6.10 Extended State Estimation for Synchronous Generator Parameters (S-15)

Summary	This project will produce a practical, accurate method for on-line identification of synchronous generator parameters. Also, the development of an estimate of the confidence of the model is included in the work. The project includes an innovative concept in the identification of synchronous generator exciters. The value of these models is an accurate representation of the synchronous generator in ETMSP and other day-to-day studies for power systems. A graphic user interface is under design. The GUI will include a user friendly data input linker, parameter estimator and tracker, user friendly output of data, and a confidence indicator.
Research Need:	There is a need (required in some NERC reliability areas) to identify synchronous generator parameters from on-line data. These parameters are used in routine stability and power flow studies, and accuracy is needed to insure confidence in study results.
Research Stem	Systems
Academic Team Members	Co-principal investigators: George Karady (Arizona State – lead: karady@asu.edu) and Gerald T. Heydt (Arizona State – lead: heydt@asu.edu)and Research team members: Keith Holbert (ASU), Vijay Vittal (ISU), and Garng Huang and Chanan Singh (TAMU)
Industry Team Members	Arizona Public Service (Baj Agrawal, Doug Selin) and TVA (Dale Bradshaw)
Funding Period	June 1, 2002 to June 30, 2005
Budget	Karady: $13,300; Heydt: $13,400; Holbert: $13,300; Vittal: $5,000; Huang: $5,000; and Singh: $5,000. Total: $55,000 per year for three years (2002-2004)

Project Description: This project is to extend capabilities of the synchronous generator parameter estimation procedure being developed in a related project to make this software practical for on-line, no standstill, accurate estimation of the Park model parameters for a large synchronous generator. The main extended capabilities are:

- Inclusion of instrumentation error in the model, and accounting for this uncertainty
- Filtering of noise from the measurements
- Bad data rejection from the measurements
- The development of, and estimation of a confidence index in the model
- Identification of the model of the machine exciter, and also the parameters of that model
- Inclusion of saturation effects on the *d* and *q* axis mutual and self inductances
- Study of an observer to model the damper windings
- Development of the theory of observability for systems with observers, and implementation of that theory in the present project
- Interface of software developed with the visual graphic capabilities developed in the companion project "Synchronous Generator Parameter Estimation - Visual Graphic Implementation."

Potential Industry Benefits: The main benefit of the project is a practical, accurate method for on-line identification of synchronous generator parameters. Also, the development of an estimate of the confidence of the model is included in the work. The project includes an innovative concept in the identification of synchronous generator exciters. The value of these models is an accurate representation of the synchronous generator in ETMSP and other day-to-day studies for power systems.

Expected outcomes: The expected outcomes are:

- A GUI for on-line identification of synchronous generator parameters
- An estimate of the confidence of the parameters
- A practical noise and bad data rejection technique
- A practical way to include saturation for high accuracy
- User friendly implementation of the methods.

Technical Approach:
The technical approach is based on state estimation theory. The methods to be studied include the usual least squares method, and also L_1 and *L*Đ methods. The latter are mathematical concepts that relate to how error is evaluated, how a norm is evaluated, and how the accuracy of an estimate is quantified. The development of the graphic user interface is described in a companion project in the Systems Research Stem. The main extended capabilities to be developed are described as:

Noise rejection: Measurements shall be studied in both the frequency and time domain. A novel experiment relating to frequency-time resolution shall be performed using wavelets or a similar technology. The idea is to identify the portion of the spectrum occupied by the noise. A time domain and also a frequency domain filter shall be developed. Experiments using a Butterworth filter have already shown improvement by reducing noise in the exciter voltage measurements. However, it is believed that one can do better. The development of a noise rejection technique shall include an estimate of the measurement accuracy. A full study of machine instrumentation is planned.

Bad data rejection: Similar to the case of noise described above, it is intended to identify and attenuate (or eliminate) bad data. Innovative concepts shall be used to locate bad sensor signals (e.g., permanent signals that do not change). The traditional concepts of bad data shall be applied to the problem as well: this includes estimation of the chi-squared statistics of the model residuals, and application of a 3ů (or similar) rule to eliminate data out-of-range.

Index of confidence development: The usual index of confidence in a state estimation problem is the residual. That is, after the problem has been reduced to the form

$$Hx = z$$

And after the estimate x' is made, a residual J is formed as the p-norm of $|Hx-z|$. If x is gaussian (due to uncertainty in measurements), then it has been shown that when $p = 2$ (i.e., the problem is a least squares problem) J is chi-squared distributed. Under the chi-square assumption, the use of J as an index of confidence has been studied exhaustively and this will be applied in the synchronous generator parameter estimation problem. However the cases of non-gaussian x, and *p* Í 2 are much less familiar -- and these shall be studied in the context of the synchronous generator model. Also, the use of non-gaussian, *p* Í 2 forms for J even under the case of a least squares estimator shall be studied; that is, the 'mixing of notation' of $p = 2$ to obtain the estimate but *p* Í 2 for the confidence index shall be studied. It is possible that these indices are conveniently displayed to the operator in some innovative graphic user interface (so that a decision can be readily made as to the confidence in the estimate).

Inclusion of saturation: The inclusion of saturation in the machine model is intended to add to model accuracy. The approach taken is to model the saturation as a nonlinear function of known form. The parameters of the assumed form shall be identified using the concomitant parameter estimation. The residual error shall be examined to evaluate which assumed form gives the best results. As an example of candidate forms for L_d, consider

$$
\begin{aligned}
L_d &= f(|I_d, I_q|) \\
&= L_{d,0} + L_{d,1}\sqrt{I_d^2 + I_q^2}.
\end{aligned}
$$

Instrumentation error: All parameter estimators work only as well as their measurements (as inputs) dictate. In the project, error due to instrumentation sensors and sensory processing shall be considered. The approach is to examine the presently used instruments and to assess their accuracy. The details of the analog to digital conversion shall be considered. Statistical modeling shall be used to determine the impact on the parameter estimates. Methods of making the parameter estimates less sensitive to measurement noise shall be considered.

Development of the theory and implementation of a damper circuit observer: An observer is a dynamic system that behaves like a physical system. In the present application, it is impossible to obtain measurements in the synchronous generator damper circuit. But it is possible to use Park's model to account for damper dynamics. The concept is to develop a Park-like model for the damper, and use this model as an observer. Then the observer parameters shall be identified using measurements as well as knowledge of the damper winding physics.

Work Plan:
The work plan is shown in Figure (1). The project is organized into 12 tasks:

1. Review of previous project results and coordination with the GUI development
2. Review of state estimators that are not least squares based
3. Selection of state estimator for this application
4. Review of the theory of system observers
5. Development of a Park-like model for the damper winding observer
6. Implementation and testing of the damper observer
7. Bad data identification algorithm development
8. Bad data rejection algorithm implementation and testing
9. Noise filtering and instrumentation error study
10. Overall project integration (continuation of Task 1)
11. Testing of the GUI based program and presentation to the sponsors, modification as needed
12. Reporting

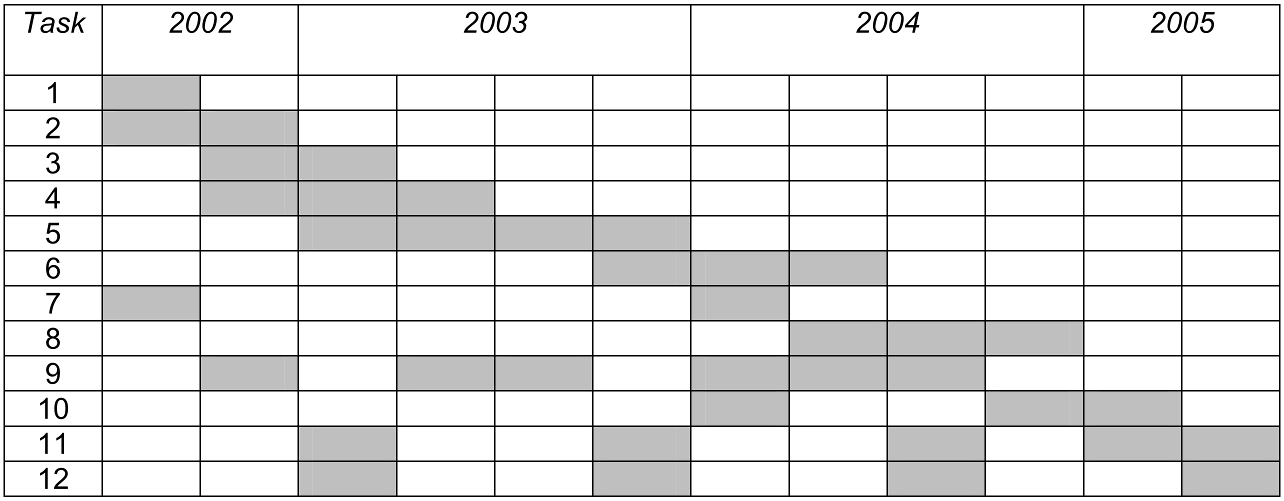

Figure (1) Project schedule

Related Work: The closest related work is a PSERC project in the Systems Stem on the identification and tracking of parameters for a large synchronous generator. Additional related work for this project includes:

- Work by Heydt, Rico, and Keyhani reported in the IEEE transactions. The proposed work builds on this and the main addition is the allowance for measurement noise and the development of a graphic user interface.
- Work by Keyhani and others at Ohio State reported in the IEEE transactions. We will use their results. The cited work does not accommodate noise and parameter saturation. And no graphic user interface has been reported. We plan to continue to collaborate with Dr. Keyhani to get his input and expertise.
- Classic state estimation methods (Schweppe and many others). This work was used as background. Much of the early work related to dedicated (off-line) testing of large synchronous generators. There is no report of the application of a graphic user interface for this application. The subjects of noise and parameter saturation are covered only in a generic way. We plan to extend and apply existing work, using on-line data acquisition.
- Recent work by Huber, Mili, and others on L_1 and $L_Ð$ estimators. These works are mainly mathematically oriented and not related to synchronous generator applications.
- Research in automatic control relating to observers: this material is mainly theory and not applied to the power area.

How this Work Differs from Related Work: The main differences in the present and classic approaches are outlined in the previous section. The salient differences in this approach versus others are:

- The technique described in this project is on-line state estimation, with no special (e.g., standstill) measurements
- The state estimation described is application oriented, in this case to synchronous generators
- An ‘observer’ is used to develop estimates of damper currents -- this is not done in other estimation technologies. The inclusion of the observer gives improved accuracy in the results, and allows the estimation of damper circuit parameters.
- The focus of the project is on innovative methods that deviate from least squares approaches.

6.10.1 Project Status

Status as Reported for the May 2002 IAB Meeting

Work progress since the report for the December 2001 IAB meeting
This is a new PSERC project. Work is just beginning.

Description of work activities and anticipated project outcomes/deliverables by each project team member during next reporting period
1. Review of previous project results and coordination with the GUI development (The entire team will participate in this task)
2. Review of state estimators that are not least squares based (Mr. Kyriakides and Dr. Heydt will work on this task, but collaboration with the entire team is planned)
3. Selection of state estimator for this application (Dr. Heydt is working on this task)
4. Review of the theory of system observers (Mr. Kyriakides and Dr. Heydt will work on this task. Collaboration with Drs. Vittal, Huang and Singh are planned in this task.)
5. Development of a Park-like model for the damper winding observer (Dr. Heydt is responsible)
6. Implementation and testing of the damper observer (Dr. Heydt is responsible. Dr. Holbert may have some input on this task.)
7. Bad data identification algorithm development (Dr. Holbert is responsible for this task)
8. Bad data rejection algorithm implementation and testing (Dr. Holbert is responsible for this task, but Mr. Kyriakides shall implement the results in the GUI)
9. Noise filtering and instrumentation error study (Dr. Holbert is responsible for this task, but Mr. Kyriakides shall implement the results in the GUI)
10. Identification of generator exciter parameters (Dr. Karady shall be responsible for this task.)
11. Implementation of generator excitation system estimator in the GUI (Dr. Karady is responsible for this task, but Mr. Kyriakides shall implement the results in the GUI)
12. Overall project integration (continuation of Task 1) (The entire team shall perform the project integration. However, Dr. Heydt shall coordinate the work.)
13. Testing of the GUI based program and presentation to the sponsors, modification as needed (Dr. Heydt shall coordinate this task, but Drs. Vittal and Singh shall assist.)
14. Reporting (The entire team shall perform the project integration. However, Dr. Heydt shall coordinate the work.)

Description of and reasons for any revisions to the workplan that was reported for the December 2001 IAB Meeting
Two tasks on exciter parameter identification were broken out as separate project tasks. This is thought to be useful for identifying researchers and task assignments.

Students working on the project during the next reporting period
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6.10.2 Project-Related Documents

Work on this project is just beginning

Click here to return to the Project Overviews