CHAPTER I

INTRODUCTION

The purpose of this thesis is manifold :

1. To present a detailed review of past literature on estimation techniques classifying them into several groups.
2. To develop an estimation scheme which transforms the least squares problem into a Two Point Boundary Value (TPBV) problem and solves it using the steepest descent technique to obtain an estimate of parameters of transfer functions or difference equations.
3. To demonstrate that the estimation procedure developed here proves to be successful in estimating the parameters of transfer functions of a turbo-alternator of an interconnected power system from normal operating input-output data heavily corrupted by noise.
4. To throw some light on the convergence properties of the estimation scheme for first, second and third order systems.
5. To suggest suitable computational algorithms to overcome convergence troubles posed by plateau and uniqueness problems.
6. To show that the effect on estimation due to dynamic noice, if not taken into consideration in the formulation of estimation scheme, can be overcome by digital filtering.
7. To present a procedure for identification of impulse response of a plant from normal operating data by deconvolving the discrete version of the Wiener-Hopf equation progressively by using the steepest descent technique.

Considerable work has been done on the "diagnosis" of black box and has been published under various guises such as "Identification", "Estimation" or "Characterization". In the literature on Circuit Theory and Communication Theory, these terms had been familiar for a long time. However the trend of research towards adaptive control during the last decade has brought an added significance to it. In the early stages, engin--eers in the field did not realize the gravity of sophisticated, computer-oriented estimation procedures and they resorted to the use of simple techniques employing physical model and perturbation techniques. Some others making use of available analytical means, emphasized the impulse response identification and its use in adaptive control, defining the optimum performance in terms of impulse response characteristics like overshoot, rise time and settling time,etc.

The introduction of state variables and the formulation of control problems in terms of variational techniques such as dynamic programming, calculus of variations and maximum princi--ple extended the scope of control research especially in optimal control and this came to be known as the modern control theory. Some began using these techniques for estimation problems on the basis of least squares criterion assuming either no or some a priori information regarding the statistical description of noise. The least squares problem is transformed into a TPBV problem which is then solved by employing different techniques like invariant imbedding, steepest gradient, etc. Apart from this, quite a few papers have been published using predominantly statistical properties and methods. Some promising work is also done employing power spectra analysis. Lately, the method of quasilinearization has also found an application but no guarantee regarding convergence in general is assured.

These diverse techniques for estimation have accumulated so rapidly in the literature that a control engineer facing the task of identifying a process is in a state of confusion as to what method is best suited for his problem. An attempt is made here to make an overall review of the literature classifying the different methods of estimation and bringing out their salient features.

The estimation scheme presented in this thesis employs the calculus of variations to obtain the best estimates of states and parameters of a dynamic system based on the minimization of performance index which is the sum of weighted squared residual errors between the discrete observed output and the calculated output for the assumed mathematical model. It is assumed that the form of difference equations of the plant is known. This assumption is often justified owing to the familiarity with the plant and thus the problem is reduced simply to the estimation of initial state (vector) which is augmented to include the coefficients of difference equation.

The minimization of the performance index constrained by the system dynamic equations is the well known Lagrange problem which needs to satisfy the necessary conditions, known as the Euler-Lagrange[1] equations, posing a TPBV problem. Cox[2] solved the TPBV problem on the basis of some known a priori statistical information. Sridhar and Detchmandy[3] tackled the TPBV problem by invariant imbedding without making any statistical assumptions regarding noise. This is of practical importance since in most of the practical problems, statistical description of the noise is not known and is difficult to determine. Pearson[4] obtained the discrete version of this scheme. All the three schemes are of sequential nature. The sequential procedure allows the processing of new observation as it occurs and gives the estimate of the current state by modifying the extrapolated value of the previous estimate on the basis of current observation. One major advantage of this estimators is that they show excellent and quick convergence making it suitable for on-line estimation. Experience with the schemes of references (3) and (4) shows that the forgoing statement is true only when the variance of noise is small as compared to the value of parameters. However, if the variance of noise is large compared to the magnitude of parameters, the present work shows that more reliable results are obtained by solving the TPBV problem nonsequentially using the steepest deseent technique. Since, in a nonsequential scheme, the entire span of assumed model output is compared again and again with the observed output data of the same span until the best fit is obtained in the least squares sense, this method takes considerable time. But this seems to be the price one must pay to obtain more reliable results under heavily noisy operating conditions.

After having gained the confidence that the nonsequential estimation scheme works successfully with the imput-output data obtained for simulated (on digital computer) systems having difference equations (corresponding to transfer functions) similar inform to those anticipated for the turbo-alternator, the technique was applied to the experimental input-output data. The input is the power demand fluctuations and the output is the corresponding variations in frequency. The transfer function representation of the system has to be transformed into difference equations as required by the general formulation of the estimation problem. The frequency of a-c power supply has to be maintained within permissible limits about the declared frequency. The variations in frequency are therefore normally counteracted by feedback loop employing governor which regulates the flow of steam to meet the power load fluctuations. It was desired to estimate the parameters of turbo-altermator transfer functions for

(a) Open-loop (feedback loop employing governor kept open)

and

(b) Closed-loop (feedback loop closed)

The input-output data was therefore made available for both the cases.

The open-loop plant is assumed to be of first order, with the open-loop gain and one time constant to be estimated from the given input-output data for the open -loop plant.

While considering the estimation of closed-loop plant from the corresponding input-output data, the feedback loop employing governor is assumed to be

i) of first order which involves the estimation of feedback loop gain and one time constant, and alternatively,

ii) of second order which requires the estimation of feedback loop gain and two time constants.

This is in addition to the task of estimating the gain and time constant of the open-loop portion. Thus the closed-loop systems corresponding to cases (i) and (ii) above are of second and third order respectively. The representation of the governor by two time constants is more typical and gives more accurate estimation results.

In using the steepest descent method to reach the minima of performance index, there were some troubles in convergence on account of uniqueness and plateau problems. But these were overcome for first and third order plants by using modified search techniques to seek the absolute minima with as less as possible computer time. The appropriate computational algorithm was first developed while experimenting with simulated systems.

After performing several trial experiments for estimation with experimental data, a low frequency(l.f.) source was suspected to be present in the form of dynamic noise which generated inside the plant. The l.f. dynamic noise did not appear in the input measurements but its effect appeared in the output measurements and in sequal, it gave estimated values different from those normally expected. The estimation method presented here has been developed to take care of only the measurement noise and not the dynamic noise. Since the plant itself is a low pass filter, any possibility of effect in the output due to high frequency dynamic noise was ruled out. Thus digital l.f. filtering of both input and output data was necessary to remove the l.f. noise.

In the end, a computational technique is presented for identifying the impulse response of a linear system from normal operating noisy data. No assumption regarding the nature of noise is required. The technique derives its idea from the Delay Line Synthesizer(DLS)[5] though in this case the DLS coefficients which discretely represent the weighting function are computed automatically employing the steepest descent method. In essence, the technique involves the deconvolution of the discrete version of the Wiener-Hopf equation. The method has been tried out on a first order as well as a second order system simulated on a digital computer and the identified impulse response is found to be very close to the true one.

The content of thesis is divided into eight chapters. Chapter II begins with the discussion on development of modern control theory stressing the importance of estimation and then passes on to the detailed review of different methods on estimation published in the past. Chapter III deals with the general formulation of the estimation problem as a TPBV problem and its numerical solution by using steepest descent technique. Chapter IV starts with the brief description of the plant and the rest of the chapter is devoted to the estimation of an open-loop transfer function of respectively second and third order closed-loop plant transfer functions of the turbo-alternator. The method for impulse response identification is developed in

Chapter VII. The important conclusions are summarized in Chapter VIII. Appendices and a list of References in the end mark the termination of thesis.