OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

FAIR USE POLICY

Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

RESTRICTED

16601

DP/ID/SER.A/961
1 February 1988
ENGLISH

OPTIMIZATION OF ELECTRIC POWER SYSTEMS

DP/CHI/84/008

CHILE

Technical report: Power System Parameter Estimation *

Prepared for the Government of Chile
by the United Nations Industrial Development Organization,
acting as executing agency for the United Nations Development Programme

Based on the work of Heinz Unbehauen

Expert in Power System Parameter Estimation

Backstopping officer: J. Fürkus, Engineering Industries Branch

United Nations Industrial Development Organization
Vienna

* This document has been reproduced without formal editing.

V.88-20976

TABLE OF CONTENTS Page No.

1. Introduction

This report presents details of the consultant work concerning parameter estimation and modelling in the Chilean power system. The main purpose of the visit was the evaluation and further suggestions for the research project DP/CHI/84/008/11-54 concerning the objectives and especially the technical relevance for the operation of the Chilean power system and its impact for industry. Based on precise dynamic and static models the optimization of the power system can be expected to be considerably improved in the future in order to provide a better economic and secure operation. In order to stimulate the discussions with the different research groups a seminar on "Estimation and system idntification techniques" was offered to about 50 engineers from universities and utilities. Based on this seminar a series of technical discussions with researchers at the University of Chile (U. Ch.), the Catholic University of Chile (C. U. Ch.), the Technical University Frederico Santa Maria in Valparaiso (U. T. F. S. M.) and at ENDESA (Empresa National de Electridad S. A.) had been conducted. As a result of these discussions, conclusions and suggestions have been elaborated, as described in this report.

2. Technical Program

Nov. 15, 87	Arrival in Santiago, Arranging the technical program with Dr. Rudnick from U.C.Ch.
Nov. 16, 87	Course lectures on "Identification and Parameter Estimation of Dynamic Systems" (8 lectures) to participants from utilities and universities at the "VII. Chilean Electrical Engineering Congress".
Nov. 17, 87	Course lectures on "Identification and Parameter Estimation of Dynamic Systems" (8 lectures) to participants from utilities and universities at the "VII. Chilean Electrical Engineering Congress".
Nov. 18, 87	Detailed discussion of current research activities on power systems at the T.U. Frederico Santa Maria in Valparaiso and Lecture on "Modern Methods of System Identification"
Nov. 19, 87	Technical discussion of current research activities on system identification and adaptive control at U.C.Ch.
Nov. 20, 87	Technical discussion of current research activities on power systems at U.C.Ch.
Nov. 20, 87	weekend
Nov. 21, 87	weekend
Nov. 23, 87	Detailed discussion of current research activities on power systems at U. Ch.
Nov. 24, 87	Working session on power system parameter estimation at ENDESA
Nov. 25, 87	Departure from Santiago

3. Importance of Parameter Estimation within the Project

Nevertheless the final aim of this project is to optimize the Chilean national system for the generation, transmission and distribution of electric power, the project will also contribute to the adaptation and transfer of modern technology, as e.g. hardware and software in microelectronics, especially for measuring and data aquisition systems and digital control.

Optimization of large-scale dynamic systems, such as power systems, can be performed off-line by intensive application of modern simulation-tools. The basic for simulation, however, is that adequate models of the dynamic and static behaviour of all partial systems are available. From the technological data only it is usually not possible to develop enough accurate models of the partial systems for generating, transmission and distribution of electric power. For existing power systems an alternative for model-building is to evaluate measurements of the real system. Several stages have to be conducted to obtain finally the desired models for the partial systems. These stages are:

- selection of representative measuring values;
- selection and installation of approximate measuring and data processing systems;
- evaluation of measurements of related input and output signals for obtaining corresponding models for the partial systems. For this purpose modern identification methods, either deterministic or stochastic have to be applied;
- valuation and testing the obtained models by real field data.

As most of the signals in electric power systems show highly stochastic character, in many cases parameter estimation methods seem to be a very powerful tool in the analysis and identification of these systems. Therefore the main aim within the present consulting was to discuss problems of adequately modelling the dynamic operation of electric power systems with the Chilean counterpart and to provide available modern methods for system identification, especially based on parameter estimation schemes.

Since the present project is carried out by three Chilean universities

- Universidad de Chile (Dr. O. Moya) U. Ch.
- Universidad Catholica de Chile (Dr. H. Rudnick) U. C. Ch.
- Universidad Technica Frederico Santa Maria (Dr. J. Bustos) U. T. F. S. M.

and the National Electric Utility of Chile

- ENDESA (Mr. E. Lucerno)

a course lecture on "Identification and Parameter Estimation of Dynamic Systems" comprising 16 hours was given to participants of universities and utilities which provided an excellent starting point for the later technical discussions. Details of the course programme are included in Appendix A.

4. Technical discussions

The technical discussions with all above mentioned 4 working groups were devoted to problems of electric power system modelling using parameter identification methods based on input/output measurements in the partial plants. Only if all subsystems can be described by realistic and validated models the entire large-scale Chilean power system can be investigated according to load effects to transient stability. This overall model consists of a number of subsystems, such as

- model of network areas including transmission (steady-state),
- model of loads (nonlinear dynamics),
- model of power stations consisting of
  - turbine and,
  - generator,

  including voltage regulator (AVR) and turbine governors.

The technical discussions showed that first systematic measurements for two important subsystems

- local load model and
- AVR-model for an electric generator

have been already carried out by two of the university working groups (U. C. Ch. and U. Ch.). The relatively difficult measurements and measuring data processing was conducted by application of adequate modern digital measurement equipment provided within this project by UNIDO. For this purpose appropriate efficient programming packages had been developed by these groups, which had been presented and discussed during the meetings.

The special load model developed by the group of U. Ch. represents a typical model of composed loads (feeders for a smaller town). The aim was to investigate the static and dynamic relations between changes of voltage as input variable and the resulting changes of effective power (output variable). The tests for voltage changes had been successfully performed only by switching capacitor banks. Unfortunately the measurements are affected with high load noise. The resulting static model of he load can be described sufficiently accurate by a linear model, whereas from the theoretical point of view it should be of second order. This is especially due to the constraints of the experiment, because the changes of the magnitude of the effective voltage V_e could only be performed within ±10% of its maxiaml value, i.e. $\Delta V_e = \pm 0,1\ V_e max$. From the available measurements only a very rough model for the dynamic behaviour can be obtained.

As further work remains to conduct a precise analysis of the noise features in order to get higher accuracy for the dynamic model. For this was proposed

- to use a longer measuring time in order to study also the long term-dynamic behaviour,
- to investigate whether the signals contain higher order harmonic modes by application of higher sampling rates or installation of an oscilloscop for more

precise measurements,

- to apply correlation or spectral methods for better analyzing the measuring signals,
- to apply special low pass filters for suppression of measurment noise.

By improving these measurements it is hoped that a more general method can be developed for other load models according to the structure of Fig. 1, from which can be seen also the influence of the frequency to the effective power

$$P_c(s) = P_0 + F_{Pf}(s)\Delta f(s) + F_{PV}(s)\Delta V(s),$$

where

P_0 ≙ constant stationary-state power before ΔV or Δf had been changed,
$\Delta V(s)$, $\Delta f(s)$ ≙ changes of Voltage and frequency,
$F_{Pf}(s)$, $F_{PV}(s)$ ≙ transfer functions for the dynamic and static behaviour.

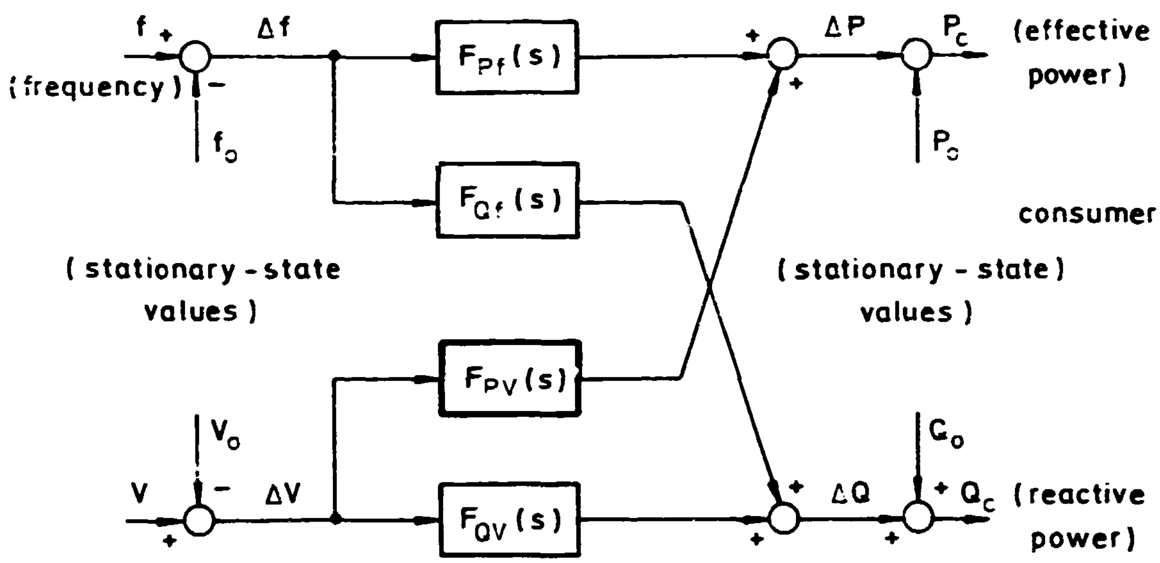


Fig. 1. Load model

Thus the next aim is to develop especially an adequate linear model for the partial system denoted by the transfer function $F_{PV}(s)$ in Fig. 1.

The model of the automatic voltage regulator (**AVR-model**) which has been studied by U. C. Ch. is based on measurements in two different power plants. The measurements had been conducted on-line in closed-loop operation according to Fig. 2, where the swich S had been opened for a duration of 2.8 sec. Because of the closed-loop behaviour the input of the AVR is not an ideal but a deformed rectangular signal. However, the measured input and output signals of the AVR provided a good basis for the model development. Different identification methods had been tried for this purpose. Frequency response analysis using FFT-techniques had not been seccessful, therefore time-response analysis had been applied. Best results had been obtained by the application of the direct least squares technique for the

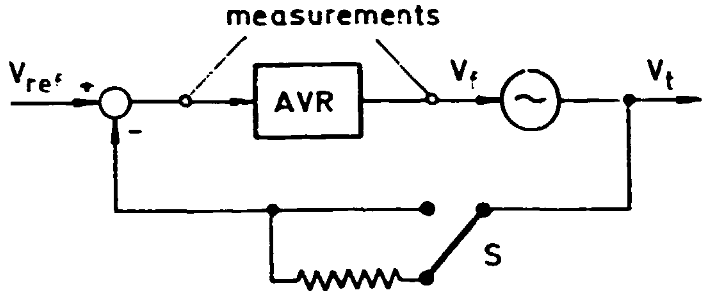


Fig. 2. Measuring device for the input and output signals of the AVR (V_{ref} reference voltage, V_f field voltage for exitation, V_t generator terminal voltage)

estimation of the model parameters. Comparison with standard parameters recommend by IEEE showed that the estimated parameters seem to be confident.

The resulting linearized dynamic model is based on the structure proposed by de Mello and Concordia (IEEE, PAS, 1969) as shown in Fig. 3a. An alternative model structure is given in Fig. 3b, which contains a modified PI-controller with the transfer function

$$G_R(s) = K_R \frac{1+T_R s}{1+T_N s},$$

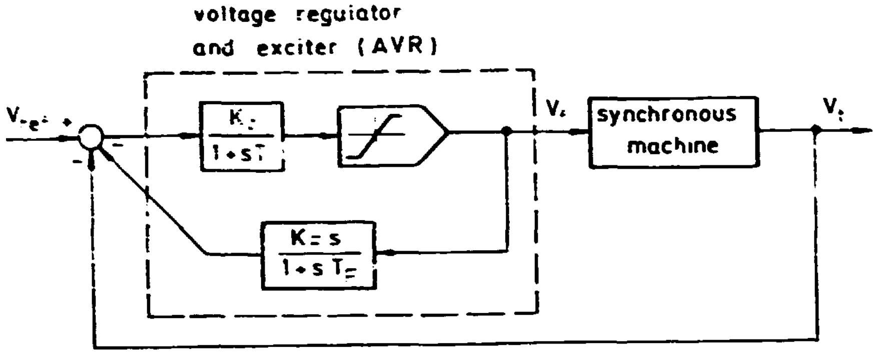
which in the middle frequency range acts similar as an ideal PI-controller.

Nevertheless the obtained results for the AVR-model are already very good it could be thought of further minor improvements, such as e.g.
- including long-term measurements into the identification process,
- application of other test signals providing a broader frequency range, for the excitation, e.g. PRBS-signals.

5. Concluding Comments

The research work on electric power system modelling based on system identification within the UNIDO project DP/CHI/84/008 shows already first good results. The quality of this work is of considerably high standard. The research teams are now from the theoretical point of view familiar with the latest identification techniques for parameter estimation. However, it would be helpful if also appropriate program packages would be available for the application of these methods. The market provides already such programming packages.

This project can become extremely important for the secure and economic operation of the Chilean power system. Therefore modelling of different types of subsystems for generating, transmitting and consuming electrical energy using modern system identification techniques will play a central part within this project. Much work has



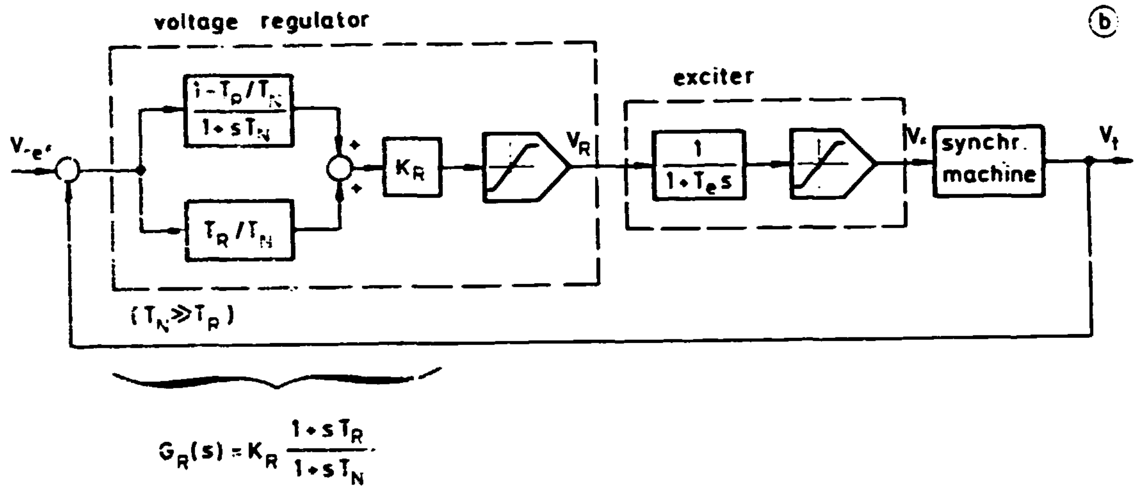


Fig. 3. Model of a synchronous machine with voltage regulator and exciter (two alternative-models)

to be done during the next years to evaluate these models for the subsystems as described in Appendix B. This will only be possible by good cooperation between the involved universities and their partners from the utilities for conducting field tests. The contribution of the universities has to consist of evaluation of measurements by the above discussed parameter identification methods in order to provide appropriate system models. The validated models then will represent the basis for extended simulation studies in order to investigate stable and optimal system behaviour which finally will lead to the improvement of secure and economic operation of the over-all electric power system.

This project is a great challenge for the involved university groups. Intensive research work must be carried out for a real large-scale technical system. On the other hand the resulting mathematical models must be realistically and critically validated in cooperation with the industrial groups. Thus a fruitful dialog between both partners can be established and this is already the case at the actual status. The active research participation of the universities provides also an excellent basis for the education of power systems engineers. Good examples for this high educational standard of the research students had been observed during the technical discussions with the university research groups. After having finished their master degree these researchers' scientific level is completely comparable to the international standard and there is no problem for them to join any foreign university in order to continue for a Ph. D. degree. From this point of view the present industrial project is at the same time of extreme scientific and educational value.

According to first good results in partial system modelling and the obvious good cooperation between the university and industry groups it can be expected that good future work and results can be expected. Reasonable measurement and data processing equipment at the universities is already available, but more powerful workstations and special portable data acquisition systems as well as special programming packages should be provided for the future work. On the other hand the Chilean researchers should have an opportunity to contact foreign research institutions in North America and Europe during short-time study trips or scholarships.

- 3 -

Appendix A

Identification and Parameter Estimation of Dynamic Systems

H. Unbehauen, Ruhr-Universität Bochum
Federal Republic of Germany

Lectures at the 7th Electrical Engineering Chilean Congress in Santiago, November 1987

1. Introduction to identification of dynamic systems - Survey and state of the art.

2. Parameter estimation techniques for linear SISO-systems using discrete-time models.

3. Parameter estimation for multivariable systems, large-scale interconnected systems and problems of model order determination.

4. Parameter estimation for continuous-time systems identification. Method of linear filters.

5. Identification of linear time-invariant systems via nonparametric models including frequency response techniques.

6. Special problems: Parameter estimation for nonlinear systems. System identification using adaptive models. Practical aspects.

Each lecture is of 2 hours duration (90 min. lecture and discussion)

Back-ground literature for the lectures

Lecture 1:

[1] Unbehauen, H. and K. Diekmann: Status and trends in system identification. Paper prepared for the 6th ICEE-Conference, Shiraz (Pesia) 1979.
Unbehauen, H.: Control Engineering III (in German). Vieweg-Verlag, Wiesbaden 1985.
Unbehauen, H. and G. P. Rao: Identification of continuous systems. North-Holland-Elsevier, Amsterdam 1987.

Lecture 2:

[2] Unbehauen, H.: System identification methods using prameter estimation - A survey. Proc. of 2nd International Symposium on System Analysis and Simulation. August 1985, Berlin, pp. 69-81.

[3] Unbehauen, H.: Introduction to system identification using parameter estimation methods. In Natke, H.: Identification of vibrating structures. Springer-Verlag Wien - New York, 1982, pp. 53-120.

Lecture 3:

[4] Unbehauen, H. and K. Diekmann: Application of MIMO-identifiation to a blast furnace. Proc. of 6th IFAC-Symposium on Identification and System Parameter Estimation. Washington D.C., USA 1982, pp. 180-185.

[5] Diekmann, K. and H. Unbehauen: Test for determining the order of canonical models of multivariable systems. Proc. of IFAC-Symposium on Theory and Application of Digital Control. New Delhi 1982, Session 13, Vol. 2, pp. 1-7.

[6] Rao, G. P., Diekmann, K. and H. Unbehauen: Parameter estimation in large scale interconnected systems. Proc. of IX. IFAC-World Congress. Budapest 1984, Colloquium 14.1, Paper No. 956.

[7] Fresewinkel, T. and H. Unbehauen: On the identification of subsystems of decomposed large scale systems. Proc. 7th IFAC-Symposium on Identification and System Parameter Estimation. York (U.K.) 1985, Vol. 1, pp. 267-272.

[8] Fresewinkel, T. and H. Unbehauen: Die Identifikation komplexer Systeme (in German). Regelungstechnik 32 (1984), pp. 3-7.

Lecture 4:

[9] Unbehauen, H. and G. P. Rao: Identification of continuous systems. North-Holland-Elsevier, Amsterdam 1987, Chapter 5.2.5.3, Chapter 5.3 (pp. 193-220).

Lecture 5:

[10] Unbehauen, H. and G. P. Rao: Identification of continuous systems. North-Holland-Elsevier, Amsterdam 1987, Chapter 2.1 (pp. 23-25), Chapter 4 (pp. 89-143 and 151-163).

Lecture 6:

[11] Jedner, U. and H. Unbehauen: Identification of a class of nonlinear systems by parameter estimation of a linear multi-model. Proc. of IMACS-Symposium on Modelling and Simulation for Control of Lumped and Distributed Parameter Systems. Lille 1986, pp. 287-290.

[12] Kortmann, M. and H. Unbehauen: Application of a recursive prediction error method to the identification of nonlinear systems using the Wiener model. Proc. of IMACS-Symposium on Modelling and Simulation for Control of Lumped and Distributed Parameter Systems. Lille 1986, pp. 281-285.

[13] Kortmann, M. and H. Unbehauen: Identification methods for nonlinear MISO-systems. Proc. of Xth IFAC-World Congress, Munich 1987, Vol. 10, pp. 225-230.

[14] Unbehauen, H.: A laboratory experiment for teaching system identification and adaptive control. Proc. 7th IFAC-Symposium on Identification and System Parameter Estimation. York (U.K.) 1985, Vol. 1, pp. 563-568.

[15] Bauer, B. and H. Unbehauen: On-line identification of load-dependent heat exchanger in closed loop using a modified instrumental variable-method. Proc. VIIth IFAC-World Congress. Helsinki 1978, paper 2-13-14-02.

[16] Unbehauen, H. and G. P. Rao: Identification of continuous systems. North-Holland-Elsevier, Amsterdam 1987, Chapter 6 (pp. 237-253).

Lecture 1

Introduction to identification of dynamic systems - Survey and state of the art

1. Description of dynamic systems
2. Two ways for system identification
3. Classical methods for identification
4. Identification using adaptive models
5. Identification based on parameter estimation

Lecture 2

Parameter estimation techniques for linear SISO-systems using discrete-time models

1. Introduction
2. Model structure
3. Numerical algorithms
4. System identification
5. Experimental conditions
6. Model validation
7. Conclusions

Lecture 3

Parameter estimation for multivariable systems, large-scale interconnected systems and problems of model order determination

Part A:

Parameter estimation for multivariable systems

1. A blast furnace as a MIMO-system
2. Model structures for MIMO-identification
3. Parameter estimation algorithms
4. Submodels and subsubmodels for the blast furnace
5. Results of identification
6. Conclusions

Part B:

Model order determination

1. Introduction
2. Model structures for MIMO-systems
3. Problem
4. Testing procedures
5. Comparison of the results
6. Conclusions

Part C:

Parameter estimation for large-scale interconnected systems

1. **Mathematical description**
2. **The algorithm**
3. **Extension**
4. **Conclusion**

Lecture 4

Parameter estimation for continuous-time systems identification. Method of linear filters.

1. Problem formulation
2. Method of linear filters
3. An example
4. Parameter estimation

Lecture 5

Identification of linear time-invariant systems via nonparametric models including frequency response techniques

Part A:

Identification using deterministic signals

1. Signal analysis
2. Obtaining step response from measurements
3. Tansfer function from nonparametric models
4. Method of moments

Part B:

Frequency response methods

1. Method of Bode asymptotes
2. Approximation of given frequency response
3. Numerical transformations

Part C:

Identification using correlation techniques

1. Random signals
2. Impulse response estimation
3. Correlation analysis with binary and ternary signals
4. Identification of a system in closed-loop
5. Direct determination of frequency response by correlation

Lecture 6

Special Problems

Part A:

Parameter estimation for nonlinear systems

1. Different model structures
2. General models
3. Particular models
4. Linear multi-models

Part B:

System identification using adaptive models

1. Gradient method
2. Parallel model approach
t. Reciprocal model approach

Part C:

Practical aspects

1. **Model structure**
2. **Sampling time and input (test) signal**
3. **Initial values for recursive algorithms**
4. **Supervision of estimation process**
5. **Model verification**

Appendix B

Block diagram of the subsystem "hydro power system"