PSERC

Massively Deployed Sensors

Final Project Report

Power Systems Engineering Research Center

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Power Systems Engineering Research Center

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EXECUTIVE SUMMARY

This is a final project report for research on the subject of massive deployment of sensors in electric power systems. There are several areas where the addition of modern, economical sensor technology can improve the quality of a large electric power grid. This report provides a quick reference for a variety of applications of massively deployed sensors (along with the advancement of communication and computer technology) that are currently being used and are also in the research and development stage. The report spans a wide spectrum of instrumentation technologies, largely correlated to the several forms of energy, namely electric, magnetic, atomic, chemical, kinetic, and potential. Because of the wide range of topics studied, a summary of the project results might better be rendered in tabular form, and Table 12.1 is reproduced here as Table 0.1.

Traditionally a variety of sensors have already been deployed to monitor conditions, protect major equipment and detect operating status in substations. As the communication bandwidth becomes available and as SCADA systems become more sophisticated, the ability of monitoring many more types of sensors becomes viable. These measurements may be implemented in a wide area control system for transmission level, shunt capacitor switching. Two indices have been proposed in Chapter 5 for the evaluation of local versus global effectiveness of capacitors in transmission systems. The results indicate that the wide area algorithm gives superior voltage control as well as line loading control when compared to local control. The significance of this result is that substantial improvement in voltage control is possible thought the use of sensors and controls.

A straightforward calculation method and model of communication delays in power systems are shown for the case of dedicated sensory communication channels. As an example, utilizing data representative of the WECC system, for a 50 Mbps network, an approximate interarea time delay of 20.6 ms is found. The standard deviation of the total interarea delay time may be calculated as well – and a typical value is about 4.6 ms.

The subject of presenting measurement data to operators is considered in some depth in Chapters 7 and 8 in the form of power system alarms. The concept of a next generation alarm processing algorithm augmented with control decisions and recommendations was presented. The addition of decision-making and action-taking modules or agents is significant for future alarm processing tools. Also, a new concept of alarms relating to economic transactions, an 'economic alarm' is introduced. There is a potential for the use of economic alarms in the same way as electrical alarms – to inform operators of impending problems related to power marketing.

The specialized sensory signal processing methods known as the Prony and Hilbert techniques have been researched in depth. The methods exhibit significant differences arising from the underlying assumptions: Prony analysis assumes a stationary signal, whereas the Hilbert transform and empirical mode decomposition are able to identify non-stationarity. Evidence established suggests that the Hilbert and Prony methods yield similar results for identical test signals. The two methods studied yield somewhat different information and it is recommended that the two methods be used in a complementary fashion.

The report concludes with a roadmap of sensor types and a summary of laboratory testing protocols for power system sensors. Three very low-cost, chip-level sensors suitable for low- and medium-voltage applications were selected for laboratory testing. Two

current sensors, one using Hall effect technology, and the other using magnetoresistive technology, and one Hall effect voltage sensor, were tested. The report contains error analysis, laboratory protocols suitable for power sensors, and typical results.

It is concluded that the next steps in commercializing the concepts described in this report mainly rest mainly on demonstration applications and their documentation. The sensory systems that *most* lend themselves to trial use are: the on-line detection of water concentration of transformer oil using alpha particles; gathering and making data available on snow pack depth measurements; ultrasound applications for transformer signature assessment; mechanical transmission tower and transmission line status sensors (e.g., inclinometers, CCTV); utilization of satellite imagery for tree trimming prioritization. With regard to the use of satellite images, it is necessary to present the case for their use to the satellite image retailers in order to render their products economical for tree trimming prioritization.

Table 0.1: Main project conclusions

Subject area	*Conclusion*	*Text reference*
Roadmap for sensor deployment	There is a need for the more concerted use of power system sensors. A roadmap for deployment is given.	(4.15)
Power systems operations	There is a wide spectrum of predictable enhancements available in the widespread use of sensors for power systems operations.	(4.3), (4.21), Chapters 5, 10
Power system control	There is a wide spectrum of predictable enhancements available in the widespread use of sensors for power systems controls. Specialized techniques for signal processing and signal delay analysis are needed and outlined.	Chapters 6, 9, 10
Alarm processing	There are specialized alarm processing techniques that are needed to process power system sensory signals. A new, innovative idea for economic alarms has been proposed and illustrated.	Chapters 5, 7, 8
Laboratory protocols	Laboratory testing protocols for power sensors have been outlined	(11.1), (11.2)

Table 0.1: Main project conclusions, continued

Subject area	*Conclusion*	*Text reference*
Unconventional sensors	There may be very large benefits in development of unconventional sensors, including the commercialization of new instruments. Actual laboratory tests of Hall effect devices have been documented.	• Online water concentration of transformer oil (4.2) • Snow pack depth measurements (4.3) • Automobile traffic congestion measurements (4.4) • Ultrasound applications (4.5) • Transmission tower and transmission line status sensors (4.6) (4.17) • Giant Magneto-resistance current sensor (4.7) • Satellite technologies (4.8) • Video technologies (4.9), (4.18) • The assessment of the measurement of the Poynting vector for power system instrumentation (4.10) • Hall effect laboratory tests (Chapter 11)
Real time line ratings	The full benefit of existing overhead transmission circuits may be obtained using real time line rating strategies and instrumentation	(2.2)
Management of end use	Management of end use using sensors offers benefits in the form of load control.	(2.3), (2.10)
Automated outage detection	These specific sensor systems are commercially available and a road map for the use of the commercialized products is contained in the report.	(2.4), (2.5)
Meter reading technologies		(2.6)
Mechanical sensors		(2.8), (3.5), (4.6)
Thermal sensors		(3.2)
Chemical sensors		(3.3)
Photogrammetric and CCTV video systems	These sensors are valuable for security enhancement and 'post mortem' security studies, including: • Atomic technologies for transformer oil integrity • Inclinometers • CCTV technologies • Satellite images.	(3.4), (4.9), (4.18)
Security enhancement	A range of new security enhancement instruments are available and well suited for power engineering applications.	(3.6)