5.10 Enhanced Reliability of Power System Operation Using Advanced Algorithms and IEDs for On-Line Monitoring (T-17)

Summary	Introduction of Intelligent Electronic Devices (IEDs) in power systems enables new monitoring applications. This project introduces new fault location, substation state estimation and wireless communication applications.
Research Need	To find new fault location, substation state estimation and wireless communications applications that enhance the reliability of power system operation.
Research Stem	T&D Technologies
Academic Team Members	Mladen Kezunovic (Texas A&M-lead: kezunov@ee.tamu.edu, 979-845-7509, Fax. 979-845-9887) Co-Leader: Ali Abur (Texas A&M) Sakis Meliopoulos (Georgia Tech) and Rahmat Shoureshi (Colorado School of Mines)
Industry Team Members	TVA (M. Ingram), Reliant Energy HL&P (D. Sevcik), ABB (M. Subramanian), AEP (D. Krummen), Entergy (L. Priez), Mitsubishi (D. Wong), Tri-State G&T Association (A. Mander), TXU (J. Bell), WAPA (P. Kaptain)
Funding Period	June 1, 2002 to June 30, 2005
Budget	Kezunovic: $50,000; Abur: $25,000; Meliopoulos and Shoureshi (advisory). Total: $75,000 per year for three years (2002-2004)
Targeted Funds	Kezunovic: $37,800 from TVA in 2002

Project Description: This project intends to demonstrate the multiplicity of benefits that can potentially be achieved by both the substation and the control center applications, as a result of utilizing Intelligent Electronic Devices (IEDs). The advancement in the development of IEDs capable of recording samples of currents and voltages and in some cases capturing the changes of the contacts of circuit breakers and communication channels has led to a wide application of these devices in the power systems. Commonly, today's applications include the use of DFRs for monitoring faults and PQ meters for monitoring power quality disturbances. The practical applications of these devices have raised several important research and development issues: a.) can these devices be used to address other needs in the utilities today allowing for further leveraging of the investment; b.) can these devices be used in a more cost-effective way to justify an extensive use in the future. The answer to the first question is to develop new algorithms and concepts for on-line monitoring of the power system conditions where better accuracy and faster response are possible. Three applications that are of common interest to the different segments of the power industry, will be considered in the project: new fault location methods, improved state estimation, circuit breaker monitoring via wireless communication. All the mentioned applications are critical for better assessment of the power system operating conditions leading to more reliable and cost effective operation. The answer to the second question is to make the data recorded by both DFRs and PQ meters readily accessible to the users in a more efficient way. For the DFR application it means an implementation of a system for automated collection and analysis of the data that may be acquired by several different IEDs in a substation (DFRs, SOEs, and Digital Relays) that perform DFR-like functions. For the PQ meters it means implementing a low cost communication infrastructure for transmitting the data to a remote site where the operators and processing capabilities are located. Both of the applications may be improved by using the wireless communication solutions and advanced software for automated data analysis. The use of wireless communications is the key to this concept since it allows the data to be integrated at an affordable cost which otherwise using the traditional wiring may prove to be prohibitively expensive. As a result of the mentioned overall concept of utilizing real-time IED data in new applications, the reliability of power system operation can be further enhanced at an affordable cost.

Potential Industry Benefits: The overall benefits are aimed at improving the power system monitoring, which in turn leads to improving the reliability of operation. The fault location development effort will enable the utilities to get automatically an accurate solution in the case when only sparse field data is available. Such a solution is not commercially available and will benefit the utilities that have a need to locate faults quickly and accurately when the measurement systems on each transmission line are not readily available. The substation state estimation development will not only benefit the system state estimator making it more robust and accurate, but will also provide for detailed monitoring of the loading and switching conditions that are not possible through today's SCADA solutions. The utility benefit of this is the ability to operate more reliably and restore the system in a more timely fashion. The wireless infrastructure development will provide the required flexibility for connecting the IEDs for the purpose of exchanging and using the substation data by variety of substation functions. The cost of additional wiring in substations may be prohibitive when considering new applications requiring data from multiple IEDs, so the wireless solutions will allow for affordable utilization of the data that may be obtained from variety of IEDs.

Expected Outcomes: Each development activity will result in different outcomes. The fault location effort will produce a robust version of the field-tested software. The substation state estimation effort will result in a state estimation program with improved bad data detection and topology error identification capabilities via the utilization of data from the substation and feeder IEDs. The wireless communications development will end up in a demo of a substation application related to monitoring circuit breaker status and a feeder application aimed at collecting PQ monitor data. In addition, a methodology for evaluating, testing, and configuring commercial solutions for wireless communications will be developed.

Technical Approach: The entire project revolves around the concept of utilizing the substation and feeder data made available through new digital IEDs. Project is addressing a fundamental question of how the data may be utilized to improve the reliability of power system operation. In the previous (on-going) PSERC projects several independent developments were initiated based on the use of substation data. After the initial stage two outcomes became evident: a.) each selected application showed major improvement over the existing solutions; b.) it appeared that each of the solutions have common use of the substation data. As a result, it is clear that continuing the projects under the same umbrella for will allow not only demonstrating the interdependency of the use of the substation data for such applications but also pointing out how the individual solutions may be improved and then coordinated to enhance the reliability of system operation.

The proposed concept of fault location uses field measurements to match the recorded waveforms to the simulated waveforms obtained by using the power system model. The approach is critically dependent on availability of the measurements from multiple sources and accuracy of the system model under the prevailing operating and switching conditions. After the initial research, it is clear that the substation state estimation project by-product is an accurate assessment of the switch status and analog measurements detected by the substation IEDs. This information will help further improvement in determining an accurate system model needed for the fault location application. The existing approach of determining the correct model had one of the major tasks determination of the switch status, which will be now readily available from the substation state estimation processing. In addition, the substation analog measurements identified by the substation state estimator may be utilized for further improvements in the waveform matching approach used in the fault location project. The waveform matching approach benefits from any additional measurements that can help in determining the pre-fault load flow and post-fault transients. The pre-processing of the analog measurements for the state estimator will track the same measurements needed by the fault location through a number of redundant measurement points. This will enhance overall performance of the fault location algorithm. Further work on the fault location algorithm will address the mentioned use-of-data synergy with the substation state estimation processing as well as further improvements in the genetic algorithm aimed at determining the optimal match between the field and simulated waveforms. The ability to use TVA's system model and field recordings will present an opportunity to further study the convergence property of the genetic algorithm. In the previous (on-going) PSERC project it was shown that the algorithm is sensitive to the model data and number of measurement points. Having a different type of the system model and additional measurements made available in the TVA system via variety of IEDs including DFRs and PQ meters, further study of the algorithm sensitivity will lead to a more accurate and robust solution.

The concept of using detailed analog measurements and switch status information at the substation level, to improve the performance of the overall system wide state estimation, has been proposed and demonstrated in the previous (on-going) PSERC project. In the project, this concept will be implemented and tested on an actual large scale power system. Furthermore, given the detailed metering capability provided by the IEDs, issues related to unbalanced loading and its effects on state estimates will be addressed via three phase state estimation methods.

The proposed state estimator has two levels. The top level involves the system wide estimation and therefore uses the less detailed network model provided by the one-line diagram of the system. The main function of this estimator is to detect any "suspicious" substations that may be sending incorrect measurements or switch status information. We will use a robust estimator at this stage in order to avoid error masking and incorrect identification of suspect substations.
Once one or more substations are suspected, then the second level state estimation will be performed using the detailed substation models and measurements. This stage requires coordination between the local (substation based) computation engines and the central computer. We plan to implement locally active software at the substations, where the detailed substation measurements, switch status information, as well as time series data on individual measurements will be continuously monitored. The resulting estimate of the substation measurements and network model will then be transmitted to the central computer for further processing in case of suspected substations.

Both the substation based and centrally executed programs will have to be coordinated in terms of the data bases and formats, in order for them to execute seamlessly during the on-line operation. This will be accomplished via a common user interface that is capable of zooming in and capturing local measurements and models at the substation level as well as visualizing the large scale network model as a whole.

The wireless communication approach is the key to the use of substation data for multiple functions. The previous (on-going) PSERC project is aimed at demonstrating the feasibility of the concept and its flexibility for the use in a number of substation applications. This allows for variety of substation data to be brought together for improving new substation and system-wide applications. In the new project, the use of wireless communications in collecting the data needed for substation state estimation and fault location functions will be demonstrated. This will require that the study of the wireless applications be extended beyond the substation considerations to include the feeder application as well. As the scope of the communication requirements is extended, further fundamental issues will need to be addressed. For example, a thorough study of the 900MHz vs. 2.4GHz solutions will be performed to conclude which option is more suitable for substation (local) and feeder (remote) applications. In addition, different spread spectrum technologies will be evaluated with the same goal. This will lead to a theoretical foundation of the use of wireless communications in power systems indicating how different applications requiring variety of substation and feeder data may have to be implemented in an integrated wireless communication system.

Work Plan: This project is aimed at developing new algorithms and models as well as implementing the supporting communication and processing infrastructure to allow for the on-line monitoring of the loading conditions, power quality disturbances and fault events. The project tasks are as follows:

***Task #1*: Implementation of a new algorithm for fault location using measurements from DFRs and other monitoring IEDs available only at selected locations in the power system**. This task will initially assume the use of the field measurements data provided by DFRs and PQ meters sparsely located in the TVA's transmission system. The required system modeling data will be taken from the CAPE program database. The application will focus on some specific needs and requirements for on-line determination of the fault location in the TVA system. The results will be correlated with the results from the Lightning Monitoring System currently in use at TVA. Milestones and completion dates are: Collection of data from TVA system (September 2002), Software set-up for TVA demonstration (May 2003), Testing of the software using TVA filed data (December 2003), Algorithm refinements and final implementation (September 04), Software deployment at TVA (December 04), Final report generation (June 05).

***Task #2*: Implementation of an improved state estimation algorithm capable of detecting/identifying bad data and switch status errors using measurements from variety of substation and feeder IEDs.** This task will concentrate on utilizing the measurements received from DFRs placed in selected substations and PQ meters located on different feeders to improve the overall performance of the state estimator. Milestones and completion dates are: Collection of TVA system data including the substation models (September 2002); Conceptual development of the state estimator for the TVA system (June 2003); Final report generation (June 04).

***Task #3*: Implementation of a wireless communication system for local substation and remote feeder applications related to the mentioned on-line monitoring functions.** This task will be concentrating on implementing both the substation and feeder communication applications using the wireless communication approach. In particular, an application where PQ monitors' data is brought to a remote data concentrator will be implemented in the TVA system as a demonstration of the benefits of using the wireless communication infrastructure.
Milestones and completion dates are: Characterization of the substation environment for wireless needs (December 02), Implementation of the CB demo application (December 03), Development of the methodology for evaluation and testing of commercial solutions (Sept. 04), completion of a survey of possible solutions (December 04); Final report generation (June 05).

The overall project will be focusing on demonstrating two (Task #1 and Task#3) out of the three implementations mentioned above in the TVA system. The solutions will be applicable to any power system.

Related Work: The previous work was performed by TAMU under three different PSERC projects: Fault Location, Substation State Estimation, and Wireless and System-Wide communications. The Fault Location project has resulted in the software development that was implemented using data from Reliant Energy HL&P system. The results are very promising and the continuation of this effort using the TVA's system model and field data will prove the robustness of the proposed solution through further enhancing the performance while utilizing different application scenarios. The Substation State Estimation project uses a novel two-stage state estimator whose feasibility has been demonstrated via simulations on prototype systems. These initial results will be used towards the development of a robust, large scale state estimator which can solve TVA's system. Actual substation models and their associated measurement configurations will be utilized for demonstrating the performance of the improved state estimation, bad data detection and topology error identification functions. The wireless communications project has resulted in the new substation communication and data processing architecture as well as field trial data utilizing different commercial products. This investigation resulted in a selection of the possible approaches for evaluating the wireless communication solutions. This knowledge will be used to develop further applications of the wireless communication systems to support the on-line PQ monitoring needs of TVA. A continuation of the wireless applications for the substation needs will be pursued through a development of a demo for CB monitoring applications. This will lead to defining the methodology for evaluating various products.

How this Work Differs from Related Work: Several detailed project reports containing the findings from the research performed so far have been generated and placed on the PSERC web site under the respective on-going projects. The mentioned projects are listed under the T&D Research Stem activity on the PSERC web site. In addition, several conference and journal papers resulting from the work performed so far have either been published or are in the process of being published. Based on the mentioned reports published on the related PSERC web site, one can see that all the activities are quite unique and do not overlap with other technical efforts pursued by other researchers. With respect to the differences between this work and the work on the on-going PSERC projects, the extensive documentation of the results obtained through the on-going projects allows defining a clear distinction and starting point of the new work. The unique contribution in the fault location area will be a robust software solution that may be used by the utilities in every day practice. The substation state estimation effort will provide a large-scale application program that can handle substation related analog and switch status errors and demonstrate its effectiveness on a real utility system. The wireless work will result in a scientifically developed procedure for evaluating and testing new solutions as well as in a demo of an application to demonstrate the benefits.

Note: The related on-going PSERC projects and results are described in several reports posted at the PSERC website http://www.pserc.wisc.edu/ecow/get/researchdo/researchst/stem2tdtec0/.

5.10.1 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
The major step for this project is to get the TVA data relevant for the project activities. In the first period (Summer 2002) an attempt to meet with TVA staff will be made.

Description of and reasons for any revisions to the workplan that was reported for the December 2001 IAB Meeting
The Task #2 has been modified to exclude the field demonstration. This is done due to the reduced funds approved for the project ($25K less than what was originally proposed).

Students working on the project during the next reporting period
The students for the project are being recruited. Several offers are extended and the allocation will depend on the arrival schedule for the new students. It is expected that the students working on this project will be assigned by June 1, 2002.

5.10.2 Project-Related Documents

Work on this project is just beginning

Click here to return to the Project Overviews