5, "Dynamic State Estimation." The objective of this chapter is to study the dynamic state estimation problem and its applications to electric power system analysis, especially short-term load forecasting. Furthermore, the different approaches used to solve this dynamic estimation problem are also discussed in this chapter. After reading this chapter, the reader will be familiar with

The five fundamental components of an estimation problem:
- The variables to be estimated.
- The measurements or observations available.
- The mathematical model describing how the measurements are related to the variable of interest.
- The mathematical model of the uncertainties present.
- The performance evaluation criterion to judge which estimation algorithms are "best."

Formulation of the dynamic state estimation problem:
- Kalman filtering algorithm as a recursive filter used to solve a problem.
- Weighted least absolute value filter.
- Different problems that face Kalman filtering and weighted least absolute value filtering algorithms.

Chapter 6, "Load Forecasting Results Using Static State Estimation." The objective of this chapter is as follows:

In Chapter 3, the models are derived on the basis that the load powers are crisp in nature; the data available from a big company in Canada are used to forecast the load power in the crisp case.
- In this chapter, the results obtained for the crisp load power data for the different load models developed in Chapter 3 are shown.
- A comparison is performed between the two static LES and LAV estimation techniques.
- The parameters estimated are used to predict a load using both techniques, where we compare between them for summer and winter.

Chapter 7, "Load Forecasting Results Using Fuzzy Systems." Chapter 6 discusses the short-term load-forecasting problem, and the LES and LAV parameter estimation algorithms are used to estimate the load model parameters. The error in the estimates is calculated for both techniques. The three models, proposed earlier in Chapter 3, are used in that chapter to present the load in different days for different seasons. In this chapter, the fuzzy load models developed in Chapter 5 are tested. The fuzzy parameters of these models are estimated using the past history data for summer weekdays and weekend days as well as for winter weekdays and weekend days. Then these models are used to predict the fuzzy load power for 24 hours ahead, in both summer and winter seasons. The results are given in the form of tables and figures for the estimated and predicted loads.

Chapter 8, "Dynamic Electric Load Forecasting." The main objectives of this chapter are as follows:

- A one-year long-term electric power load-forecasting problem is introduced as a first step for short-term load forecasting.
- A dynamic algorithm, the Kalman filtering algorithm, is suitable to forecast daily load profiles with a lead-time from several weeks to a few years.
- The algorithm is based mainly on multiple simple linear regression models used to capture the shape of the load over a certain period of time (one year) in a two-dimensional layout (24 hours $\times$ 52 weeks).
- The regression models are recursively used to project the 2D load shape for the next period of time (next year). Load-demand annual growth is estimated and incorporated into the Kalman filtering algorithm to improve the load-forecast accuracy obtained so far from the regression models.

Chapter 9, "Electric Load Modeling for Long-Term Forecasting." The objectives of this chapter are as follows:

- This chapter provides a comparative study between two static estimation algorithms—namely, the least error squares (LES) and least absolute value (LAV) algorithms—for estimating the parameters of different load models for peak-load forecasting necessary for long-term power system planning.
- The proposed algorithms use the past history data for the load and the influence factors, such as gross domestic product (GDP), population, GDP per capita, system losses, load factor, etc.
- The problem turns out to be a linear estimation problem in the load parameters. Different models are developed and discussed in the text.

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