MASTER

SECURITY ASSESSMENT
OF POWER SYSTEMS
INCLUDING ENERGY STORAGE

Progress Report
for Period July 1, 1978 - Sept. 30, 1978

D. P. Carroll and D. M. Triezenberg

Energy Systems Simulation Laboratory
School of Electrical Engineering
Purdue University
West Lafayette, Indiana 47907

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

October 1978

Prepared For

THE UNITED STATES DEPARTMENT OF ENERGY
UNDER CONTRACT NO. EC-77-S-02-4206.A000

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed or represents that its use would not infringe privately owned rights.

CONTRACT ACTIVITY

The principal investigators have devoted 50% of their workload to this contract during this quarter. This is expected to continue through the remainder of this year.

TABLE OF CONTENTS

ABSTRACT	iv
SECTION 1 - FURTHER EVALUATION OF SIMPLIFIED CFFCC MODEL	1
SECTION 2 - POWER SYSTEM IDENTIFICATION.	2
2.1 Maximum Likelihood Estimation.	2
2.2 Autocorrelation Calculation	3
2.3 Autocorrelation Estimates	4
2.4 An Experiment	4
APPENDIX	7

*Conf. paper to be processed
separately*

ABSTRACT

Energy Storage

Further evaluation has been performed on the previously developed simplified model of the current-fed force-commutated converter (CFFCC). The highlights of this investigation are reported in an IEEE paper submitted to the Power Engineering Society. A copy of this paper is included in the Appendix of this report.

Identification

A maximum likelihood estimation procedure has been partly developed. The procedure uses auto correlation information as an input rather than the observed time series.

SECTION 1

FURTHER EVALUATION OF SIMPLIFIED CFFCC MODEL

In previous progress reports a simplified model was developed and verified for a current-fed force-commutated converter (CFFCC). Validation studies were performed using the CFFCC as a control interface between a one-machine, three-bus power system equivalent and a superconducting magnetic energy storage device. In this inductor-converter (IC) application, the dc power is modulated proportional to changes in machine speed to provide damping for system disturbances. Since damping controls inherently require very low frequency power modulation, the validation studies performed for this practical application may be too limited in scope. Although comparisons between the simplified CFFCC model and detailed simulations showed good agreement for the power system damping applications studied, it was believed that a more basic evaluation of the simplified model was necessary. This investigation was performed during the present project period, and the highlights are reported in a paper submitted to the IEEE Power Engineering Society, a copy of which is contained in the Appendix.

SECTION 2

POWER SYSTEM IDENTIFICATION

This section of the progress report concerns identification of power system electromechanical models from system measurements, with only normal load variation as a disturbing input.

2.1 Maximum Likelihood Estimation

Earlier in this research, a "conventional" maximum likelihood parameter estimation scheme was implemented and appeared to function properly. This estimator recursively processed system time series data recursively to evaluate the likelihood function (Schweppe: Uncertain Dynamic Systems). This approach was abandoned because of the large computational load. It had, however, several commendable features, chiefly that it allowed search in the space of fundamental system parameters (inertias, reactances, etc.) rather than in the space of transfer function coefficients.

In the past quarter it became understood that the Yule-Walker equations as presented by Box and Jenkins (Time Series Analysis: Forecasting and Control) for a single output system are most easily generated in the multiple output case as an output autocorrelation calculation. This has led to a maximum likelihood parameter estimation procedure that uses output autocorrelation estimates as the required data. This procedure has a lesser computational requirement than the "conventional" maximum likelihood procedure.

The procedure is based on the observation that an autocorrelation estimate is a Gaussian random variable with calculable mean and variance. Thus for a given autocorrelation estimate, $\hat{R}$, and a given set of system parameters, θ , the conditional density

$$p(\hat{R} \mid \theta)$$

can be evaluated. Fixing $\hat{R}$ and allowing θ to vary casts the problem into a standard maximum likelihood framework. Computation of the likelihood function reduces to evaluation of a quadratic expression, and search techniques are used to find θ^* that maximizes the likelihood function.

2.2 Autocorrelation Calculation

The estimation procedure requires calculation of the system output autocorrelation function for iterative guesses of the system parameters. This is easily accomplished.

A multimachine power system driven by small load variations can be described by the discrete time equations

$$x_{i+1} = Ax_i + bu_i$$

$$y_i = Cx_i + du_i$$

where U_k is an uncorrelated Gaussian random variable and y_k is a vector of measured deviations of line flows. Matrices A and C and vectors b and d are functions of θ , the fundamental system parameters. With the notation,

$$R_{yy}(k) = E \{y_i y_{i-k}^T\}$$

the autocorrelation of the state vector and lag zero is found by solving the equation

$$R_{xx}(0) = AR_{xx}(0)A^T + bR_{uu}(0)b^T.$$

Output autocorrelations are then found as

$$R_{yy}(0) = CR_{xx}(0)C^T + dR_{uu}(0)d^T$$

$$R_{yy}(k) = CA^{n-1} [AR_{xx}(0)C^T + bR_{uu}(0)d^T],$$

$$k = 1, 2, \dots$$

2.3 Autocorrelation Estimates

From samples of the system output y_i , $i = -k+1, \dots, n$, an estimate of the output autocorrelation at lag k can be made as

$$\hat{R}_{yy}(k) = \frac{1}{n} \sum_{i=0}^n y_i y_{i-k}$$

Because of the summation in the above equation, each element of matrix $\hat{R}_{yy}(k)$ approaches Gaussian density as $n \rightarrow \infty$. The elements of any arbitrary number m of autocorrelation estimates $\hat{R}_{yy}(k)$, $k=1, \dots, m$ are jointly Gaussian.

The mean of this joint distribution is the true autocorrelation $R_{yy}(k)$, $k=1, \dots, m$ and the variance has not yet been completely calculated. The diagonal elements of the covariance matrix have been found, and the off-diagonal elements are understood but not yet worked out.

2.4 An Experiment

Although true maximum likelihood estimates cannot be made until the covariance of the $\hat{R}_{yy}(k)$ random variables is available, a preliminary experiment has been performed. The transfer function of Fig. 1 was implemented on an analog computer and driven by a hardware Discrete Interval Binary Noise source. An integrator produces the random walk signal that is characteristic of power system load variation. The second order transfer function is representative of the response of a one machine system. Parameter values for the transfer function are $\omega_n^2 = 80.$, $2\xi\omega_n = 1.5$, $c = 20.$, $d = 0.4$.

Fig. 1 - System simulation

Six thousand samples were taken of the system output and autocorrelation estimates at lags 0 through 5 were calculated. In place of the likelihood function, the sum of the squares of the differences of the true and estimated autocorrelations was calculated. This sum of squares function is a log likelihood function only if the relevant covariance matrix is the identity matrix (which it isn't). Repeated calculations of the sum of squares function, while perturbing one parameter at a time from its true value, show that some estimation bias is present (See Fig. 2). When the correct covariance matrix is determined, more accurate estimates should be possible.

Fig. 2 - Results of sum of squares calculation.